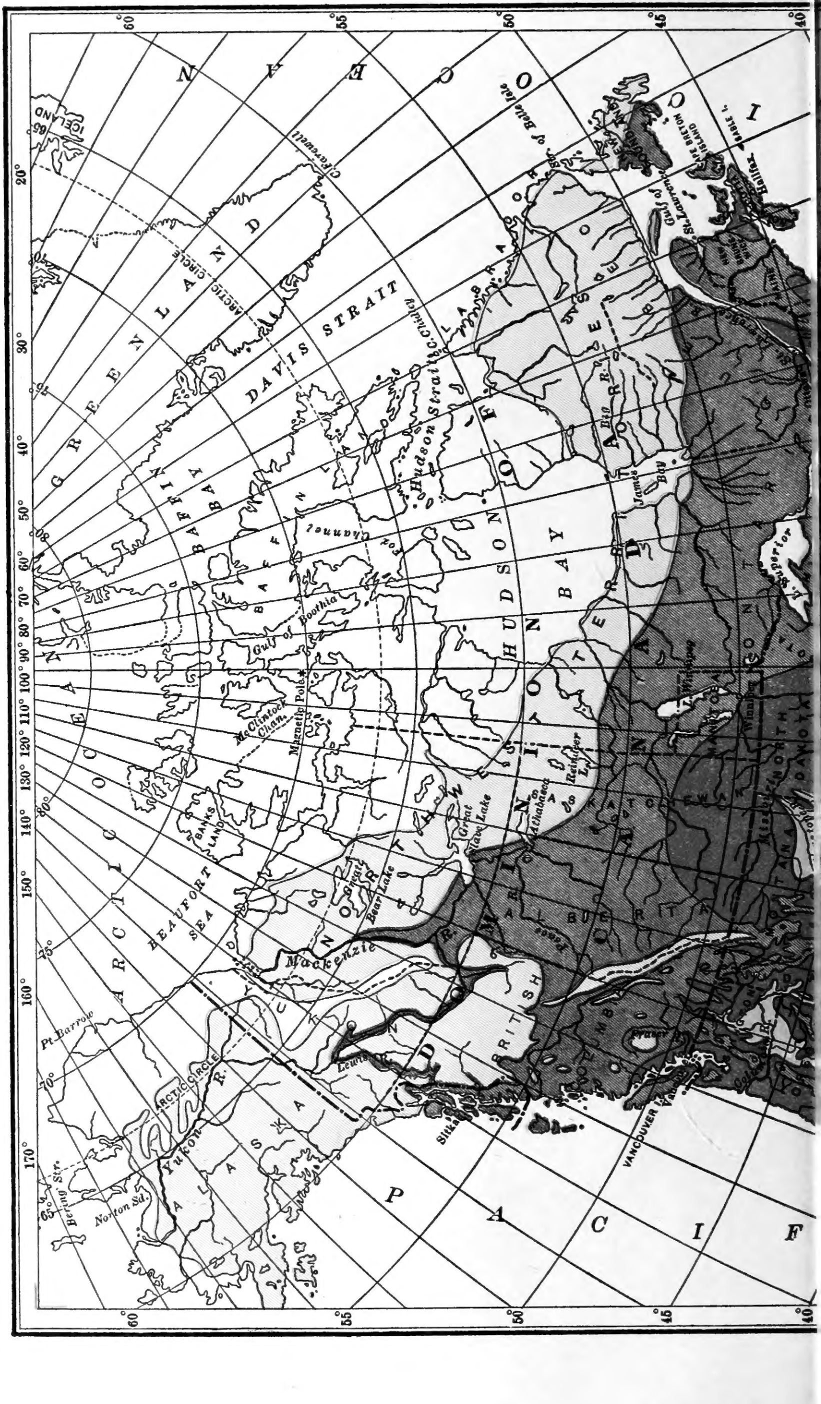
FOREST PHYSIOGRAPHY


ARCTIC OCEAN
GREENLAND
ICELAND
BAFFIN BAY
DAVIS STRAIT
BAFFIN LAND
Gulf of Boothia
Fox Channel
Hudson Strait
C. Chidley
C. Farewell
HUDSON BAY
James Bay
LABRADOR
NEWFOUNDLAND
Str. of Belle Isle
Gulf of St. Lawrence
CAPE BRETON ISLAND
SABLE I.
Halifax
McClintock Chan.
Magnetic Pole
BANKS LAND
BEAUFORT SEA
Great Bear Lake
Great Slave Lake
Athabasca L.
Reindeer L.
L. Winnipeg
Winnipeg
L. Superior
Mackenzie R.
Peace R.
Fraser R.
Columbia R.
Vancouver
VANCOUVER I.
Sitka
Lewis R.
Yukon R.
YUKON
ALASKA
ARCTIC CIRCLE
Pt. Barrow
Bering Str.
Norton Sd.
NORTHWEST TERRITORIES
BRITISH COLUMBIA
ALBERTA
SASKATCHEWAN
MANITOBA
ONTARIO
QUEBEC
NORTH DAKOTA
MONTANA
PACIFIC OCEAN
ATLANTIC OCEAN
20°
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60°
65°
70°
75°
80°

Zone Map of North America.

FOREST PHYSIOGRAPHY

PHYSIOGRAPHY OF THE UNITED STATES AND PRINCIPLES OF SOILS IN RELATION TO FORESTRY

BY

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To

Eugene Woldemar Hilgard

LEADER IN AGROGEOLOGY

PREFACE

Students of forestry in the United States are constantly demanding a guide to the topography, drainage, soils, and climatic features of the country. The need for such a book is keenly felt, since students in the professional schools of forestry have little time for the study of original sources of material in a subject which is not forestry but the basis of forestry. On the other hand, such general sources as are available are both too brief and too elementary for the somewhat comprehensive requirements of the American forester.

In preparing this book I have attempted to steer a middle course between that purely descriptive writing with which the forester is too often satisfied, and that altogether explanatory writing which the technical physiographer is inclined to regard as the real substance of a scientific book. The descriptive portions are intentionally rather comprehensive, for the relief and not the explanation of it is of immediate value to the forester, no matter how important the explanation may be in assisting him to appreciate and remember the relief. A chief concern has been the reduction of geologic data to a minimum. A geologic statement frequently runs off into so many consequences that the most important of these almost force one to a more extended and complex discussion than the forester, a lay student of geologic and geographic science, can assimilate. Emphatically, some geologic data are essential, but only in so far as they have an immediate physiographic bearing.

A further point concerning the organization of the material of this book requires statement here. It seems so clear that one can not know forestry without knowing under what physical conditions trees grow, that one finds it impossible to see how even the least philosophical view of the subject can exclude a knowledge of physiography. It would seem that one should pay a great deal of attention to lumbering as related to drainage and relief, to silviculture as related to soils, climate, and water supply, and in general that one should emphasize the forester's dependence upon physical conditions. This would appear to be so plain a doctrine as not to require restatement here, were it not for the fact that some students of forestry and even some schools of forestry still pay too little attention to the subject. If the forest is accepted merely as a fact, and the chief concern is its immediate and thoughtless exploitation, physiography may indeed be the fifth wheel to the coach, although even so practical a view as the lumberman's must include some knowledge of topography and drainage if merely to put forest products upon the market. But forestry is more than lumbering, and if forests are to be conserved, if they are to be improved and extended, every direct relation of the tree to its physiographic environment is vital.

The title, "Forest Physiography," does not imply a book on forestry but rather a book on physiography for students of forestry; and, as nearly as has seemed advisable from the nature of the subject, it has been prepared for their special needs. It is hoped, however, that the book may be of service to historians also, and to economists, since a knowledge of the physiography of the United States has heretofore depended upon one or two short and general chapters on the subject, or upon a study of hundreds of original papers and monographs.

No attempt has been made to show the connection between soils and agriculture, which is the general theme of text-books on soils. Neither has it been attempted to make a complete classification of all the types of rocks and soils found in nature. The distinctions which such a classification implies may be serviceable to the geologist, the farmer, and the gardener, but they are too finely drawn for the forester, whose needs are met by a broader classification based upon qualities of wider application. It is our purpose to discuss the origin of soil, and the physical and chemical transformations it undergoes in the process of gradual decay and of interaction with the plants that thrive upon it. Soil water, drainage, plant foods in the soil, soil warmth, and soil improvement are additional topics; the most important point of all concerns the actual preservation of soils that occur upon forested lands. In a broad way all soils are an inheritance from a geologic past; they are slow of accumulation, precious, and vital to man's welfare, for agriculture is the basis of our modern organized life, and soil is the basis of agriculture. Imprudent forest cutting and thoughtless land tillage tend to disturb a natural balance between great forces. That they may be a sowing to the wind is amply shown by the whirlwind of destruction which man is reaping in extensive tracts of deforested, soilless uplands of America, Europe, and Asia. Forestry affects not only trees but also soils, one of the greatest of man's geologic inheritances.

I am under obligations to many for advice and assistance. First of all to Prof. H. E. Gregory, who has given most generously of his time in reading both manuscript and proof. Prof. J. Barrell gave helpful advice in the preparation of certain chapters in Part One, and Prof. J. W. Toumey of the Yale Forest School supplied important criticisms. Dr. G. E. Nichols of the Sheffield Scientific School made a large number of corrections and alterations in the botanical descriptions. Prof. E. W. Hilgard of the University of California, and his colleague, Prof. R. H. Loughridge, have read Part One with great care, and the benefit of their searching criticisms lays me under deep obligations. My obligations to Professor Hilgard extend beyond this, however, for his great work on soils has been an invaluable source of experimental data.

The United States Geological Survey has followed its usual generous policy and supplied many of the illustrations. Prof. R. DeC. Ward has kindly allowed me to use the expensive original drawings of two climatic maps after Köppen. A number of publishers, acknowledged in a separate list, have permitted the reproduction of illustrative material. I have also obtained illustrations from the Canadian Geological Survey, Prof. C. N. Gould of Oklahoma University, Prof. C. A. Reeds of Bryn Mawr, Mr. H. Brigham, Jr., of Cortez, Colorado, and a number of my students in forest physiography.

ISAIAH BOWMAN.

Yale University,
June 10, 1911.

ACKNOWLEDGMENT OF ILLUSTRATIONS

Fig. 10, p. 91, from H. W. Wiley, *Soils*, Chemical Publishing Company, Easton, Penn.

Fig. 11, p. 99, from E. W. Hilgard, *Soils*, Macmillan Company, N. Y.

Fig. 13, p. 111, and Fig. 14, p. 113, from R. DeC. Ward, *Climate*, G. P. Putnam's Sons, N. Y. Based on Köppen.

Fig. 29, p. 146; Fig. 48, p. 189; Fig. 61, p. 230; Fig. 62, p. 231, from F. H. Newell, *Irrigation in the United States.*

Fig. 80, p. 285, from Gilbert and Brigham, *Physical Geography*, D. Appleton & Co.

Fig. 271, p. 676. From E. de Martonne, *Traitê de Geographie Physique*, Armand Colin, Paris, France.

The largest number of illustrations are from the *Collections of the United States Geological Survey.*

A number of the block diagrams of the Basin Ranges are from W. M. Davis, *Mountain Ranges of the Great Basin*, Bull. Mus. Comp. Zool.

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PART ONE

THE SOIL

CHAPTER I

THE IMPORTANCE, ORIGIN, AND DIVERSITY OF SOILS

The Soil in Relation to Life

Men whose work brings them into touch with the soil and its relation to life do not employ the phrase "mother earth" in a casual sense. The great hosts of plant and animal life that people the lands in large part have their origin in or draw their support from the cover of land waste whose upper layers are the soil. They are, directly or indirectly, the dependent children of the earth. Viewed from such a standpoint the soil is not mere dirt, a substance to be despised, a synonym for filth, but a great storehouse of energy, a great home, a bountiful mother. Countless billions of micro-organisms — the bacterial flora — throng its dark passageways while the roots of countless higher plants ramify through it in eager quest for food and water. Only less numerous are the earthworms, insects, and burrowing animals that delve into it for food as well as for shelter. To supply all these needs is no mean function; it is probable that no other planet in our solar system has so large an endowment of life-giving, life-supporting soil; the evolution of the life of the earth would have been on far lower levels if the endowment had not been so generous.

The Soil and the Forest

From the standpoint of the forest the soil is a factor of great importance. The home of the tree is the soil and the air; and a forester, whose chief concern is the tree, requires a somewhat comprehensive knowledge of these two elements of the environment of every forest. Without soil in some amount tree growth of any kind is impossible, although the amount required to produce a poor growth may be very small. Low forms of vegetation, such as lichens, mosses, and shrubs of many varieties, may find life possible in a region where there appears to be practically no soil; but a careful examination will usually disclose rock pockets partially filled with small quantities of soil, tiny crevices that contain particles of dust, and joints in greater or lesser number that have caught soil fragments washed from the adjacent surfaces almost as fast as formed. These accumulations afford a foothold for the lower forms of vegetable life which tend to disintegrate both soil and rock and further to increase the amount of available soil. Ordinary weathering will tend toward the same result, and if the climatic conditions, the relief, etc., are favorable, a soil cover capable of sustaining a denser growth of vegetation of a higher order will eventually be formed. In time and through the gradual development of a soil cover a dense forest may grow on what was in a preceding portion of a geologic period a bare rock terrane.

While the broad relation of the soil to the forest is thus readily distinguishable, the finer relations are often difficult of determination and there are many physical conditions that evoke no recognizable response in the forest world. A study of the maps, Fig. 23 and Plates IV and V, representing respectively the forest regions of the United States, the physiographic provinces and the geologic formations, will enable the student of forest physiography to appreciate at once that the physiographic features and related soil types are of more local development than the broad forest types which they support; and that the finer distinctions between soil types are of little value in understanding the range of a given forest type, however directly they may affect the welfare of the individual tree by modifying its habitat. In short, it may be said that the conditions which limit either the growth or the distribution of most forest species are so extreme that they embrace or overlap a large number of physical subdivisions.

In general plants are rather impartial as to soil unless the soil characters are of an extreme type; relatively few have absolute soil requirements. Competition among forest trees may drive out some species, in which case the unsuccessful species can not be described as incapable of growth on the soil from which they have been driven; simply, their competitors are able better to use the given resources of soil and air. It often happens that a given species is markedly tolerant of soil and climate except at the limits of its range where competition begets an apparent intolerance.

It is concluded that plants possess a peculiar inherent force by the exercise of which they directly adapt themselves to new conditions and become fitted for existence in accordance with new surroundings. Thus plants are thought to have a certain physiologic plasticity or power of self-regulation that tends to adjust them to a new environment, a feature that goes far in explaining the absence of a rigid control of physiographic conditions over forest distributions although an approximate control is often manifested.[1] The forester, then, requires a scientific knowledge of soils and climate, but in the final application of his knowledge to the distribution and growth of forests it is often necessary for him to employ somewhat broader generalizations than those employed by the geographer and the botanist for the special purposes of their sciences.

The Maintenance of a Soil Cover

Everywhere on the land we find at work the two forces of soil making and soil removal. In regions of aggradation the two tend in the same direction; in regions of degradation the soil may be removed as fast as formed and bare rock everywhere exposed at the surface; or there may be established so delicate a balance between soil formation and soil removal that though the soil cover is continually wasted the process of soil formation takes place at an equivalent rate and a covering of soil is perpetually maintained.

The matter of soil formation is of special importance to the people of North America, for not only is denudation (chiefly glacial) responsible for an area of bare, denuded country almost twice as great as that of the continent next in order in this respect, Africa, but denudation is probably proceeding at a faster rate on our continent than on any of the other five. The saving quality of glacial denudation in the past has been its occurrence chiefly in mountain regions of the United States and in the upper boreal and the arctic regions of Canada where extreme climatic conditions would largely offset the advantages of soil.[2] A physiographic map of the United States, Plate IV, appears to show that approximately one-fifth to one-sixth of the total area is now undergoing alluviation; everywhere else, no matter what process has been active in the immediate geologic past, the surface is now being eroded. The action is so slow in some places as to be exceeded by the rate of rock decay, and in such cases no fear need be entertained for the safety of

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[1] See especially, V. M. Spalding, Distribution and Movements of Desert Plants, Carnegie Inst. Pub. No. 113, 1909; also E. Warming, Œcology of Plants, Ox. ed., 1904, pp. 370–372.

[2] For an outline presentation of the balance of soil-making and soil-destroying forces that have produced the main soil types now at the surface of the earth see the table, p. 25.

the soil; in other localities the action is rapid and disastrous and its checking should be a matter of the gravest concern. As early as 1890, Shaler[1] estimated that the soils of about 4000 square miles of country had been impoverished through wasteful agricultural methods, representing a loss of food resources sufficient to support a million people; and that at least 5% of the soils which at one time proved fertile under tillage "are now unfit to produce anything more valuable than scanty pasturage." To us of a later generation this figure appears gratifyingly small beside the figure that would express the deplorable ruin of the past quarter century of reckless timber cutting and baneful neglect of fields abandoned by the upland farmer.

The forest is an important factor in soil erosion because it plays a considerable part in the flow of water by which such erosion is effected. The inequalities of the forest floor offer many mechanical obstacles to the flow of surface waters. Innumerable pools of water collect in hollows and are gradually absorbed by the underlying soil instead of running off at the surface. The leaf canopy catches and reëvaporates about 12% of the rainfall, while 10% of it runs along the tree trunks and reaches the ground by a circuitous course. The forest litter, the moss-covered and leaf-strewn ground, is capable of absorbing water at the rate of from 40,000,000 to 50,000,000 cubic feet per square mile in 10 minutes, — water whose progress is delayed by some 12 to 15 hours after the first effects of a heavy freshet have passed.[2]

While the forest thus plays an important part in the maintenance of a soil cover and in the better equalization of the run-off of streams, it would be a mistake to assume that it is the only agent which accomplishes these highly beneficial results. It is scarcely more necessary to know that deforestation may permit a precious soil cover to be wasted than it is to understand that many other types of vegetal covering besides the forest effect these desirable results. Of the same order of importance is the fact that the effects that follow upon deforestation are not equally harmful upon all types of topography and soil. If these conclusions are true it is necessary that the soil, the topography, and the secondary vegetative forces of a given region be evaluated before the statement is made that excessive soil erosion is the necessary correlative of deforestation.

That the soil is protected by many vegetal types other than the forest is now a well-established fact. The high alpine meadows of the Pacific

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[1] N. S. Shaler, The Origin and Nature of Soils, 12th Ann. Rept. U. S. Geol. Surv., pt. 1, 1890–1891, p. 333.

[2] B. E. Fernow, Relation of Forest to Water Supplies, in Forest Influences, Bull. U. S. Dept. Agri., Forestry Division, No. 7, 1902, p. 158.

Cordillera consist in many cases of a thick turf which supports natural grasses of luxuriant growth. The interlacing roots of the grasses in many situations bind the soil past all reasonable possibility of excessive erosion, the stems of the grasses impede the run-off by breaking up in one locality any incipient streams formed in another locality exceptionally favorable to concentration of run-off, the whole grass cover breaks the force of the falling rain and prevents erosion. Added to these is the influence of ponds and lakes of glacial origin in the higher situations. The retention of the soil above timber line on the Beartooth Plateau, southwestern Montana, is attributed to such a combination of grass cover and storage basins;[1] it was as natural a result that gullying should follow overgrazing of these meadows as that evil results should follow deforestation in the well-known case of the Southern Appalachians. The binding of the soil and the checking of erosion are also effected by brush and vines which in moist regions may spring up in a few years following deforestation and form an almost impenetrable covering. Such a tangle of vegetation offers even greater resistance to the surface flow of water than does the vegetation of a forest, besides permitting the formation of snowdrifts, one of the most important forms of surface water storage.[2]

The retention of rainfall by the mosses that cover the hill slopes of the Laurentian Plateau, a feature especially well developed in the Labrador peninsula, diminishes the run-off and equalizes it to a degree far exceeding that of the thin spruce forests of the region. Even the steepest slopes are slippery with loose dripping Sphagnum moss, whose effects obviously exceed those of the most porous forest floor. The very existence of a steep hillside bog is in itself proof of an unusually powerful retentive effect of the moss cover upon both soil and run-off.

All of these consequences are subject to changes in degree depending upon variations in soil and topography. If the soil is very porous the imbibition of rain water is rapid and run-off and erosion are correspondingly lessened; if the soil is compact there is little absorption, and run-off and soil erosion are more active. A hill-and-valley country, one consisting entirely of slopes of strong gradient, such as the well-dissected Allegheny Plateau, has a high percentage of run-off and soil erosion, for almost every drop of water falls upon a slope and begins a downhill movement the moment it strikes the surface. A flat surface like the till plains of central Indiana or the outer part of the coastal

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[1] J. B. Leiberg, Forest Conditions in the Absaroka Division of the Yellowstone Forest Reserve, Montana, Prof. Paper U. S. Geol. Surv. No. 29, 1904, pp. 15–19.

[2] J. C. Stevens, Water Powers of the Cascade Range, pt. 1, Southern Washington, Water-Supply Paper U. S. Geol. Surv. No. 253, 1910, p. 16.

plain of South Carolina absorbs a high proportion of the rainfall, and soil erosion is of trifling importance. Combinations of these factors are both numerous and variable. A part of the southern slope of Long Island is a natural prairie unforested even before the coming of the whites. It bears almost no signs of erosion, and such as occur had in most cases a very special origin. The absence of erosional features is not surprising when the low gradient of the plain, 10 feet per mile, and the high porosity of the sand are taken into account. These flat-lying porous sands absorb from 60% to 75% of the rainfall, perhaps as great a value as that found on any other area of equal size in the eastern half of the United States.

In New England it has been noted that the quick-growing brush and the special qualities of the glacial soil prevent the undue erosion of deforested hill slopes in the Berkshires where the relief is so strong that landslides sometimes occur. The pebbles and bowlders of the till constantly divert the run-off and lessen its velocity, while the bottoms of ravines sunk into the till are in a measure protected from erosion by a pavement of stones derived from the till. In many cases in western Massachusetts and Vermont and New Hampshire steep mountain slopes "have been several times stripped of their forest growth with little, though doubtless some, injury to the soil," and "the mountain streams are beautifully clear except immediately after a heavy rain."[1]

The large number of rock ledges that occur in this region contribute to the same effect. The soil is thin, and irregularities of the underlying bed-rock assist in holding it in place not only by physically retaining it but also by preventing the streams held upon the projecting rock ledges from expending the whole of their erosive energy upon its loose material.

The effect of the forest upon the run-off alone is extremely difficult of determination, for soil and topography are in this respect of much greater importance. That forests tend to conserve the run-off is clear; their effects in individual cases, however, may be so small as compared with the effects of soil and topography as to be overshadowed by the latter.

"Donner und Blitzen River, in central Oregon, is a very uniform stream with a well-maintained summer flow, but its area does not produce a tree, except here and there a juniper. On the other hand, Silvies River, which exists under the same climatic conditions as Donner und Blitzen River and discharges its waters into the same lake, is anything but uniform in its flow, although its drainage area is heavily forested. Niobrara and Loup rivers, in Nebraska, are very uniform in flow, but there is hardly enough timber on both areas to build a cabin. Nearly

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[1] H. F. Cleland, The Effects of Deforestation in New England, Science, n. s., vol. 32, 1910, pp. 82–83.

all the streams of western Oregon and Washington are subject to enormous floods, and all run comparatively low in summer, yet no streams in the world have more densely forested drainage areas."[1]

The conclusion that forests are not a guaranty of uniform stream flow, in spite of the fact that they tend in the direction of uniformity, does not diminish the interest of students in such influence as forests do exert, since theirs is a *controllable* influence. Man can not greatly modify the porosity of the soil or the slopes of the land, and the effects that follow upon these causes are therefore irremediable; but man may save a forest or plant one and thus mitigate effects which he can not wholly prevent. In precisely those regions where run-off and soil erosion are most extreme through unfavorable topographic and soil conditions, man may find it possible to preserve a tolerable state of affairs by saving the forest from destruction. In regions where the conditions are critical the destruction of the forest may mean the quick destruction of the soil, its preservation the preservation of the soil and the indefinite occupation of the region by man.

The retaining influence of the forest on the soil is most strikingly exhibited where the balance between soil formation and soil removal is delicately established and may be easily destroyed. An extreme instance is Kanab Creek, Utah, where the burning of the forest and the overgrazing of the pastures have resulted in torrent conditions. The tributaries have become deep washes, many new and deep gulches have been formed, dams and bridges have been destroyed by the floods and coarse gravel deposited on formerly arable valley lands.[2]

It is of importance, then, to examine at the outset the relations of soil denudation and soil accumulation, that we may be the better prepared to study those forces which tend to bind and partially to retain the covering of soil; not only that forests themselves may be perpetuated, but also that the flood-plain soils on the borders of the forests may be adequately preserved and the natural advantages of the waterways retained.

SOIL-MAKING FORCES[3]

The complex cover of rock waste which we call the soil is the product of a great number and variety of forces. Only the principal ones are here outlined.

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[1] J. C. Stevens, Water Powers of the Cascade Range, Southern Washington, Water-Supply Paper U. S. Geol. Surv. No. 253, 1910, p. 17.

[2] H. S. Graves, The Forest and the Nation, American Forestry, vol. 16, 1910, p. 608.

[3] The section on soils is necessarily brief and somewhat technical and assumes on the part of the student a knowledge of ordinary rocks and rock-making minerals as well as an elementary knowledge of chemistry. Those students who are deficient in such knowledge should consult

OXIDATION.
CARBONATION.
HYDRATION.
SOLUTION.
MECHANICAL ACTION OF WATER AND ICE.
TEMPERATURE EFFECTS.
WIND.
BACTERIA.
ANIMALS AND THE HIGHER PLANTS.

OXIDATION

Oxygen is the most active element of the air, and the process of oxidation is of great importance in reducing rock masses to soils. The action is perceptibly manifested only in rocks containing iron either as a sulphide, a carbonate, or a silicate. Of these the sulphides are changed to sulphates which are soluble and may be removed in solution. The most common minerals attacked are ferrous carbonate associated with the carbonates of lime and magnesia and the silicates of mica, amphibole, and pyroxene. The minerals become gradually decomposed through oxidation and disintegrate into unrecognizable forms. The oxidation of the iron-making minerals of a rock is always attended by increase in bulk, and when this takes place in cracks and crevices it tends, like the freezing of water, to widen the cracks and to increase the surface exposed to attack. In general the action of the air in soil formation is of secondary importance and depends chiefly on the oxidation of the lower to the higher basic forms. The ferrous and ferroso-ferric oxides are converted into ferric oxide or its hydrate limonite, iron rust, which gives to soils containing much iron their characteristic reddish or yellowish colors.

The presence of ozone[1] in air without doubt causes it to have a more active oxidizing effect. Ozone is present in considerable quantity in the air only when the air is free from organic impurities and products of decay. The average amount of ozone in a hundred cubic meters of air is 1.4 mg., but the amount may be doubled after thunderstorms.[2]

Merrill, Rocks, Rock-weathering and Soils, 1897. For purposes of brief inspection of the mineralogical composition of ordinary rocks and the chemical composition of rock-making minerals the tables in Appendix C in this book should be consulted, and a text-book of Lithology such as Pirsson, Rocks and Rock-forming Minerals, 1909.

[1] Ozone is a very active form of oxygen in which the molecules consist of three atoms of oxygen instead of two atoms as in a molecule of ordinary oxygen. It is formed by silent electrical discharges, and is chemically unstable, readily parting with one of its atoms, hence chemically active.

[2] J. Hann, Handbook of Climatology, 1903, pp. 80–81.

The amount of ozone in the air is determined by the rate of change in an easily oxidized substance — not a very accurate method.[1] Ebermayer emphasizes the more powerful oxidizing effects of ozone in the air and its formation in the forest in unusual amounts.[2]

CARBONATION

The oxidation of organic materials (both plant and animal remains) by bacteria and oxygen in the zone of weathering produces a concentration of carbon dioxide near the surface. The degree of concentration of this gas in the zone of weathering is appreciated by comparison of the soil air with the atmosphere. The amount of carbon dioxide in the atmosphere is 45 parts in 10,000 by weight; the amount in soil air or soil gases is represented in the following table:

AMOUNT OF CARBON DIOXIDE IN SOIL AIR[3]

Derivation	Parts by weight in 10,000
Air from sandy subsoil of forest	38
Air from loamy subsoil of forest	124
Air from surface soil of forest	130
Air from pasture soil	270
Air from soil rich in humus	543

The carbon dioxide in the soil is the agent in the important weathering process known as carbonation, by which is meant the union of carbonic acid with bases in the formation of carbonates. It is dominantly accomplished by the substitution of carbonic for silicic acid. To some extent carbonates are also formed (1) by the substitution of carbonic acid for other acids, e.g., phosphoric acid, and (2) by the union of carbon dioxide with oxides not united with other acids, e.g., ferrous oxide in magnetite.[4]

The process of carbonation takes place on a vast scale. It is most rapid in the tropics, takes place at a moderate rate in temperate lands, and is least important in the frigid zones and in arid regions. It has a direct relation to the amount of vegetation, since it is chiefly through the decay of the vegetation that carbon dioxide is supplied for the reaction involved in carbonation. On the other hand a soil containing carbon-

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[1] W. M. Davis, Elementary Meteorology, 1898, p. 5.

[2] E. Ebermayer, Lehre der Waldstreu, etc., 1876, p. 202.

[3] Boussingault and Levy, quoted by G. P. Merrill, Rocks, Rock-weathering and Soils, 1897, p. 178.

[4] C. R. Van Hise, A Treatise on Metamorphism, Mon. U. S. Geol. Surv., vol. 47, 1904, p. 475.

ates is ordinarily fertile and supports an abundant vegetation. The surface vegetation and the soil carbonates are therefore mutually interactive and helpful. The cumulative effect of the act of carbonation would therefore appear to be constantly increasing amounts of carbonate substances. But this tendency is offset or matched by the liberation of silica in the process of carbonation; about one and one-third times as much silica is released from the silicates as there is carbon dioxide combined in the carbonates.[1]

HYDRATION

The action of hydration is the union of water with chemical compounds in the production of hydrous minerals. It is the most extensive reaction in the zone of weathering and next to carbonation the most important. It affects practically all of the anhydrous silicate minerals of the igneous, sedimentary, and metamorphic rocks to some degree, and many of them to a great degree. The decomposition products of the rock minerals are almost all strongly hydrated, such as the zeolites, chlorites, and kaolin in the silicate class and aluminum and iron among the oxides.

The action of hydration is always accompanied by the liberation of great quantities of heat and by increase in bulk. It is calculated that the transition of a granite rock into arable soil, provided such transition takes place without loss of material, is attended by an increase in bulk of 88%. In rocks as a class hydration effects volume increases which range from a very small per cent to 160% (corundum to gibbsite). In general the increase is less than 50%. Such volume increases prevent complete hydration at any great depth below the surface; partly hydrated rock when artificially exposed at the surface, as in railway cuttings, may become completely hydrated at so rapid a rate as to expand greatly in volume and soon disintegrate. Notable increase in bulk does not follow if the pore space is ample; if the pore space is small and the rock dense the action is either incomplete or involves great increase in bulk.

Commonly hydration takes place in connection with carbonation and solution. In so far as soil water is consumed in the formation of new (hydrous) minerals it can not be used in the process of solution; the amount so consumed is, however, but a small part of the whole, and solution is therefore a companion process of hydration.

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[1] C. R. Van Hise, A Treatise on Metamorphism, Mon. U. S. Geol. Surv., vol. 47, 1904, p. 480.

SOLUTION

WATER AS AN AID TO CHEMICAL ACTION

Water is the most important weathering agent, not only because of its direct effects but also because its presence conditions all phases of weathering, such as hydration, etc. It has so great a dissolving power that few substances found in rocks are wholly insoluble in it, while in water charged with acids of various sorts many rocks are readily soluble and all are somewhat soluble. The number of such acids is small, but their action is so general that they powerfully aid solution in reducing rocks to soil. Nitric acid is present in some amount in rainfall, in surface waters, and in the soil water, in which it may be supplied in small quantities by the action of bacteria. Sulphuric acid may be derived in somewhat the same manner; an important source in some regions is iron pyrites, which on decomposition may yield free sulphuric acid. It is altogether probable that many if not all soils constantly receive small amounts of sulphuric acid, and it is possible that in some cases the solvent action of this acid on the mineral constituents of the soil may become important.[1] Among these substances is chlorine the amount of which in the air varies with the distance from the sea and is greatest at the seashore. On the island of Barbados 116 pounds of chlorine are contributed annually to each acre.[2] Two or three extractions of soils, however, seldom show the presence of any free acid other than carbonic acid.

Carbon dioxide, which is the basis of carbonic acid, is contained in all natural water and in rainfall so that all percolating waters are real acid solvents and exercise a far-reaching effect, a fact now universally recognized. That dissolved carbon dioxide may act directly as an acid, thus increasing the solvent power of the water in which it is contained, is probable.[3] The destructive action of water charged with carbonic acid is most strikingly exhibited in limestone but it is not confined to this type of rock; even quartzose rocks of the ordinary kinds are attacked by it and granite and related rocks are rather quickly affected. Its effect both in the soil and in the zone of weathering[4] generally is due largely to a reduction of the mass of the hydrates of the hydrolyzed bases by the formation of bicarbonates. The result of its action upon the feldspars is the forma-

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[1] C. R. Van Hise, A Treatise on Metamorphism, Mon. U. S. Geol. Surv., vol. 47, 1904, p. 205 et al.

[2] Harrison and Williams, Jour. Am. Chem. Soc., vol. 19, 1897, p. 1.

[3] Carbon dioxide is soluble in water to the extent of equal volumes at ordinary temperature and barometric pressure.

[4] The zone of weathering extends from the surface to the ground water (Van Hise, A Treatise on Metamorphism, Mon. U. S. Geol. Surv., vol. 47, 1904).

tion of clay, a most essential element of soils from the physical standpoint, and the freeing of potash, one of the most essential plant foods. In the case of granite rocks the silica set free by the carbonic acid remains partially or wholly in the resulting soils; in the case of limestones the lime at first remains in the form of a carbonate, but potash and soda compounds, which are readily soluble in water, are largely carried away either by percolating water or absorbed by plants. The action of carbon dioxide is also manifest in the formation of carbonates of iron and magnesium.

In certain experiments carried on in the laboratory of the U. S. Bureau of Soils some powdered minerals, among which were muscovite and albite, were kept in contact for fourteen months with water and certain solutions in paraffin cylinders. Excepting the results obtained with albite, those obtained by treatment with water saturated with carbon dioxide are so much greater than the corresponding results obtained with pure water that no reasonable doubt can exist that the effect of the carbon dioxide is not only to hasten the rate of solution, but actually to increase the absolute solvent action of the water.[1]

In nature all the elements in the rock and the soil minerals in the zone of weathering are being dissolved all the time, but at variable rates depending (1) upon the strength and abundance of the active compounds in solution and (2) upon the solubility of the constituent minerals.

WATER AS A CARRIER

In addition to being the substance necessary for the chemical decomposition of nearly all kinds of rocks and soil, water has an important influence in removing large amounts of soluble plant food from the soil. Nearly five billions of tons of mineral matter are annually carried away in solution from the land into the sea, while the amount of sediment is many times greater.[2]

The amount of nitric acid found in drain water (water that runs off through drains, i.e., tiles, etc.) sometimes shows a heavy depletion of the land by the leaching out of this highly important substance. In all drain water lime is found to be leached out most abundantly, mainly in the form of bicarbonate. Magnesia is next in order, then soda and other substances of minor value. Potash is present in drain water in small amounts. Carbonic acid is the most abundant of the acids found in such water, and chlorine and silicic acids are next in order.

MECHANICAL ACTION OF WATER AND ICE

An important mechanical effect of water is exhibited during rain storms when the erosion of soil on all slopes and its rapid erosion on unprotected steep slopes occur and may lay bare the rock surface

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[1] Cameron and Bell, The Mineral Constituents of the Soil Solution, Bull. U. S. Bur. Soils No. 30, 1905.

[2] E. W. Hilgard, Soils, 1906, p. 24.

and enable other soil-making forces again to act upon the exposed rock. Falling raindrops also beat upon and jostle the soil grains or move them about upon the rock surface in such manner as to break off smaller particles, an action which on flat surfaces may tend to increase the amount of soil.

It has been computed with reasonable accuracy that 783 million tons of earth and rock measured as soil are removed each year by erosion from the surface of the United States. The amount removed from different watersheds varies greatly, not only on account of differences in the sizes of the drainage areas but also on account of differences in the depth and porosity of the soil, the extent and nature of the vegetable cover, the lengths and declivities of the slope, the rainfall, the temperature, the extent of lakes, etc. In the north Atlantic basin the rate is 130 tons per square mile per year; the rate in the Hudson Bay basin is 28 tons and is the lowest on the continent; the southern Pacific basin heads the list with 177 tons. Individually the Colorado River brings down the greatest amount of suspended matter; it delivers 387 tons per year for every square mile of its drainage basin. Practically no suspended matter is transported by the St. Lawrence River, since the water is cleared by sedimentation in the Great Lakes. In general the northern streams carry much less suspended matter than the southern streams, a result due probably to the large number of lakes in the drainage basins of the northern streams, the large extent of bare rock outcrop, and the hindrances to erosion imposed by soil frozen during a large part of the year.[1]

The action of freezing water is due mainly to the expansive force it manifests as it passes from water to ice, and has been described as equivalent to the pressure of a column of ice a mile high, or about 150 tons to the square foot. If a given rock contains much water in its pore space and is repeatedly subjected to freezing temperatures, the rock will in time be disrupted by heavy internal strains. The extent of the strain effect depends (1) upon the climate, (2) upon the weather conditions, whether uniform or variable, and (3) upon the amount of water contained by the various kinds of rock, which in turn differs with the nature of the minerals and their state of aggregation.

All rocks when freshly exposed hold by capillary attraction a certain amount of water, which occurs largely as interstitial water. The amounts that may be contained are expressed roughly as follows: granite, 0.37% by weight; chalk, 20%; ordinary compact limestone, 0.5% to 5%; and sandstones from 10% to 12%; while clay may contain nearly one-fourth its weight

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[1] These computations show that the surface of the United States is being removed at the average rate of .0013 of an inch per year, or 1 inch in 760 years. Dole and Stabler, Water-Supply Paper U. S. Geol. Surv. No. 234, 1910 (Denudation), pp. 82–83.

> in water. The amount in white chalk is as much as 19% and a piece of such chalk may be shattered into fragments by a single night's frost. The freezing of absorbed water is one of the most general sources of disintegration of building stones.[1]

In addition to the expansive force of interstitial water when frozen is the action of freezing water in the joints of the rock, which tends to disrupt large masses from the faces of cliffs and other bare rock surfaces. The effect is heightened if freezing and thawing alternate in periods of short duration. Alternate freezings and thawings may be beneficial to the soil after formation, because the freezing of the water in the pore spaces increases the bulk of the whole mass of frozen soil, — an increase which is not immediately compensated on thawing, so that aeration and root penetration derive a certain benefit from the process.

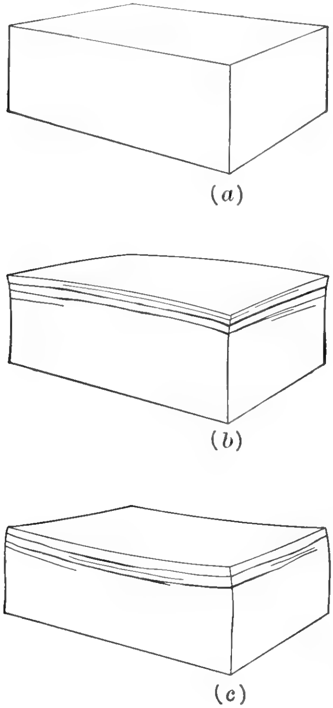

Fig. 1. — Effect of unequal heating of the surface of a rock. (*a*) shows the condition of a block at uniform temperature; (*b*) the manner in which the upper portion expands when heated above the average temperature; (*c*) the contraction of the upper portion by cooling below the average temperature. When contraction and expansion are sufficiently great they result in the splitting of the surface layers. (Van Hise, U. S. Geol. Surv.)

TEMPERATURE EFFECTS

While the agencies we have so far enumerated are active in nature in breaking down rock, soil would be formed without such agencies, though at a slower rate, through the inherent instability of the rock under changing temperatures. The breaking of a hot glass plunged suddenly into cold water is a manifestation of the same force that in humid regions to a lesser extent, in arid regions to a greater extent, tends to disrupt rock masses and to form soil. The temperature effects upon rock are of several kinds: (*a*) the breaking apart of large rocks into smaller masses through expansion and contraction of the whole mass at an unequal rate; (*b*) the peeling off of rock layers and chips from a rock surface or from the surfaces of bowlders through unequal expansion and contrac-

[1] A. D. Hall, The Soil, 1907, p. 11.

tion between the surface layer and the layer immediately beneath, a process known as exfoliation; and (*c*) temperature changes which expand different minerals at different rates and cause an internal strain to which the rock may finally yield. The first process (*a*) is so familiar as to require no description. The second process (*b*) may be understood by the recognition of the high temperatures which bare rock surfaces attain when exposed to the summer sun. On a hot day they may attain a temperature of 150° or 160°, a temperature so high that the hand can not be held on exposed surfaces without being burned. Between the highly heated surface particles and the particles some distance beneath the surface there must be a zone of shear, for at these high temperatures the surface rock will expand greatly, while the cool rock only a short distance beneath the surface is so much lower in temperature as to occupy smaller bulk, Fig. 1. From observations made near Edinburgh, Scotland, during 1841–42, the range of earth temperatures at varying depths in soil, sandstone, and trap rock was determined to be as follows:

VARIATION OF TEMPERATURE WITH DEPTH[1]

Depth	Trap Rock			Sand of Garden			Craigleith Sandstone		
	Max.	Min.	Range	Max.	Min.	Range	Max.	Min.	Range
3 feet	52.85°	38.88°	13.97°	54.50°	37.85°	17.65°	53.15°	38.25°	14.90°
6 feet	51.07	40.78	10.29	52.95	39.55	13.40	51.90	38.95	12.95
12 feet	49.00	44.20	4.80	50.40	43.50	6.90	50.30	41.60	8.70
24 feet	47.50	46.12	1.38	48.10	46.10	2.00	48.25	44.35	3.90

Of course the surface inch or two or three inches show much greater ranges; and between the first and twelfth inches the differences may be extreme on hot summer days. The author has noted as the result of temperature observations on loose dry soil during several summer months a maximum difference of 35° to 50° between the first and fifteenth inches, which was reduced to 5° or 10° before the following sunrise.

Translating differences of temperature into units of expansion we have the rate of horizontal expansion varying from .000004825 inch per foot for each degree Fahrenheit in granite to .000009532 inch in sandstone.[2] A change of temperature of 150° in a sheet of granite 100 feet in diameter would thus produce a lateral expansion of about 1 inch, an expansion that tends to lessen the cohesion of the rock and to cause a shearing of

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[1] Trans. Royal Society of Edinburgh, vol. 16, 1849. From G. P. Merrill, Rocks, Rock-weathering and Soils, 1897, p. 184.

[2] W. H. Bartlett, Experiments on the Expansion and Contraction of Building Stones, etc. Amer. Jour. Sci., vol. 22, 1832, p. 136.

the upper over the lower layers. Although these movements seem slight they are sufficient to produce in time a weakening and breaking of the rock, thus affording a better opportunity for the action of other physical and chemical agencies such as freezing water, bacteria, plant roots, etc.[1]

This form of rock disintegration is most pronounced in massive coarse-grained rocks located in regions of great extremes of daily temperature such as occur in the arid and semiarid portions of the West. When it occurs in homogeneous massive rock it may produce rounded forms or bosses of very characteristic appearance.

Stone Mountain, Georgia, 650 feet high, 2 miles long, and 1½ miles wide, owes its elliptical dome-like form to such exfoliation along preëxisting lines of weakness in the form of joints. The surface sheets are buckled up in very characteristic forms. They are rarely more than 10 inches thick, but are 10 or 20 feet in diameter. In a few instances small avalanches have been caused by the giving way of such sheets.[2]

The third process (*c*) of rock disintegration through temperature change, that of crystal crowding, may be understood from the fact that in all rock composed of crystals there is an internal strain due to the unequal rates at which the component minerals expand upon increase of temperature. Such expansion has two forms of inequality: (*a*) the cubical expansion varies with the kind of mineral and (*b*) the rates along the various crystallographic axes of the constituent minerals are unequal.[3]

It is self-evident that a coarsely crystalline rock under these conditions will disintegrate more rapidly than a rock of finer grain. Rocks of granular structure, all other things being equal, undergo disintegration much more quickly than those in which the individual minerals are closely compacted, as a diabase or a quartzite. It is believed that dark-colored basic rocks tend to respond to the forces manifested by changes of temperature somewhat more readily than do light-colored acidic rocks, because of the more rapid absorption of heat by dark-colored objects in sunlight. It has also been shown that the thermal conductivity of rocks varies in direction according to the structure, being greatest in the direction of the schistosity, where this feature is developed. The result is that in massive, homogeneous rocks the conductivity is the same in all directions, while in finely fissile rocks it may be four times as great in the direction of the fissility as at right angles thereto.[4]

WIND AS AN AGENT IN SOIL FORMATION

While the action of wind is most clearly seen on the surfaces of land waste where loose dry material may be shifted about in the form of dunes and sand drifts of variable size and shape, wind may also be an important agent in the actual production of soil. Loose particles of rock may be driven through the air against projecting rock ledges, and not only do they themselves tend to become finer through attrition in

[1] G. P. Merrill, Rocks, Rock-weathering and Soils, 1897, p. 181.

[2] Idem, pp. 245–246.

[3] G. P. Merrill, Stones for Building and Decoration, p. 419.

[4] G. P. Merrill, Rocks, Rock-weathering and Soils, 1897, p. 184.

the air, but they also abrade obstructing ledges. This action takes place on a considerable scale in dry regions and may become one of the most important agents in the denudation of desert lands.[1] It has been estimated that the dust in a cubic mile of lower air during a dry storm weighs not less than 225 tons, while the amount of dust in the same volume of air during a severe storm may reach 126,000 tons.[2] The great importance of the wind as a soil builder is shown by the wide distribution of the loess deposits of the world. "It would perhaps be an exaggeration to say that every square mile of land surface contains particles of dust brought to it by the wind from every other square mile, but such a statement would probably involve much less exaggeration than might at first be supposed."[3] Dust transportation is not confined to desert regions, but takes place almost everywhere on some scale.

Not the least important of the effects of wind on soil has been the wide distribution of volcanic dust as in Oregon, southern Idaho, etc. In the Tertiary period volcanic eruptions took place on a vast scale in many portions of the West. Great quantities of volcanic dust were raised aloft and then deposited at varying distances from the volcanic vents. In many instances such bodies of dust were swept by the wind hundreds of miles from their points of origin, and finally deposited as a sheet of loose waste. Since their original deposition the wind has played upon the surface layers, shifting them about, reworking and redepositing the material, and by these means modifying the qualities of the surface soil of many great tracts.

BACTERIA

Certain bacteria are able to draw their nourishment directly from the air in a purely mineral environment such as that found upon the surfaces of bare rock, so that even the denuded rocks of high mountains may be populated by these minute organisms. The ragged rocks of high altitudes and steep slopes in the Alps, the Pyrenees, the Vosges, etc., are composed of minerals of the most varied nature, all of which have been found to be coated with a "nitrifying ferment." These bacteria develop by absorbing carbonate of ammonia and vapors of alcohol from the air and they even assimilate carbon dioxide. The wide distribution of these organisms, their great number, and the manner in which

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[1] W. Cross, Wind Erosion in the Plateau Country, Bull. Geol. Soc. Am., vol. 19, 1908, pp. 53–62; S. Passarge, Die Kalahari, 1905; W. M. Davis, The Geographical Cycle in an Arid Climate, Jour. Geol., vol. 13, 1905, pp. 381–407.

[2] J. A. Udden, A Geological Romance, Pop. Sci. Mo., vol. 44, 1898, pp. 222–229.

[3] Chamberlin and Salisbury, Geology, vol. 1, 1904, p. 22.

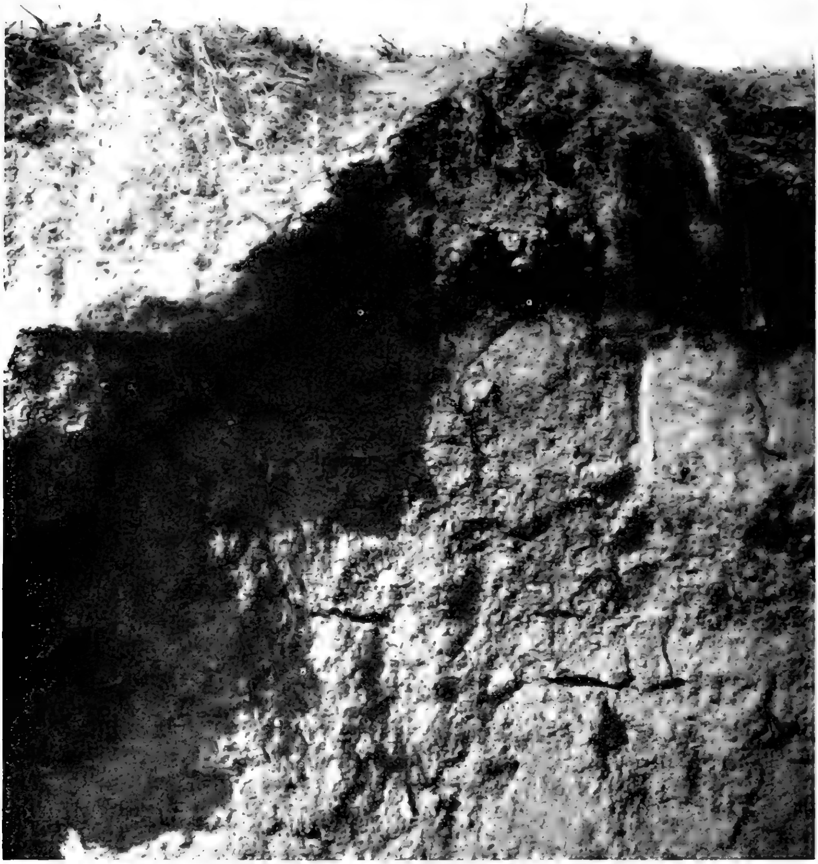

Fig. 2.—Underground burrows and chambers of earthworm population, in well-drained sand bank near New Haven. The vertical burrows connect with underground chambers showing as dark lenses within an inch and an inch and a half of the bottom of the photograph. Seven or eight can easily be identified. At the time the photograph was taken many of the chambers and some of the burrows were completely filled with dark humus collected by the earthworms. When the humus was scraped away it was seen that each chamber had a smooth and generally flat floor and an irregularly arched roof. Such of the openings as had been filled with humus had been abandoned. The open chambers and burrows were teeming with earthworms and with insects of many genera. The upper edge of the bank was broken down during a dry spell and at a time when the ground was fully stocked. The scale in the upper right hand corner is three inches long. (Photograph by Mason.)

they prepare the rock for the microscopic vegetation which is usually found in the form of a layer covering rock surfaces and soil particles, place them among the important geologic agencies that have effected the disintegration of the rock and the formation of soils.[1]

Their action is carried on on a small scale in cold temperatures and on a very large scale under normal temperatures where the rock is but thinly covered with earth. The action is also carried on among rock fragments, tending gradually to reduce them. The bacterial organisms penetrate every cleft or crevice, and by the chemical action of their secretions continually reduce the rock to smaller and smaller sizes, acting even on the most minute fragments. Each rock particle is found covered with a film of organic matter accumulated by these bacteria and the plants of a higher order which secure through them a food supply.

ANIMALS AND HIGHER PLANTS AS SOIL MAKERS

The most active animal agencies in producing and modifying soils are earthworms, which influence the physical state of soils by making them more porous and open. Darwin's studies showed that the intestinal content of worms has an acid reaction which has an effect on the soils passing through the alimentary canal. They still further modify soils by drawing into their holes leaves and other organic materials which gradually decay and are converted into humus, Fig. 2. Darwin estimated that an average of about 11 tons of organic matter is in this manner annually added to each acre of soil in regions where earthworms abound. Earthworms tend also to increase the amount of ammonia in the soil, to make the soil finer by attrition during the process of digestion, and to mix the soil by bringing to the surface portions of the subsoil. They thus play a notable part in maintaining soil fertility. The excreta of earthworms contains more nitrogen and other easily oxidized compounds than the original soil, and after excretion by worms soil contains phosphoric acid and calcium carbonate in more readily soluble forms.[2] It has been observed that when earthworms are drowned out the surface soil layer remains compacted and vegetation grows very feebly until earthworm immigration has restocked the soil.[3] The action of burrowing animals, worms, insects, etc., in the soil, allows freer access of rain water and drainage water and increases the depth and the rate of rock and soil decay. Ants sometimes produce

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[1] H. W. Wiley, Principles and Practice of Agri. Analysis: Soils, vol. 1, 1906, pp. 39–40.

[2] Cameron and Bell, Mineral Constituents of the Soil Solution, Bull. U. S. Bureau of Soils No. 30, 1905, p. 41.

[3] A. D. Hall, The Soil, 1904, p. 159.

highly important effects upon the soil, especially in tropical countries as in Brazil, where they often build tunnels hundreds of yards long which give the soil-making forces access to the subsoil. They carry great quantities of leaves into their nests and by this means and by their excreta contribute vegetable acids to the soil and thus promote rock and soil decay.[1]

More general in their action upon both rock and soil are plants and plant roots. Roots force themselves into the crevices of rocks and minerals, they wedge apart rock masses, and thus expose new surfaces and a larger extent of surface to the action of other forces. The mechanical force exerted by growing roots is very great. The root of the garden pea has a wedging force equal to 200 or 300 pounds per square inch, a force that is exerted without harmful effects upon the small roots because of the protection afforded by the corky layer of the root tips.[2] Vegetation also assists in rock decay by shading the surface and permitting the retention of a larger amount of water upon the immediate surface where it exercises a dissolving action as already described. The organic matter contributed to the soil by decaying vegetation promotes rock decay by furnishing carbon dioxide or carbonic acid. Rootlets of plants in contact with limestone dissolve large portions of this rock through the solvent action of root moisture. The action of rock disintegration is also extensively carried on by the lower forms of vegetation, among which the lichens produce the most important effects. The rock surface is corroded and a soil cover originated. A prominent ingredient of the lichens is oxalic acid, an acid that compares in strength with hydrochloric and nitric acids, and that powerfully aids rock decay.

Plant roots that permeate the soil are agencies of oxidation which have a very appreciable effect in altering some soil constituents and influencing soil fertility. Active extracellular oxidation is carried on by the plant roots chiefly by means of the enzymes (the name applied to any unorganized chemical ferment such as diastase, pepsin, etc.) which they excrete, and not to organic (carbonic acid alone excepted) and inorganic acids which they were formerly supposed to excrete. It is believed that the effect of the roots of growing plants in dissolving the organic substances of the soil is due chiefly to this action. Among phanerogams extracellular oxidation is strongly localized and limited to the absorbing surface of the root; the most intense oxidation is effected by the root hairs. Oxidation is more marked when an optimum water

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[1] J. C. Branner, Ants as Geological Agents in the Tropics, Bull. Geol. Soc. Am., vol. 7, 1896, p. 255; idem, Geologic Work of Ants in Tropical America, Bull. Geol. Soc. Am., vol. 21, 1910, pp. 449–496.

[2] E. W. Hilgard, Soils, 1906, p. 19.

content is maintained in the soil, while saturation of the soil produces a decided depression in the rate of oxidation. Oxidation by plant roots is increased by the presence of calcium salts, potassium salts, phosphates, nitrates, etc.[1]

The action of plants in promoting the formation of soil is well illustrated by the manner in which plant associations succeed each other upon extensive areas of bare rock, a succession that is dependent upon the ability of each plant group to live under the hard conditions which exclude the next higher group. Crustose lichens are the only plants which are able to establish themselves on a bare rock face. Upon the thin soil formed by these, other lichens are able to secure a foothold. Then appear the mosses, for example Hedwigia, Grimmia, etc., which eventually eliminate all but the erect (fructicose) lichens. The mosses still further increase the soil layer, both through the accumulation of mineral particles and by their own decay, and are in turn wholly or partly displaced by the more xerophytic species of ferns such as the spleenworts. With the ferns appear many herbaceous flowering plants, notably the stonecrops and saxifrages, and certain grasses. In addition to the carbonic acid which is excreted by the roots of all plants many of them secrete vegetable acids such as oxalic and citric acids which assist in soil formation. The herbaceous plants in turn prepare the way for, and are eventually succeeded by, shrubs and trees.

Senft describes the vegetation that takes hold of landslips and coarse terrace deposits (near Eisenach) and shows how it undergoes great changes in type due to soil changes brought about chiefly by the vegetation itself. In the locality examined the bare stony heaps were first clothed with mosses, then xerophytic grasses; later other xerophytic herbs came in and also shrubs like the juniper which gave rise to dense, bushy growths. In twelve years an impenetrable bush land had arisen and finally Sorbus, Fagus, and other trees appeared and a forest arose. During this change in vegetation type the soil had constantly changed and improved. Each kind of vegetation suppressed another — bush land vanquished xerophytic grasses, and forest vanquished bush land.[2]

The effects of minor rock structures upon plants is extremely interesting. Peculiar and variable rock habitats induce variations in plant societies which are due chiefly to local differences in the nature of crevices — joints, fissures, etc. — in the rock.

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[1] Schreiner and Reed, The Rôle of Oxidation in Soil Fertility, Bull. U. S. Bureau of Soils No. 56, 1907, pp. 7–9 et al.

[2] Quoted by Warming, Œcology of Plants, 1909, Ox. ed., pp. 352–353.

> "Some of these receive water percolating from higher parts of the mountain, and may remain moist throughout prolonged periods of drought; other crevices obtain their water exclusively from the strictly local rain. Some crevices contain abundant detritus and are therefore endowed with a greater power of storing water; others are poor in detritus and allow the water to pass away. The chemical composition of the detritus also varies, as some crevices contain abundant humus, in which numerous earthworms may lurk, whereas others are poor in humus. Cracks in rocks supply an endless variety of habitats, each of which forms a special kind of environment."[1]

The point is of exceptional importance in regions of thin soil where the lower roots of all plants and all the roots of some plants are in intimate association with the rock. Talus slopes frequently show similar variations. Their lower slopes or lower margins are commonly wooded because of the finer rock waste and the greater amount of water which here reappears. The loose upper slopes are treeless except where the talus has become temporarily stable and clogged with finer waste or where a change of geologic formation or the arrangement of crevices cause seepage, a common condition at the upper edge of talus slopes.

The Causes of Soil Diversity

The preceding discussion will enable us to see that the soil is an extremely complex mixture. There are present mineral débris from rock degradation and decomposition; organic matter, the partly decomposed remnants of former plant and animal tissues; the soil atmosphere, always richer in carbon dioxide and generally in water vapor than the atmosphere above the soil; living organisms, such as various kinds of bacteria, and often molds, ferments, and enzymes; and finally the soil water, a solution of products yielded by other substances. This enumeration is sufficient to show how diverse are the origins of the different components, and to suggest how varied are the reactions that take place in the soil even after its formation. These facts need emphasis because of the general view that soil is mere dirt or rock waste, or that it is everywhere the same, whereas the truth lies nearer the other extreme. The soil is a great complex of varied elements, formed in many ways, and subject to the most widely diverse changes after its formation. Nor have we exhausted the list of diversifying forces. We have yet to consider briefly the transportation of rock waste after formation, the various agencies concerned in it, and the results upon the soil texture and fertility.

All soils are subject to some movement at the earth's surface, and since the soil particles are of different sizes, weights, and compositions, they must respond in different ways to the forces that tend to move

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[1] E. Warming, Œcology of Plants, Ox. ed., 1909, p. 245

them. The simplest case is that of deposition by running water, with gradually diminishing velocity, where on the whole the coarser particles are deposited first and the finer last. The action and the result are so familiar to all as to require no extended discussion. The distribution of material in an alluvial fan or a delta or a flood plain always follows this well-recognized law. The effects of creep and rainwash are not so simple. Under the influence of constantly changing temperature all hillside or *colluvial* soils tend to move down slope. Contributing toward the same result is the action of percolating soil water and ground water, cultivation, etc. In all these cases the fundamental and ultimate force is gravity, but because gravity is manifested in so large a number of forms it is clearer to consider the forms themselves and not the basic force on which they depend. In such cases of creep there is not that suspension of particles in water that permits thorough stratification or sorting, consequently coarse and fine are left mixed together, and the rate of movement may be so slow as scarcely to be perceptible.

Where rock formations succeed each other in short distances soil creep may cause an important lack of sympathy between the underlying rock and the overlying soil. The soils of the higher may come to rest over the lower formations, and the rock character give little clue to the nature of the overlying soil. Cases of this kind are frequent in the Appalachian Mountains and the ridges of the Great Appalachian Valley, and are especially well marked where the boundary between two unlike formations occurs on a hill slope. If the slopes are quite steep and the rock formations numerous on a given slope, such overplacement of soils may produce extreme effects and the waste from the different rocks become so mixed as to show at the foot of a slope or on the inner border of a foreland plain but little relation to any particular rock. On broad plateaus where the boundaries between rock formations are far apart mixtures of soil types take place to an important degree only near the boundaries of the formations; over the greater part of the outcrop of a given formation there is a close relation between the underlying rock and the soil. The Colorado Plateaus of the Southwest and portions of the Cumberland Plateau furnish excellent examples of this law.

The rate of movement has been made the basis of a classification of soils according to origin that deserves a word of explanation. While all soils are subject to some movement, the movement may be so slow as to be of no importance, as on portions of flat tablelands or base-leveled areas like the Piedmont Plateau of Georgia and Maryland. Such cases of no movement or of little movement will tend to cause a certain sympathy between soil and rock in a given locality, and the minerals that occur in the rock are found in the soil or at least their decomposition products are found there. Such soils are sedentary or residual soils, and the term generally implies a fundamental relation between a rock terrane and the soil covering it. On the other hand, if the soil has once been in the grip of a transporting agent such as the wind, running water in the form of river or brook, or a continental ice sheet, or a glacier, it is considered a transported soil; and the term *transported* always connotes a mixture of soil ingredients in the case of ice, and sorting in the case of water and wind. By these agencies soils may come to rest far from their place of origin. The alluvial deposits of the Mississippi flood plain are derived from fully one-fourth the whole United States. The underlying rock now perhaps deeply buried in a given locality may be limestone, but the alluvial soil overlying it may be deficient in lime and in still other ways less fundamental bear little or no relation to it because it was not derived from it to any important degree, or perhaps to any degree at all. No less true are these statements when applied to wind-borne soils. In every dry region whirlwinds raise aloft great clouds of dust that settle down near by or become more or less permanently lodged perhaps hundreds of miles away in extra-desert regions, where their relation to the rock or soil they overlie is purely fortuitous. The great loess deposits of western China, the dust soils of Oregon and Idaho, the loess deposits of the Mississippi Valley, all are illustrations of wind-borne soils, though they are not all fundamentally related to the extremes of arid conditions.

Glacially transported material has or may have the same discordance with respect to the underlying rock. Over the sandstone and limestone areas of the Great Lake region has been swept glacial detritus in vast amounts, and although the material reflects the character of the underlying rock to a notable degree (perhaps on the average about 80% of it is locally derived), yet an important share is also derived from northern localities. Bowlders of granite, gneiss, greenstone, slate, and basalt may be found scores and even hundreds of miles from their nearest outcrop, and everywhere in the glacial till are found important amounts of clay which were derived at least in small part from northern localities. The effects of the continental ice cap on the soil are discussed in greater detail in succeeding pages, and need not be further described here. Alpine glaciers have had less important effects upon soil because of their relatively slight development and because they have produced their effects chiefly in mountain valleys where their deposits are so restricted that though they may be important to the farmer they are relatively of less importance to the forester.

The part that the various agencies concerned in soil formation have played in the making of the soil of North America is brought out in the following table.[1]

DISTRIBUTION OF SOIL TYPES BY REGIONS [2]

(The surface of each continent is taken as 100)

	North America	South America	Europe	Africa	Asia	Oceania	New World	Old World	Whole Land Surface
I. Alluvial regions:									
Loam predominating	17	2	22	1	37	15	10	21	18
Mountain débris (gravel, etc.)	....	....	....	....	1	....	....	1	0
Laterite (red ferruginous residual clay characteristic of the tropics)	9	43	....	49	16	16	24	25	25
II. Equality of destruction and transportation	4	9	8	3	3	0	6	3	4
III. Denudation preponderating:									
Eolian denudation	2	....	....	14	7	2	1	8	6
Glacial denudation	25	1	9	....	0	....	14	1	5
IV. Accumulation preponderating:									
Glacial accumulations	23	4	36	....	1	....	15	4	8
Marine accumulations	....	0	....	0	....	....	0	0	0
Stream and lake accumulations	1	27	5	2	3	....	13	2	5
Shifting sand	0	1	0	13	8	19	1	10	7
Fine eolian accumulations (steppe soils)	13	1	13	18	20	41	7	21	17
Volcanic accumulations	1	2	0	0	1	2	2	1	1
V. Dissected loess deposits	5	10	7	....	3	0	7	2	4
VI. Coral Islands	....	....	....	0	0	5	....	1	0
Total	100	100	100	100	100	100	100	100	100

The kinds of residual soil that result from the decomposition of the various kinds of rock at the earth's surface are both numerous and variable. For a number of typical illustrations the student is referred to the convenient tables from Merrill in Appendix B. These tables present in summary fashion the chief facts with which he should be acquainted. They may well be supplemented by readings in Merrill[3] and Pirsson,[4] and by the chapter on Land Waste by Davis.[5] In the interpretation of these data it is well to bear in mind that not always is the rock character revealed in the soil character even in the case of residual soils. Limestone soils usually contain adequate amounts of lime, but sometimes they are so deficient in this respect that artificial liming is one of the chief neces-

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[1] Compiled by A. von Tillo from Sheet 4 of Berghaus' Physikalischer Atlas and from Richthofen's Führer für Forschungsreisende, p. 498. Original table occurs in Die Geographische Verteilung von Grund und Boden, Petr. Mittheil., vol. 39, 1893, pp. 17–19.

[2] Translation from von Tillo with modifications.

[3] Rocks, Rock-weathering and Soils, 1896.

[4] Rocks and Rock-making Minerals, 1909.

[5] Physical Geography, 1899, pp. 263–296.

sities to bring them up to normal fertility. Likewise the soil resulting from the decay of rocks such as certain basalts of Idaho that contain a great deal of apatite (phosphate of lime), a mineral which generally yields phosphoric acid to the soil, may hold the phosphorus in an insoluble form and make the addition of this ingredient one of the first necessities. To some extent also the geologic history of a region is important in the interpretation of the soils, for a cherty dolomite overlying a shale may yield its insoluble elements to the shale surface long after the soluble part of the dolomite has been removed. Some regions have been dry that now are moist, some moist that now are dry, and each change has effected a change in the soil. Many similar geologic inheritances are known that produce soil effects of fundamental importance.

CHAPTER II

PHYSICAL FEATURES OF SOILS

Size and Weight of Soil Particles

We have now seen that the soil is a complex mixture of mineral particles, soluble and insoluble chemical substances, gases, liquids, living organisms and dead organic matter, various kinds of bacteria, and often molds and enzymes. But the chief ingredients of most soils and important ingredients in all soils are the mineral particles originally derived from rock. A soil may be so coarse that it consists of little more than huge stones and bowlders with which are intermingled small quantities of rock fragments; or it may be so fine that, as in the case of the finest clays, the diameter of the individual particles is only one-thousandth of a millimeter. A pound of such material would be composed of grains whose aggregate surface extent would be 110,538 square feet, or more than 2½ acres. The number of grains in a gram of soil of such fineness would be 720,000 billion. In ordinary soils the number of grains in a single gram varies from about 2 to about 5 million.[1]

The average specific gravity of soils with an ordinary amount of humus will range between 2.55 and 2.75. The lightest constituent is kaolinite, 2.60, and the heaviest are mineral particles containing much iron such as mica and hornblende, which may range over 3.00. The specific gravity is, however, of less importance than the volume weight, or the weight of the natural soil in terms of an equal volume of water. A cubic foot of water weighs 62½ pounds, while the average weight of an equal volume of soil is about 75 or 80 pounds. The extremes are represented by calcareous sand, 110, and peaty and swampy soils, 30.[2] It is important to see at once that what are known as light and heavy soils in agriculture and forestry are not light and heavy in terms of either gravity or volume weight but in terms of tillage and root penetration. Clay is a light soil (70–75 pounds) as to volume weight; pure or moderately pure clay soils are among the heaviest known to agriculture. In general the greater the amount of humus in the soil the lighter it is.[3]

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[1] Milton Whitney, Bull. U. S. Weath. Bur., No. 4; F. H. King, Physics of Agriculture, p. 117.

[2] E. W. Hilgard, Soils, 1907, p. 107.

[3] For standard methods of determining the specific gravity of soil see H. W. Wiley, Prin. and Prac. of Agri. Anal., vol. 1, 1906, pp. 96–97.

Pore Space and Tilth

The physical organization of the soil is extremely varied from place to place. Certain sandstones are composed of grains of very uniform size, and weather into a soil of unusually uniform texture. The relations of the individual grains of such a case are represented in Fig. 3 B, where a high percentage of pore space is afforded. If, however, the grains vary in size, the smaller will occupy the interstices between the larger, the volume weight will be increased and the pore space will be diminished, Fig. 3 C. The extent of the pore space may be determined by finding the difference between the specific gravity and the volume weight of the soil. For soils composed of particles of uniform sizes the smaller

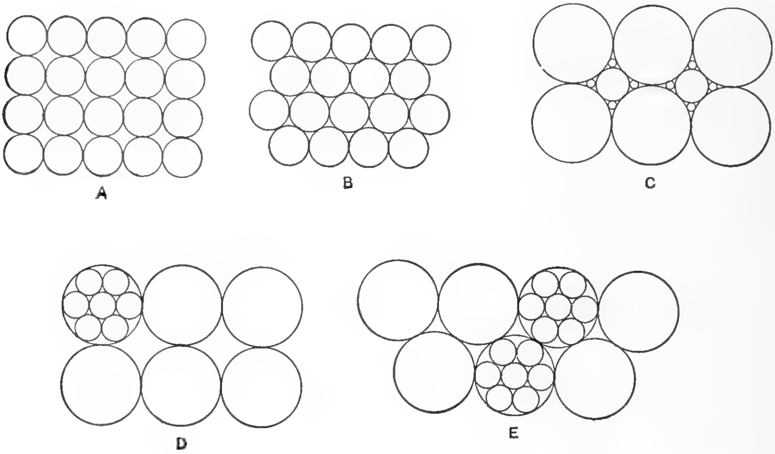

Fig. 3. — Diagram to illustrate pore space in soils

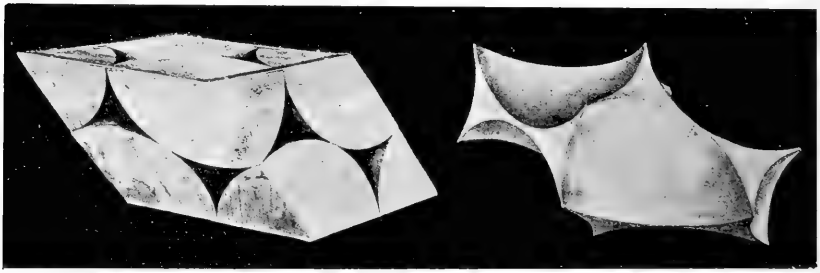

Fig. 4. — The most compact packing of a mass of spheres (left), and unit element of the pore space in such a mass (right). (Slichter, U. S. Geol. Surv.)

the size of the grain the smaller the unit pore space, the larger the size of the grain the larger the unit pore space; under all circumstances the amount of pore space is decreased by increase of variability in the size of the individual particles. The value of the porosity is independent of the size of the grains where these are uniform in a given mass; it is dependent merely upon the manner of packing. The minimum porosity of a mass of uniform spheres is 25.95% of the whole mass occupied by them, Fig. 4; the maximum porosity is 47.64% of the whole space.[1] The pore space in most cultivated soils ranges from 35% to 50%, and theoretically may be as high as 74.05%, if the soil is flocculated and the floccules or crumbs arranged as in Fig. 3 D; in sandy soils it may be only 20%.

The actual field condition of a soil as to pore space will depend upon the rainfall, methods of tillage, types of vegetal growths, and the chemical composition of the soil particles. Cultivation results in the formation of soil crumbs or soil aggregates which give the soil a loose condition known as tilth. The volume weight is decreased and the pore space increased by this condition. Wollny[2] estimates that the increase of soil volume through such flocculation may amount in the case of consolidated clay to as much as 41.9%; on moistening, dry clay increases in bulk 30% to 40%. Flocculation may be caused by lime carbonate, and to the action of this substance are due the easy tillage of limestone soils and the loose condition of the loess deposits of the western part of the country. The aggregates may range in size from 10 or more inches to those of microscopic size. The steep bluffs characteristic of loess are explained by the gripping together of the rough soil aggregates which compose the loess. The most common cement that aids crumb structure or soil flocculation is clay, and the action is one of the most important attributed to this soil substance. The fresh colloidal humates of lime, magnesia, and iron act in the same manner, while silica, silicates, and ferric hydrates have the same action but to a less important extent. Tilth is maintained in nature by humus (one of its most important functions) and by root penetration, while the deflocculating action of beating rains is prevented in nature by a cover of forest litter or of grass and herbage. Saturated soils have many defects, such as a high percentage of acids, lack of aeration, etc., but one of their chief defects is the absence of crumb structure, the compact subsoil to which this leads, and the difficulty of root penetration.

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[1] C. S. Slichter, The Motions of Underground Waters, Water-Supply Paper U. S. Geol. Surv. No. 67, 1902, p. 20.

[2] Quoted by E. W. Hilgard, Soils, 1907, p. 110.

SPECIAL ACTION OF CLAY

When soils contain too much clay they may act almost like pure clay and, like certain of the prairie soils of the western part of the United States, develop wide cracks during the dry summer months. This action has been described as contributing greatly to the drying out of the soil to some depth, the mechanical tearing of the delicate roots, and sometimes the total destruction of vegetation. In some clay soils the shrinkage after rain or irrigation is sufficient to cause the surface crust to contract about the stem and so injure the bark as to interfere with the proper growth of the plant.[1] The amount of shrinkage in the case of heavy clay soils has been measured; it ranges from 28% to 40% of the original volume. When the content of colloidal clay falls below 15% the shrinkage in drying is so slight as to produce no damage, and in sandy soils no perceptible volume change occurs. In the case of certain alkali soils of California the alkaline carbonates prevent flocculation and render tillage difficult or impossible, a result that is effectively offset by the use of gypsum. Such action is not, however, wholly destructive, for the falling into the cracks of the surface material at the next wetting causes a sort of inversion of the soil, to which is thought to be due in part the long duration of fertility in the case of many clay soils.

SOIL AND SUBSOIL

No sharp distinction has yet been generally accepted between soil and subsoil. A change in color from the darker surface layer (due to the presence of humus or ferric hydrate) to the lighter subsurface layer is the usual basis of the distinction, but this breaks down in the arid region where humus is either present in very small quantities or is wholly absent. Some would base the distinction upon change from rock to rock débris, and while this works well in the case of a shallow cover of land waste it is unsatisfactory in the coastal plains of the world and in a number of other types of places where the loose material of geologically recent deposition may reach down hundreds of feet. The color and humus distinctions harmonize with a number of other qualities, such as absence of structure, in setting off the surface layer of a few inches to a few feet as the soil and the material below that as the subsoil, and we shall regard this distinction as the most valid and acceptable.

Among the distinctions noted between soil and subsoil one of the most important is the humus content. The depth to which humus is found varies somewhat with the nature of the plant growth and is often

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[1] E. W. Hilgard, Soils, 1907, p. 112.

found to extend in notable quantities to the lower limit of development of the roots of annual plants. Variation in the root habit of different kinds of plants therefore brings about a variation in the depth of the soil as determined by the humus content. Fertilization tends to change the structure, chemical composition, and degree of compactness. In swamps and marshes the humus tint may reach to such depth as to invalidate the distinctions based upon humus content.

Since humus is porous and has a high water-absorbing and water-holding capacity, and since the surface layer of soil may consist of much finer particles than the subsoil, it is clear that the water content of soil and subsoil may be very unlike, both in time of drought and in time of abundant rain. Aeration is also more nearly perfect in the surface soil than in the subsoil and perpetually continues many chemical processes of great importance in transforming soil substances into available plant food.

Further differences between soil and subsoil deserve consideration. As a rule the subsoil is more clayey than the surface soil, hence subsoils of residual origin are generally less pervious and more retentive of moisture and plant foods in solution than the surface soil. Since the finest particles of soil are usually those richest in plant foods, subsoils as a rule would tend to accumulate larger potential supplies of plant food than the surface soil. These results are due to the penetration of the soil by rain water, which carries the finer particles down with it into the subsoil. The steady depletion of the surface soil in the humid regions by downward percolation would tend to produce far-reaching contrasts between soil and subsoil were it not for the fact that between rains evaporation progresses steadily and capillary action tends constantly to bring soluble salts nearer the surface, where they are deposited through evaporation of the water in which they are held, thus periodically increasing the amount of available plant food in the surface soil. The process is always beneficial in a humid region, but in an arid region may result in so large a surface accumulation of salts (p. 97) as to be injurious to plant growth.

Subsoil is usually more calcareous than the overlying surface soil, and this difference is so marked in some cases that the surface soil requires lime replacement when the subsoil contains a relatively large amount of lime carbonate. It may accumulate to such an extent as to form a solid subsoil mass or hardpan. It is noteworthy that the minerals of the subsoil are in a less weathered condition than those of the surface soil — a condition due largely to the absence of humus and associated carbonic and other acids, so that the subsoil is often spoken of as "raw." In arid regions the characteristic differences between soil and subsoil as developed in humid regions disappear to a large extent. The slight percolation of water does not greatly favor the accumulation of fine colloidal clay in the subsoil, so that both soil and subsoil are of the sandy type and air penetrates to a great distance. Extreme figures for aeration in arid subsoils are a few hundred to a thousand feet, as shown by oxidation of ore in rock to that depth. The distinction between soil and subsoil in humid regions as based on the humus content likewise disappears in arid regions partly because the amount of vegetable matter contributed to the soil is so small, partly because oxidation is so active that vegetation is in some cases completely "burnt up" and is not incorporated in the soil, and partly because the long roots of arid region plants are widely distributed through the deeper layers and largely absent from the surface layer.

The porosity of arid soils and subsoils and their dryness result in an extraordinary root penetration in trees, shrubs, and taproot herbs whose fibrous feeding roots are found deep in the subsoil and sometimes wholly absent from the surface soil. The roots of grapevines have been found 22 feet below the surface, and in the loess of Nebraska the roots of the native Shepherdia have been found at a depth of 50 feet. It is quite otherwise in the case of humid soils. The greater fertility of the surface layer and the abundance of air and other desirable substances, including humus, result in a great development of small feeding roots at the surface, where the largest and most active portion of the root system is found; while the water supply is derived either through a long taproot or through deeply penetrating water roots having the same function, or the whole root system of the plant has been modified to suit moist surface or subsoil conditions.

Sometimes the geologic mode of origin of the land waste of a locality is responsible for an extremely coarse subsoil overlain by thin layers of fine wind-blown or stream-deposited material. The coarseness of the subsoil of such a locality tends not only to depress the water table (p. 44) but also to repress capillary action. The result is often disastrous to all but the most deep-rooted vegetation. Indeed some localities exhibit extreme conditions; the subsoil may be almost perfectly dry during a dry season, while the surface soil is perceptibly moist and supports growing plants. This condition is seen on many outwash plains of the glaciated region and is one of the most serious drawbacks in the development of agriculture on the outwash plains of Long Island, as well as in the larger valleys of the arid region. The possibility of the condition should always be borne in mind, for it is always a reasonable expectation in transported and water-laid soils. This class of soils may offer conditions of soil and subsoil quite unlike those outlined above. When they are of recent origin almost any contrast between soil and subsoil may occur. The wandering of a waste-laden stream over an aggrading flood plain may bring about a covering of fine silt over clay or gravel; on the other hand the same stream in a near-by locality may cause the formation of clayey deposits where it formerly deposited the coarsest material. On the seaward margin of a coastal plain it is also common to find wide variations between soil and subsoil, but the variations are not always of the same kind or to the same degree, and will depend to some extent upon the shore conditions at the time of deposition of the coastal plain sediments of a given locality, and to a great extent upon the drainage conditions and degree of dissection since uplift of the coastal plain.

Soil Air

Plants may be drowned through lack of free oxygen when their roots are submerged. Besides this harmful effect of submersion is the lack of continued oxidation of the soil particles and the formation of plant foods. Furthermore, nitrification ceases and denitrification sets in. Aeration is therefore an essential process for the best plant growth, and by this is meant the admission of air not merely into the surface layers but deeply into the root zone so that the decaying organic matter in the form of roots and leaves carried down by earthworms may be formed into nitrogen by the carrying forward of the nitrifying process, which is dependent upon a supply of oxygen. In addition it should be noted that many purely chemical reactions essential to soil fertility require a certain amount of oxygen and carbon dioxide for their continuance.

The amount of air space in soils is from 35% to 50% of their volume, and when soils are in their best condition for the support of vegetation about one-half of this space is filled with water, the other half with air. A number of investigators agree in assigning to uncultivated forest soil only about half as much air per acre foot as in the case of a well-cultivated garden soil, or from 4000 to 6000 cubic feet. The composition of soil air is different from that of the atmosphere in that soil air usually contains a larger amount of water vapor, a higher nitrogen content, a lower oxygen content, a larger amount of carbon dioxide, etc.

One of the chief objects in draining a soil is to facilitate aeration. For while soil water is composed in part of oxygen it is not in a free state and requires chemical alteration to be suitable for the transformations in which oxygen plays a part. The various bad effects of lack of aeration are, chiefly, a stoppage of the important process of nitrification, the but partial decomposition of organic matter in the soil, a drowning out of earthworms, insects, etc., whose effects in maintaining soil fertility are important, and a reduction of the soil temperature. Aeration denotes good drainage; lack of aeration poor drainage, except in the case of stiff clay, where air may be excluded to a certain extent even when the clay is relatively dry. Clay soils are in general poorly aerated because their fineness of texture causes a large area of grain surface and this in turn a large water-retaining capacity. On certain areas of the Oxford clay and London clay of England the pastures degenerate in a few years into masses of creeping plants and the land must be cultivated afresh in order to aerate it. The clays are so fine-textured that they become water-logged when allowed to stand without cultivation. In order to aerate the soil the Dutch farmer of the lowlands causes the water table to sink to a depth of a meter during autumn and winter, but during the remaining months only to a depth of a half-meter; and a similar practice is followed in certain meadows in Denmark. A wet, badly aerated soil, poor in oxygen, obstructs plant respiration and represses the functional activity of the roots.

The amount of air in the soil affects the internal structure of the plant so that in very wet soil the plants that thrive frequently have very large internal air spaces which are in communication with one another throughout the whole plant and can even convey air from the atmosphere itself to the most distant root tips and parts of the rhizomes.[1]

LOAM, SILT, AND CLAY

Loam, silt, and clay are of exceptional importance in the soil. The fineness of their constituents causes notable effects upon the water content of soils, upon the solubility of the soil substances, and upon the facility of root penetration, so that it may be taken as a general principle that the fine material of a soil has an importance quite out of proportion to its relative volume or volume weight, and the determination of its existence and amount are of the greatest importance in a mechanical analysis of the soil.

LOAM

The term "loam" is perhaps one of the most indefinite words in the vocabulary of the layman who undertakes to speak about soils. It is used in a very loose and sometimes wholly indefinite way even by some soil physicists and it is therefore necessary to note its features in a special manner. From the table on p. 722 it is easy to derive the empirical formula for loam. As there defined it is a soil that contains less

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[1] E. Warming, Œcology of Plants, Ox. ed., 1909, p. 44.

than 55% of silt and more than 50% of silt and clay; but the essentials of that formula are not brought out by its mere statement. The essential feature of a loam is that it is a mixture in certain proportions of fine with less fine material. That mixture may represent the widest extremes of soil material, such as stones and bowlders mixed with silt and clay in right proportions, and would then be called a stony loam; or it may be either a coarse or fine or medium sand that is mixed with clay or silt or a mixture of these two substances, in which case it would be called a sandy loam. *Loam is therefore not to be thought of as a certain soil ingredient such as sand or silt or stones, but as a condition of mixture which makes it desirable to designate the mixture and not the individual components and to express such designation by a specific name.* This explanation can not be stated too emphatically, because a great many writers loosely consider a soil to be a loam when "loam" predominates, and call it a sandy loam if a certain important amount of sand occurs in the soil. If on the other hand the sand predominates they call the sample a sandy loam instead of a loamy sand. Such a designation makes the erroneous assumption that "loam" is a substance instead of a condition of mixture. It is scarcely necessary to add that humus added to clay or sand or silt in right proportions makes a loam or that clay added to gravel in certain proportions makes a loam, etc.

SILT

The term "silt" is commonly employed to denote the finest material of the soil above clay. In the mechanical analysis of soils only differences in size of grain are determined and it might therefore be assumed that silt resembles sand in chemical constitution. They are on the contrary unlike in their chemical nature but the differences are not radical. In sand, quartz is the principal mineral; in silt the hydroxides and hydrous silicates predominate. Neither product is wholly free from the other and neither is uniform in character since the character of the sediments everywhere reflects to some degree the character of the rock from which the sediments were derived. In regions of basic rock, for example, the sediments are rich in iron; in granite regions the sediments are composed largely of aluminous residues.[1]

CLAY

Residual clays originate through the decomposition of crystalline rocks. They are pure or of high grade when they are derived from rocks which contain only silicates of alumina or when the movement of the

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[1] F. W. Clarke, The Data of Geochemistry, Bull. U. S. Geol. Surv. No. 330, 1908, p. 428.

ground water is thorough enough to remove other more soluble salts as fast as formed. Since these conditions are rarely fulfilled it follows that even the purest deposits of clay usually contain crystals of quartz and other types of resistant minerals. The acids of ground water have far less effect upon aluminum than upon the other bases, so that the greater part of this base remains in the soil and collects in such amounts as to form deposits containing large percentages of clay (silicate of aluminum) or kaolin.

> "Clays may be defined as mixtures of minerals of which the representative members are silicates of aluminum, iron, the alkalies, and the alkaline earths. The hydrated aluminum silicate, kaolin ($Al_2O_3.2SiO_2.2H_2O$), is the most characteristic of these. Some feldspar is usually present. The grains of these minerals may show crystal faces (especially in the case of kaolins), but more commonly they are of irregular shapes. Upon most of these grains is an enveloping colloid coating. This is mainly of silicate constitution, but may consist partly of organic colloids, of iron, manganese, and aluminum hydroxides, and of hydrated silicic acid. Quartz grains, which are generally present, and mica, which is frequently present, do not have the colloid coating or have it in much less degree. Almost any mineral may be present in clays and modify the properties somewhat. The combination of granular materials and colloids is in such proportion that, when reduced to sufficiently fine size (by crushing, sifting, washing, or other means) and properly moistened with an appropriate amount of water, plasticity is developed. If the colloid matter is in excess the clay is considered very plastic, fat, or sticky, but if the granular matter is in excess it is called sandy, weak, or nonplastic."[1]

Transported clays owe their existence to the sorting action of water. The deposition of the transported material according to size leaves the fine clay to be deposited last. Hence clay deposits may be found on lowlands where more or less regular inundations permit of the subsidence of clay as the end of a series of quiet water depositions in back swamps and flood plains. Clay may also be formed as a marine or lacustrine deposit to become dry land either through the elevation of the deposits by crustal movement or through the draining of a lake or partial draining by the cutting down of the outlet, the silting up of the lake floor, the tilting of the land, or the growth of shore vegetation. The formation of pure clay can take place only under exceptional conditions, since deposition is usually in the form of floccules of coarser material which carry down the finer particles with them even when the water is undisturbed.

COLLOID CLAY

The name "colloid" (resembling glue or jelly) is applied to the clay particles that remain suspended in water for 24 hours or longer. The presence of an electrolyte such as a soluble salt causes the discharge of the static electrical charges either positive or negative to which the suspension is thought to be due and the subsidence of the colloid follows.

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[1] H. E. Ashley, The Colloid Matter of Clay and its Measurement, Bull. U. S. Geol. Surv. No. 388, 1909, p. 7.

This explains the hastened subsidence of colloidal matter in river water when it is discharged into a salty sea. Besides the true clay of the extremely fine substance of soils there are present, usually in all soils, substances such as silicic, aluminic, and zeolitic hydrates, which are all nonplastic and yet fine enough to form part of the clay substance as usually described.[1] The plasticity appears to be due solely to those particles of the clay substance which do not settle in the course of 24 hours through a column of pure water 8 inches high. Colloid clay is a jelly-like substance which shrinks greatly on drying and when dry appears like glue. It adheres to the tongue with great tenacity, swells rapidly when wetted, and is highly adhesive and plastic. It may also be separated from water by evaporation of the water or by the use of lime which flocculates the clay particles and causes them to subside.[2]

CLASSIFICATION OF CLAYS

Clays are designated according to the predominance of certain constituents: some are calcareous and are called marls; some contain a great deal of fine quartz and are known as siliceous clays; while others are rich in iron oxides and are called ferruginous clays or ochers, etc.[3] The brickmaker, the ceramist, and others have refined classifications based upon the special qualities clays exhibit when used for special purposes and under special conditions. These are, however, not natural features of clay in the soil and therefore lie outside our field of study.

Of all the mineral constituents of the soil clay is without doubt the most important because of its peculiar rôle in the physical structure of the soil, whereby it affects root penetration, drainage, fertility, etc. Its fineness and plasticity cause it to fill the soil spaces to the degree to which it is present and to cause the soil particles to adhere and to form soil crumbs, or floccules, which in turn results in a more open structure and therefore better aeration, better drainage, more rapid humification of organic matter, etc. Without clay, sand flocculates only when moist; when thoroughly wet or thoroughly dry the particles collapse and the soil assumes a single grain structure instead of a crumb structure. The whole soil mass then becomes densely packed and its fertility reduced

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[1] H. W. Wiley, Prin. and Prac. of Agri. Anal.: The Soil, 1906, p. 182; and E. W. Hilgard, Soils, 1907, 59–85.

[2] For further data concerning the various theories of plasticity and the composition of clays see the following references:

Th. Schloesing, The Constitution of the Clays, Compt. Rend., vol. 79, 1874, pp. 386–390, 473–477.

A. S. Cushman, The Colloid Theory of Plasticity, Trans. Am. Ceram. Soc., vol. 6, pp. 65–78.

[3] L. V. Pirsson, Rocks and Rock-forming Minerals, 1909, p. 281.

both because of the exclusion of adequate amounts of water and because roots are not able to penetrate it. The compacting is furthered by the presence of grains of many sizes in somewhat equal proportions; under these circumstances the smaller grains fit into the interstices of the larger and give the soil an imperviousness that makes it very difficult of cultivation. The same result may be achieved in a soil with a high percentage of fine sediments and an equally high percentage of large grains. This combination in the absence of either intermediate grains or clay will effect a high degree of impermeability. The comparable influence of forest litter, humus, etc., on soil tilth, is discussed in Chapter VI and will not be treated here.

It is to the tendency of clay to bind the particles of the soil and give it tilth or open texture that the loaminess of soils is due when their chief constituent is sand. The small percentage of clay required to produce important effects is shown in the following table,[1] but in interpreting it the reader should keep in mind that by clay is meant the colloidal clay as noted above and not alone the fine substance separated by elutriation and of different character both physically and chemically from a colloid.

Very sandy soils	.5% to 3% clay
Ordinary sandy lands	3.0% to 10% clay
Sandy loams	10.0% to 15% clay
Clay loams	15.0% to 25% clay
Clay soils	25.0% to 35% clay
Heavy clay soils	35.0% to 45% and over

Like humus, clay is very retentive of water and soil gases as well as of solids dissolved in water, qualities so markedly absent in certain coarse soils as to render them almost useless for agriculture in spite of the presence of a rather large amount of plant food as shown on chemical analysis. Furthermore the clay substance in the soil while it itself contains nothing of value to the plant (silicate of aluminum in its pure state being of no importance whatever in nutrition) yet contains within its mass in a fine, easily dissolved, and highly decomposed condition other soil minerals or substances of great importance. Among the most important of these are potash, lime, soda, etc. As an illustration of the origin of such substances may be mentioned the soda-lime and potash feldspars. Those containing lime are more readily attacked than those containing potash. All clays arise from the decomposition of the feldspars, augite, hornblende, etc., and as these minerals all gen-

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[1] According to E. W. Hilgard, Soils, 1907, p. 84.

erally contain potash the clays are the source of the available potash in the soil; therefore the amount of potash in the soil usually varies with the amount of clay.[1] In many cases also zeolitic compounds are associated with clay. These are hydrous silicates of lime or alumina which in the presence of a solution containing a stronger base such as potash or soda may yield the displaced base to the soil as a soluble substance of great potential value to plants.

The insolubility of clay, suggested by the fact that it is an ultimate product of rock decomposition, is one of its chief defects, though the defect is generally not apparent in nature because clay has a strong affinity for many soluble salts of great importance as plant food. The manner in which the soluble material of a soil rapidly increases with increase in fineness and the importance of clay in this respect are well brought out in the following table modified from the table by R. H. Loughridge.[2]

RELATION OF SOLUBLE MATTER TO SOIL CLASS

Conventional Name	Clay	Finest Silt	Fine Silt	Medium Silt	Coarse Silt
Per Cent in Soil	21.64%	23.56%	12.54%	13.67%	13.11%
Diameter of Particles	?	mm. .005–.011	mm. .013–.016	mm. .022–.027	mm. .033–.038
Constituents	%	%	%	%	%
Insoluble residue	15.96	73.17	87.96	94.13	96.52
Soluble silica	33.10	9.95	4.27	2.35	....
Potash (K_2O)	1.47	0.53	0.29	0.12	....
Soda (Na_2O)	(1.70)	0.24	0.28	0.21	....
Lime (CaO)	0.09	0.13	0.18	0.09	....
Magnesia (MgO)	1.33	0.46	0.26	0.10	....
Manganese (MnO_2)	0.30	0.00	0.00	0.00	....
Iron sesquioxide (Fe_2O_3)	18.76	4.76	2.34	1.03	....
Alumina (Al_2O_3)	18.19	4.32	2.64	1.21	....
Phosphoric acid (P_2O_5)	0.18	0.11	0.03	0.02	....
Sulphuric acid (SO_3)	0.06	0.02	0.03	0.03	....
Volatile matter	9.00	5.61	1.72	0.92	....
Totals	100.14	99.30	100.00	100.21	....
Total soluble constituents	75.18	20.52	10.32	5.16	....

The table shows that clay contains about 33% of soluble silica, finest silt about 10%, and medium silt about 2½%. The total soluble in-

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[1] A. D. Hall, The Soil, 1907, p. 19.

[2] On the Distribution of Soil Ingredients among the Sediments obtained in Silt Analysis, Am. Jour. Sci, vol. 7, 1874, p. 18. Analysis based on a yellow loam from Mississippi. Designations of soil classes do not follow present conventions.

gredients in the same order are 75%, 20½%, and 5%. The clay is by far the richest in mineral ingredients, the amount being more than twice as great as that contained by all the other soil substances combined. Its insoluble residue is very small, its volatile matter is the largest, it contains more soda and manganese, and it heads the list in the amount of free silica it contains. The availability of the soluble material, however, depends on the tilth and the water supply to a large degree, and a fine soil must have a proportionately greater water supply than a coarse one or its otherwise more favorable qualities will be counterbalanced by excessively slow transference of plant food.

CHAPTER III

WATER SUPPLY OF SOILS

Relation to Plant Growth and Distribution

Water is of fundamental importance in ecology. It constitutes from 65% to over 95% of the tissues of plants, is a necessary part of all cell walls and of protoplasm, is vital to all transference of plant food and even to the forming of plant food in the soil, is the agent of respiration, in general is the factor that most frequently conditions life and death, and hence has a predominating influence upon both the internal and external structures of the plant.[1] Not only does the rainfall determine the great regional types of vegetation; it determines also the finer shades of detailed distribution where topographic differences occasion great variability in the rainfall distribution from point to point. It is of even more importance than heat, for it is of more irregular distribution. Its importance is reflected in a number of indirect ways as well as in the more familiar direct ways. For example, a windy region is likely to be a dry region for plants, and if not dry in a physical sense is almost bound to be dry in a physiological sense.[2] Wind dries the soil and increases transpiration in the plant to such a degree that places most exposed to it have a relatively xerophilous vegetation. The eastern protected hill slopes of central Jutland are clothed with forest; the western exposed hill slopes are covered with heath. On the northern border of the subarctic forest, bands of trees extend down the sheltered valleys far beyond the continental timber line. The most remarkable case is that of the Ark-i-linik, a tributary of Hudson Bay, which is bordered for 200 miles (lat. 62½° to 64½°) by a nearly continuous belt of spruce, although the stream flows in the midst of the Barren Grounds.[3] Undoubtedly in the last-named case the distribution is favored also by the higher temperature of the seepage water on the lower slopes and valley floors during the autumn, a condition that prolongs

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[1] E. Warming, Œcology of Plants, Ox. ed., 1909, pp. 28–29.

[2] For definition of physiological dryness see Schimper, Plant Geography upon a Physiological Basis, Ox. ed., 1903, p. 2.

[3] E. A. Preble, A Biological Investigation of the Athabaska-Mackenzie Region, No. Am. Fauna, U. S. Dept. Agri., No. 27, 1908, p. 48. Excellent for exact delineation of the continental tree line in northern Canada.

the growing season and mitigates the effects of extremely low air temperatures. Some part of the effect may be attributed also to the deeper snows of the valleys which prevent extremely low ground temperatures.

It is found that each species of plant requires its own specific water supply for most favorable conditions of growth, and that the quantity of water in the soil has a greater influence than any other condition on the distribution of plant species. To illustrate adaptations within a single genus the larches may be taken. *Larix decidua* prefers loose, well-drained soil and hence flourishes in dry situations where many other species die.[1] It is partly to similar adaptations with respect to physiologic dryness that *Larix sibirica* owes its northerly range in Siberia where there is an extremely short growing season. The tamarack (*Larix laricina*) prefers a swamp habitat, though it will endure a hillside situation; it often occupies shallow lake basins recently reclaimed or partially reclaimed by lower forms of vegetation.[2] With the ascent or descent of the ground water new species may come in and old ones die out, so that changes in the level of the ground water have been found gravely to affect the character of the grasses and shrubs and even the trees of a region.[3]

The amount of water required by growing plants is large in proportion to the amount of dry vegetable substance produced. It varies according to the extent and structure of the leaf surface, the number and size of the stomata of the leaves, and the climatic conditions, especially the wind, which when strong and continuous has so intense a drying action on plants as sometimes to lead to special modifications of structure even when the ground is well supplied with moisture, a feature well developed in vegetation that occurs on windy mountain slopes. It has been found that the same plants use more water in humid than in dry climates, as if physiologic adjustment had been made in the latter case in response to a lessened water supply before the development of special structural adaptations.

In general the amount of water required by a growing plant varies from 50 to 900 times the weight of the dry substance. Birch and linden transpire 600 to 700 pounds of water for every pound of dry matter fixed in the plant; oak, 200 to 300 pounds; spruce, fir, and pine, 30 to 70 pounds; European evergreen oak, 500 pounds. What this means in terms of rainfall may be estimated from the last-named case, the European evergreen oak, which, with the water requirement indicated, and with 250 trees to the acre, and 40 pounds of dry matter per season to the tree, would require a rainfall of 22½ inches per year. In general, about 35% of the rainfall is lost through plant transpiration.

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[1] H. L. Keeler, Our Native Trees, 1905, p. 480.

[2] Idem.

[3] P. Feilberg, Om Enge og vedvarende Gräsmarker. Tidsskr. Landökon. Kjøbenhavn, p. 270. Quoted by Warming, p. 46.

Naturally the required amount of rainfall varies with the kind of soil, whether porous and nonretentive or compact and retentive, with the topography, and with the seasonal and yearly fluctuations in cloudiness, insolation, etc. The amount of rainfall necessary to the growth of forests is about the same as the amount necessary for agriculture without irrigation; that is, from 20 to 40 inches. Timber growth in regions having a mean annual rainfall less than the minimum amount is of so stunted a character as to be of little value. Furthermore the growth is so slow that once the timber has been removed by fire or lumbermen, the time necessary for a new growth is very great.[1] In studying the water supply of a region the lowest rainfall is of quite as much if not more value than the mean rainfall, for it is in a season of unusual drought that the growing trees may be most affected, so that in dry climates it is difficult to establish a forest without prohibitive expense.[2] It is suggested that the cyclic changes in climate which appear to affect the entire earth might be studied to the benefit of the forester in planting forest seedlings, by enabling him to plant during the time of greatest rainfall so that an adequate root system shall have been developed before the advent of the driest years.

The high water content of the soil may in part make up for the dryness of the air, as on the banks of streams in tropical savannas where lines of forest occur, or on steppes and deserts where trees are found near running water or where the ground water approaches the surface.[3] This is, however, not a universal condition, for some plants flourish on very dry soil and in a humid air but are excluded from places with dry air. The heads of alluvial fans and cones where rivers leave mountain canyons at the common border of mountains and piedmont plain are often covered with small patches of forest. The forest vegetation is maintained by a kind of subirrigation or seepage through the porous sands and gravels of the fans. It often happens that this natural watering is too deep for agriculture and that forests in such cases grow where agriculture without irrigation is not possible.[4]

As an instance of the effect of soil character upon the amount of soil water available for plants and hence upon the specific character of the vegetation may be mentioned the Steilacoom Plains, south of Tacoma,

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[1] J. W. Powell, The Lands of the Arid Region of the United States, U. S. Geog. and Geol. Surv. of the Rocky Mountain Region, 1879, pp. 14–20.

[2] J. Wilson, The Modern Alchemist, Nat. Geog. Mag., vol. 18, 1907, p. 791; see also Rept. of the Sec'y of Agri. for 1907.

[3] J. W. Powell, The Lands of the Arid Region of the United States, U. S. Geog. and Geol. Surv. of the Rocky Mountain Region, 1879, pp. 15–16.

[4] Idem.

Wash., which have such an extremely porous soil of coarse gravel, with only a thin veneer of silt, that they constitute a locally semi-arid district in what is otherwise a humid region. The rainfall is about 44 inches per year, but percolation is so rapid in the loose stony ground that the district is a barren island surrounded by dense forests characteristic of the region. Instead of the Douglas spruce (*Pseudotsuga taxifolia*), the white fir (*Abies grandis*), the tideland spruce (*Picea sitchensis*), and the western hemlock (*Tsuga mertensiana*), the district bears the yellow pine (*Pinus ponderosa*); and species of gophers and the desert horned lark, which are at home in the dry districts east of the Cascades, are also at home in this restricted and peculiar area.[1]

The Coalinga district of California exhibits a plant distribution intimately related to water conditions. Certain gravelly and sandy beds of the district have superior absorptive capacity, while the adjacent clay beds have but little power of absorption.[2] The sudden rains run off the clay beds without wetting them notably. The coarse beds are therefore marked by a varying abundance of vegetation; the clay beds do not support vegetation at all. The result is a marked parallelism and alternation of belts of vegetation and belts of barren country in sympathy with the belted outcrop of the strata.

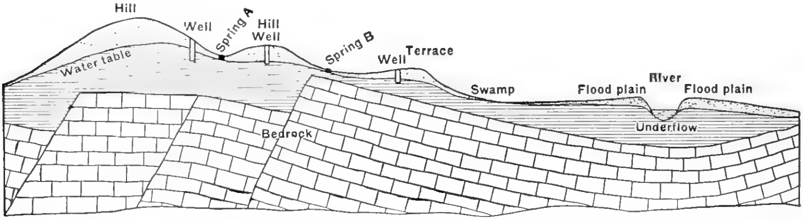

Fig. 5. — Ideal section representing the ground water in relation to the surface and the bed rock. (Slichter, U. S. Geol. Surv.)

Forms of Occurrence

Water is contained in the soil in three different ways — as ground water, as capillary water, and as hygroscopic water.

GROUND WATER

Ground water is the name applied to the water in the saturated zone of soil or rock; it occurs from a few feet to a few hundred feet below the surface, Fig. 5; in humid regions it is found usually from five to fifty feet

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[1] Willis and Smith, Tacoma Folio, Wash., U. S. Geol. Surv. No. 54, 1899, p. 2.

[2] Arnold and Anderson, Geology and Oil Resources of the Coalinga District, Cal., Bull. U. S. Geol. Surv. No. 398, 1910, p. 33.

below the surface. The surface of the saturated zone or of the ground water is known as the water table or water plane. The depth of the water table below the surface varies in a striking way not only as between arid and humid regions, but also from place to place in a given region as shown in Fig. 6, because of topographic, soil, and other variations.[1] The available pore space of the surface rocks occupied by water or moisture is generally about 10% of their total volume.

The water contained in porous soils and rocks as ground water is not stationary but possesses a very slow although perfectly definite motion as shown by geologic data which indicate very important chemical and physical effects due to permeating waters and by direct measurement of the rate of movement. The cause of the movement of ground water is gravity alone, and the rate depends upon the size of the pores, the total porosity, the pressure gradient in the direction of flow, and the temperature of the water, being more rapid the larger the size of the pores, the greater the porosity, and the higher the gradient and the temperature. The motion of the ground water as a whole is somewhat like the slow motion of a viscous substance, but is not generally in the nature of an underground stream as is ordinarily supposed. Underground streams may exist in limestone regions in great numbers, but they are on the whole exceptional hydrologic

Fig. 6. — Contour map of water table (continuous lines), showing direction of motion of ground water (arrows) and drainage lines (heavy lines). (Slichter, U. S. Geol. Surv.)

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[1] C. S. Slichter, The Motions of Underground Waters, Water-Supply Paper U. S. Geol. Surv. No. 67, 1902, p. 33.

features. The general trend of moving ground water is into neighboring streams and lakes; and the marshy zone on the borders of a valley flat, or on the bluffs of an intrenched valley, or on the shore of a lake, is a manifestation of the ground water appearing at the surface. In many dry western localities the ground water does not find its way immediately into the channel of the river, but takes a general course down the valley within the porous material of the valley floor; this movement, called the underflow, may often be utilized by constructing across the valley a subsurface dam which causes the ground water to rise to the surface or so near it as to become available to plants. If a natural dam crosses the valley the effect may be a similar raising of the underflow and of the ground water, as is the case at the Bunker Hill dike near San Bernardino in southern California.[1] A convergence of canyon walls will produce a similar augmentation of the water in a river because the underflow is forced to the surface. The debouchures of the rivers in such dry regions are usually marked by huge alluvial fans, as along the western base of the Sierra Nevada. In such cases both the underflow and the surface flow are distributed by a set of complex and anastomosing[2] distributaries through gravelly fan deposits and so are gradually dissipated. Sometimes the underflow may be quite independent of the water flowing in the surface channel.

The surface of the water table is seldom level; the nearest approach to this condition is found in the case of a flat topography such as local areas of a coastal plain and of alluvial bottom lands. The surface of the water table shows a close sympathy with the surface contours of the land, although geologic conditions may greatly modify this general fact. Subsurface layers of impervious material may cause a rise and fall of the water table quite out of harmony with the surface contours, Fig. 5. The surface of the ground water is never fixed, for its level is responding continually to changes in rainfall, in barometric pressure, and in temperature by such important amounts as notably to affect the strength of flow of springs and flowing wells.[3]

After a rainy period has passed, the surface zone of saturation gradually descends through the flowing off of water from the surface of the saturated zone, and continues to sink at a constantly decreasing rate

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[1] W. C. Mendenhall, The Hydrology of San Bernardino Valley, Cal., Water-Supply Paper U. S. Geol. Surv. No. 142, 1905, p. 26, and plate 11, p. 72.

[2] A term applied to the characteristic branching and reuniting pattern exhibited by streams that terminate upon piedmont alluvial plains.

[3] A. C. Veatch, and others, The Underground Water Resources of Long Island, N. Y., Prof. Paper U. S. Geol. Surv. No. 44, 1906; also idem, Fluctuations of the water level in wells, with special reference to Long Island, N. Y., Water-Supply Paper U. S. Geol. Surv. No. 155, 1906.

until another rainy season causes it to rise again toward the surface. The responses of the ground water to rainfall are not immediate, and depend upon the depth of the water table and the duration of both the rainy and the rainless period. It may happen that the water table is actually rising between rains and falling during a rainy period. The amount of such lag is usually rather small, however. In arid regions, where the ground water is far below the surface, say 100 feet, a rain of considerable magnitude may be absorbed by the dry surface layer and again reëvaporated without replenishing the ground water at all. In humid regions light rains may be evaporated in the same way, but the water of prolonged rains is contributed to the ground water to the extent of 35% to 60%; the remainder is disposed of in the immediate run-off and by evaporation.

Plants growing upon the soil rob it of moisture during the growing season to a degree that varies with the temperature, the kind of plant, and the texture of the soil, so that the amount of water in the soil diminishes from spring to autumn, at which time the water table is at its lowest and may be from five to seven feet lower than in the spring. In the forest various species of plants act as weeds because they consume water before it reaches the roots of the trees. Shallow-rooted plants in the forest have on the whole a relatively small effect, however, because the greater supply of moisture for trees is derived from deeper lying sources.

The level of the ground water is invariably lower in a forested tract, for the forest consumes water in exceptional quantities from the subsoil; and this in spite of the fact that the surface soil of forested regions is as a rule moister than the surface soil of unforested regions. Many trees assume a peculiar shape or can not grow to normal height in a soil in which the ground water is near the surface.[1] The forest sometimes has an important power in maintaining the soil water (not ground water) near the surface, i.e., not only the immediate surface but the whole surface zone in which the plant roots are found. The removal of the forest cover may in delicate cases destroy the capacity of the surface soil for water. Forest litter and particularly humus have high capacities not only for water but also for water vapor, and their destruction by leaching, burning out through excessive oxidation, and the absence of any additions through fallen foliage, trees, twigs, etc., may cause a region that was once fairly moist to become dry. A concrete instance is furnished by the Karst of Austria. This region lies

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[1] For the rate of evaporation from a free water surface, from bare soil, and from soil covered with vegetation see R. Warington, Lectures on Some of the Physical Properties of the Soil, Oxford, 1900, pp. 107–126, where the results of Ebermayer, King, and others are discussed in detail.

along the Austrian shores of the Adriatic and is composed of porous, fissured limestone. For centuries it furnished the ship timber and wood supplies of Venice, but excessive cutting, burning, and pasturing left it almost a desert waste, not only by decreasing the amount of soil water but also by allowing excessive soil erosion. Through government assistance 400,000 acres of the karst were placed under forest, beginning in 1865, and the government has also backed up planting efforts by passing (1884) a reforestation law to control torrents.[1]

The beneficial effect of the forest in maintaining a soil cover by decreasing the delivery of ground water and retarding the immediate run-off is easily appreciated by recalling the fact that each of the waterways in the forest is occupied by a perennial brook fed from the spongy soil, while the small stream beds of tilled land are dry except when rain is actually falling. The difference in the amount of erosive energy applied by the rain to the earth in these two contrasted conditions is very great. In the forest the rain creeps through the openings in the vegetal coating and moves so slowly that it does not expend any sensible energy upon the soil cover, while, if the surface is deprived of vegetation, the water may have a swift motion and an intense erosive force may be expended upon the incoherent soil.[2]

The fact and rate of movement of the ground water may be determined (*a*) by the electrical method of Slichter,[3] in which the gradual motion of the ground water from one point to another is determined by the use of an electrolyte which passes with the ground water in its general direction of movement; the method is very accurate, and is the standard one in use by the United States Geological Survey to-day; (*b*) by the use of the lysimeter, which is a receptacle inserted into the ground in such a manner that one side has an outlet discharging into a measuring gauge. It has been found by the Slichter method of measurement that the rate of movement is on the average from 2 to 10 feet per day for areas of moderate relief. A closer average figure is not possible because of the effects of variable soil texture, variable topographic and structural gradients, differences in the amount and time of occurrence of rainfall, etc.

Since the amount of soil moisture most favorable to plants (the optimum water content) is about half the maximum it can hold, it is clear that the saturated zone does not supply the most favorable conditions

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[1] European Countries' Reclamation of Waste Land, Forestry Bull., Dec. 12, 1909, p. 2.

[2] N. S. Shaler, The Origin and Nature of Soils, 12th Ann. Rept. U. S. Geol. Surv., pt. 1, 1890–91, p. 254.

[3] C. S. Slichter, The Motions of Underground Waters, Water-Supply Paper U. S. Geol. Surv. No. 67, 1902, pp. 48–51.

for plant growth. These conditions are supplied only in the zone immediately above the mean position of the ground water, where occasional immersion takes place through the raising of the water table but where opportunity is afforded for aeration and for the formation of plant foods without their being swept away immediately by movements of the soil water. Chemical decay and the formation of soluble plant foods take place in the soil only when a certain amount of water is present, but their most rapid rate is attained above the ground water not in it; with an excess of water the soil chemicals are too widely diffused upon their formation to effect soil changes of sufficient importance for the immediate needs of a plant. The most favorable conditions for the full utilization of the advantages of ground water are to be found in those places where the water table is from 5 to 10 feet beneath the surface, is relatively constant in position, the rainfall evenly distributed throughout the year, and where the vegetation is in the form of trees.

It is noteworthy that the root systems of trees are very responsive to the ground water. A layer of feeding roots occurs in the surface soil where there is the greatest amount of soluble plant food immediately available, while the roots supplying moisture to the tree will be found to descend almost vertically to a point a little above the surface of the ground water, where a broad extension of the terminal roots may be found. Serious disturbance in the life of the tree is occasioned by sudden and unusually large changes in the level of the ground water, as through irrigation, which may raise the level of the ground water and cause the root terminals to suffer from want of aeration; or by too thorough underdrainage, either by tile or pumping, which may more or less permanently depress the water table and move it out of reach of the deep-lying roots adapted to a certain normal position. It is important, whatever the position of the ground water, that it be maintained at a relatively fixed position. Even short periods of immersion may work great injury to roots accustomed to perform their functions in an aerated soil.

In an undrained soil the roots are confined to a shallow layer from which they quickly abstract the available moisture, and if the subsoil is clay the plant may suffer through the inability of capillarity to supply the needed amount of water. In a drained soil the roots traverse the whole three feet or more into which air is admitted, and this mass of soil holds a very large quantity of capillary water. A water-logged soil is one in which the harm is not confined to the above results but extends to the solution of plant foods in superabundance and their removal in the water. The same condition also leads to the setting free of a large part of the nitrogen as nitrogen gas instead of its accumulation as a nitrate and to the breaking down of nitrates in the soil. Vegetable acids in exceptional amounts occur in wet soils, and in their presence bacteria can not thrive. Earthworms and insects and the benefits derived from their action are excluded from all saturated soils.

CAPILLARY WATER

Capillary water is the most important form of water in the soil, since it is the normal means by which plants absorb food and sustain the rapid evaporation of the hot summer season. Furthermore, few plants have roots adapted to normal action in the saturated zone where free oxygen is not available. There is for all land plants a definite time limit beyond which their roots can not live or at least remain healthy in a submerged state. The period is about three weeks for deciduous orchards when in their winter condition.

In most cultivated soils the pore space is about 25% to 50% of their volume and this is known as their maximum water capacity or saturation point. The amount of this space occupied by water and required for the best development of plants is generally not more than 50% nor less than 40%, which means that the pore space must be about half filled with air for best results. All of these figures are subject to considerable variation in individual cases. For example, the maximum water content for lodgepole pine as it occurs in the dry hills about Sulphur Springs in Middle Park, Colorado, is 35% in loam and about half as much in sand and gravel. The optimum water content is between 12% and 15%, rising to 20% where the rapid decay of the needle cover decreases the amount of available water. The minimum water content may fall below 5% in gravel without injury to the tree except in decreasing its rate of growth.[1]

Loblolly pine also illustrates the great variation among trees in the amount of water they can endure. While this tree is adapted to a wide range of soils and can grow almost equally well on poor sandy upland soils and low rich bottom lands, it everywhere requires an abundant supply of water. When the soil becomes dry the loblolly pine of Texas and North Carolina gives way ultimately to the longleaf and shortleaf pines. Its immediate occurrence in the zone of contest between it and the other pines sometimes follows, not because the water supply is at an optimum for it but because its prolific seeding and rapid early growth cause it to come in more readily on land made vacant by fire or by lumbermen.[2]

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[1] F. E. Clements, The Life History of Lodgepole Burn Forests, Bull. U. S. Forest Service No. 79, 1910, p. 52.

[2] R. Zon, Loblolly Pine in Eastern Texas, Bull. U. S. Forest Service No. 64, 1905, p. 8.

NATURE OF CAPILLARY ACTION

The phenomena of capillarity depend upon the well-known fact of *surface tension.* If the molecular attraction of the particles of a solid for those of a liquid exceeds the attraction of the liquid molecules for each other, the liquid adheres to or wets the solid and the water rises until the pressure of the raised water column equals the pull (molecular attraction) of the solid upon the liquid.[1]

If a soil is saturated with water the whole pore space is filled, and, when this is allowed to drain away, some of the water is pulled down by gravity, but much remains clinging to the particles in a state of tension which just balances gravity. Reversing the process we find that water will always pass into the soil from a wet to a dry place until the film surrounding the particles is evenly stretched throughout. The capillary rise of water in soil materials is well shown in the accompanying illustration from Johnson, Fig. 7.

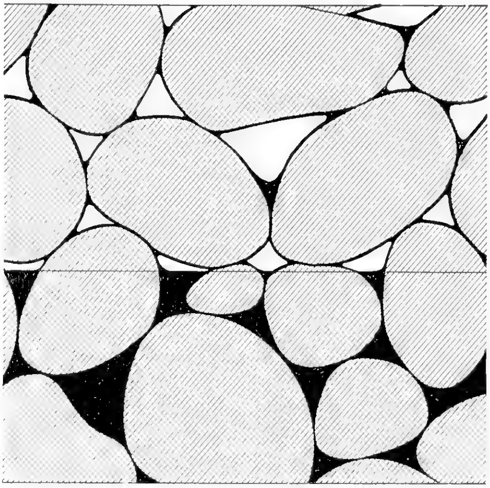

Fig. 7. — Capillary water about soil grains. The horizontal line is the water table.

The nature of capillary action is easily illustrated by the immersion in a basin of water of an open tube filled with soil. The water will rise in the soil of the tube to a height depending upon the temperature of soil and water, upon the amount of pore space in the soil, and upon the size of the capillary tubes or pores. The finer the particles of a soil the greater its water-holding capacity, the slower the capillary movement in a given unit of time, and the higher the ultimate capillary rise. The maximum height of capillary rise thus far observed is 10.17 feet in material whose particles range from .0005 mm. to .016 mm. in diameter, although eighteen months are required to obtain the maximum. The rise of water in capillary tubes is at first rapid, but soon becomes

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[1] For a complete statement of the laws of capillary action see any standard text-book of physics.

slower and after a few months usually reaches a maximum height beyond which it can not rise. The most rapid continuous rise and the longest and ultimately the highest rise usually occurs in salty soils containing a small percentage of clay. Capillary movement takes place in moist soils much more rapidly than in dry soils, but the final adjustment as to height and water content will be the same. Wetting the surface layer or cooling it as in a cold rain tends to raise additional supplies from below, but in the latter case the action is probably to be attributed in part to the condensation of the evaporated subsoil moisture on coming into contact with the cool surface zone.

Water will rise in the capillary tubes of the soil to a greater distance than will any other soil liquid. It is thought to be the limit of capillarity in trees which determines to a large extent the limit of their height.

REGULATING ACTION OF THE SUBSOIL

The subsoil acts as a regulator of the amount of water contained in the surface soil. It absorbs the water which percolates through the surface during the rainy seasons and yields water to the soil during the dry periods by capillary action. This is well illustrated in the following table where the gain and loss of the surface layer are shown.

RELATION OF THE SUBSOIL TO THE WATER CONTENT OF THE SURFACE SOIL

Water in inches	Months and Days			
	30/iv to 30/v	30/v to 9/vii	9/vii to 7/ix	7/ix to 27/x
Rainfall	0.18	4.53	3.47	5.65
Evaporation	3.45	2.96	5.71	1.83
Gain or loss of water in top foot	−1.0	+1.4	−0.24	+0.61
Water furnished by (−), or passed on to (+) subsoil	−2.27	+0.17	−2.0	+3.21

Since the changes in the water content of the surface layer are not represented by the difference between the rainfall and the evaporation, some water must in the one case have passed to the subsoil and in the other case have been lifted from it by capillary action.[1]

The studies of the Dnieper above Kiev during a twenty-nine-year period (1876–1905) appear to show that there is in certain periods an overconsumption by evaporation of the moisture stored in the soil and made available by capillarity. This overconsumption has to be supplied during the first wet year which follows one or more dry years, so that the amount

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[1] A. D. Hall, The Soil, 1907, p. 95.

of evaporation may not in a given year be strictly the difference between the rainfall and the discharge, being less than this difference in wet years and greater in dry years. The influence of forests and marshes on the discharge in the summer of a dry year is to diminish the discharge; but in wet years the forest stores water.[1]

The steady movement of capillary water toward the surface and its evaporation in the surface layer of soil results in highly beneficial effects. The upward-moving water holds in solution the soluble products of soil or rock decay, or both, and as it approaches the surface and is steadily evaporated it becomes more and more concentrated and may finally deposit its contained salts upon and among the soil grains. In either case enrichment of the surface soil or of the soil solution is the result. To be sure, the downward percolation of water, as after rains, neutralizes these effects to some degree, but since percolation is most active, almost wholly active, in the larger openings among the soil grains, and since downward percolation in the surface soil is an exceedingly temporary phenomenon, the contributions of plant food from below upward are more abundant than the losses by downward percolation.[2] A slow concentration of plant food thus goes on in the surface soil, and it is therefore in the surface soil that the feeding roots of plants are chiefly disposed. It is from the surface layer or layers that they derive their chief nutrient substances; deeper-lying roots are mainly for supplies of water. In arid regions, where the ground water is far below the surface and the zone of weathering correspondingly deeper, and plant food more widely disseminated, plant roots are of course not confined to the surface soil.

LIMITS OF ADEQUACY

The entire amount of capillary water in the soil is not available to plants, for their roots are not in contact with all soil particles of the mass of earth they permeate, and, long before the mass as a whole has become dry, the particles in contact with the roots may be robbed of their moisture to such an extent that the soil may be said to be physiologically dry. In the case of certain apple trees in the arid region of California, 8.3% of water was sufficient to keep the trees in excellent condition on a loam soil, while on a clay soil 12.3% was too small an amount for proper growth.[3] It is thus seen that the welfare of the plant is determined not by the total moisture content but by the free moisture held as capillary water by the capillary tubes.

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[1] E. V. Oppokov, 11th International Navigation Congress, St. Petersburg, Russia, 1905.

[2] Cameron and Bell, The Mineral Constituents of the Soil Solution, Bull. U. S. Bur. Soils No. 30, 1905, p. 68.

[3] R. H. Loughridge, Rept. Cal. Exp. Sta., 1897–98, pp. 65–96.

HYGROSCOPIC WATER

Dry soil if exposed to moist air absorbs water vapor, the rate and amount of absorption varying greatly with the character of the soil and the degree of saturation of the air to which the soil is exposed. The finer the particles the greater the capacity of the soil to absorb water vapor. Humus and finely divided ferric hydrates are substances with exceptional capacities for such absorption. Sachs has shown by experiment that the amount of moisture absorbed by dry soil as aqueous vapor may be so high in the presence of saturated atmosphere as to supply distinct portions of the normal vegetal demands. For example, in the arid regions the chief supply of water is derived through the deeply penetrating main roots; on the other hand the feeding roots of the plant, which are nearer the surface, are surrounded by soil that is almost air dry and yet slow growth and nutrition are possible. In such cases the water made available through the absorption of aqueous vapor is thought to be sufficient to have an effect upon vegetation especially in coast regions of summer fog, e.g., the coasts of California, northern Chile, and Peru. In the last-named cases a fog bank hangs over the edge of the land almost every night and frequently during the day at an altitude of 1500 to 2000 feet, and a band of vegetation thrives at this elevation, whereas at lower and higher elevations the natural vegetation is much inferior or wholly lacking.

High moisture absorption at night and its evaporation by day are also thought to prevent the rapid and undue heating of the soil and thus to improve the condition of plants under extreme temperature conditions. In humid regions where plants have become adapted to a higher water content hygroscopic water can not maintain plant growth, for wilting begins some time before even the capillary water is exhausted. Sachs[1] found that a young plant began to wither when the dark humus soil in which it grew still contained water equivalent to 12.3% of its dry weight; and plants were found to wither on loam and sand when the percentages of water fell to 8% and 1.5% respectively. A conservative estimate of the value of hygroscopic water would be that ordinarily it has little if any value to plants directly; but, by increasing the amount of water in the soil that will be evaporated the following day, it lowers the temperature and thus indirectly increases the amount of available water by decreasing the rate of evaporation.[2]

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[1] J. von Sachs, Handbuch der Experimental-Physiologie der Pflanzen, 1865, p. 173.

[2] For velocity of flow of aqueous vapor through soil and its control by the dimensions of the apertures between the soil grains see Brown and Escombe, Static Diffusion of Gases and Liquids in Relation to the Assimilation of Carbon and Translocation in Plants, Phil. Trans., vol. 193, 1900, pp. 283–291. Abstract in Annals of Botany, London, vol. 14, 1900, pp. 537–542.

CHAPTER IV

SOIL TEMPERATURE

ECOLOGIC RELATIONS

THERE are for each plant certain air and soil temperatures most favorable to development, known as optimum temperatures. The red birch (*Betula nigra*), peculiar among the birches in preferring a warm habitat, will grow in situations where important temperature changes occur, but it reaches its greatest size in the damp misty lowlands of Texas and the bayous and swamps of Florida and Louisiana. For most plants it is true that if the temperature at any time varies widely from the mean the activity of the vegetative functions is diminished or stopped, or the plant enters into a pathologic condition or dies. Beech, oak, and ash can survive in an air temperature of − 9.4° F.; their finer roots succumb to cold at from 8.6° to 3.2° F.[1]

Were the harm confined to mere stoppage of growth it would not be great, for a return to favorable temperatures would mean a revival of plant growth. But when during the summer season either seeds or plants remain in the soil at a temperature but little above the freezing point, bacteria and fungi of many varieties which are able to live at low temperatures may attack and destroy the vegetation. The limit below which most cultivated plants are practically inactive lies between 40° and 45° F. Tropical plants usually germinate at a temperature of about 95° F. Even when seed germination progresses at a low temperature the rate is very greatly hastened by a higher temperature, and the same holds true of the normal growth of the plant. The temperature most favorable to germination and growth, and the degree of tolerance of high or low temperatures vary greatly with different plants; apparently each plant has become adapted to a certain mean temperature as well as to a certain range of temperature. Seeds and seedling plants should be put into the ground at a time when the temperature is most favorable for active growth, otherwise they may be destroyed by the micro-organisms of the soil.

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[1] C. von Mohl, Über das Erfrieren der Zweigspitzen mancher gewisser Phycochromaceon. Bot. Zeitg., vol. 41, 1848.

The degree of adaptation to cold made by some plants is quite remarkable. In the Arctic the shallow-rooted flora develops rapidly under the influence of continuous sunshine in the course of five to eight weeks. The seeds are capable of germination at very low temperatures, so that a mass of flowers may be found growing only a few feet from a snow bank or a glacier. The extreme conditions of development are easily appreciated. The ground is soaked with water nearly ice cold, and at a depth of only a few inches, and at the most but a few feet, ground ice may occur in large masses. But insolation during the period of continuous sunshine is very great and on June 21st surface insolation at the pole is almost as great as at the equator.[1] The conditions under which Arctic plants live during their short cycle of growth in the Arctic summer have been described in a number of records of experiments and observations among which are those noted below.[2]

Soil temperature is of further importance in plant growth because of the stimulation which relatively high temperatures give to the useful bacteria of the soil, — bacteria which increase the supply of available nitrogen. It has been found that bacteria cease to develop nitric acid from humus when the temperature drops below 41° F., their action is of trifling importance when the temperature is at 54° F., it becomes vigorous at 58° F., but at extremely high temperatures the activity is reduced to a degree as unimportant as when too low temperatures prevail.[3] The influence of high temperatures in promoting rapid chemical action in the soil is shown by the sharp contrast between the highly decomposed soils of wet tropical regions and the moderately decomposed soils of polar regions. The contrast is of course heightened by the greater rainfall in the tropics.

Influence of Water on Soil Temperature

Water has a predominating influence upon the temperature conditions of soils in humid regions. This is because the capacity of water for heat is about four or five times as great as the heat capacity of the average soil, weight for weight; so that while one unit of heat is required to raise one pound of water 1°, the same change of temperature is produced in a pound of dry sand by the expenditure of .19 unit, and a pound of pure clay requires about .224 unit. Indeed water has the greatest capacity for heat or the greatest *specific heat* among known substances. This means that when the sun shines upon moist sand or clay a large amount of heat is expended in evaporating the water in it, while a relatively small amount is expended in raising the temperature of the soil particles. A well-drained field is therefore warmer on the whole than a poorly

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[1] J. Hann, Handbook of Climatology, 1903, p. 93; R. DeC. Ward, Climate, 1908, p. 15.

[2] M. Smith, Gardening in Northern Alaska, Nat. Geog. Mag., vol. 14, 1903, pp. 355–357; Raising Crops in the Far North, Geog. Notes, Jour. Geog., vol. 3, 1904, p. 91; Agriculture and Grazing in Alaska, Geog. Notes, Jour. Geog., vol. 11, 1903, pp. 528–529.

[3] F. H. King, The Soil, 1905, p. 224.

drained field and a dry soil warmer than a wet soil.[1] It also follows that a fine-grained soil like clay will have a lower temperature than a coarse-grained and easily drained soil like gravel or sand. Hence clay soils are "cold" and sand soils are "warm." Were the clay and the sand air dry, the clay soil would be the warmer because its volume weight is less than the volume weight of sand. Since, however, few soils in the humid region contain no water, it is clear that clay will always be relatively cold and sand relatively warm under comparable conditions of water content. The following table summarizes the temperature differences between clayey and sandy soils, the table representing observations on a well-drained clay loam and a well-drained sandy loam.

TEMPERATURE CONTRASTS BETWEEN SANDY AND CLAYEY SOILS[2]

	First Foot	Second Foot	Third Foot
Sandy loam......	76.5° F.	74.7° F.°	72.1° F.°
Clay loam.......	69.5°	69.3°	67.0°
Difference....	7.0°	5.4°	5.1°

Soil Temperature and Chemical Action

One of the first functions of soil water is to take into solution from the soil mineral substances which dissolve under all conditions with extreme slowness. It is here that the influence of soil temperature is perhaps as marked as in the beginnings of seed germination and plant growth in the spring. With a rise in the temperature of the soil chemical action becomes more effective, the supply of plant food in the soil rapidly increases, and osmosis and the diffusion of the dissolved material away from the soil and through the roots and other tissues of the plant are hastened. When we recall the fact that the soil air can occur in favorable quantities only in a well-drained soil and that both high temperature and an abundant supply of air are necessary to many chemical reactions in the soil, it is clear that the conditions favoring a high temperature favor the disintegration of the soil minerals and the formation of available plant food.

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[1] The exception to this condition may be noted in the autumn when the warmer soils are those containing the more water on account of the slow radiation of heat by water. The condition may be compared to that of a lake in the temperate zones, which is colder in summer but warmer in autumn and winter than the adjacent land.

[2] F. H. King, The Soil, 1905, p. 228.

Influence of Slope Exposure, Soil Color, Rainfall, and Vegetation

A rough surface will be colder than a smooth surface, other things being equal, because a larger surface of soil grains is exposed when the ground is rough than when it is smooth, and while the slopes exposed directly to the sun receive more heat than the sheltered slopes they lose more than they gain, by radiation and by contact with the air. This is overcome in agriculture by leveling the land or "rolling" it. The slope of the whole surface with respect to the sun's rays also has an important influence on the temperature of the soil. This principle is illustrated by Fig. 8. It will be seen that the slopes *ad* and *db* are equal in gradient and length. The difference in the amounts of insolation is shown by the difference between 1–3 and 3–5, 1–*a*, 2–*e*, etc., representing the sun's rays. Upon a flat surface, as *acb*, the amount of heat received in the two cases is the same, that is, 1–4 equals 4–5. It also follows from the diagram that the greater the relief the sharper the contrasts between the slopes directed toward the sun and those directed away from the sun, i.e., 1–2 is much smaller than 2–5. Southern slopes in the northern hemisphere are dry and warm, northern slopes are cool and moist, and the two often bear markedly different types of vegetation. Near Findelen, Switzerland, one may observe patches of snow on northern mountain slopes at elevations *lower* than the barley and rye fields on the southern slopes at 6900 feet.[1] This difference is most marked in high latitudes and high altitudes combined

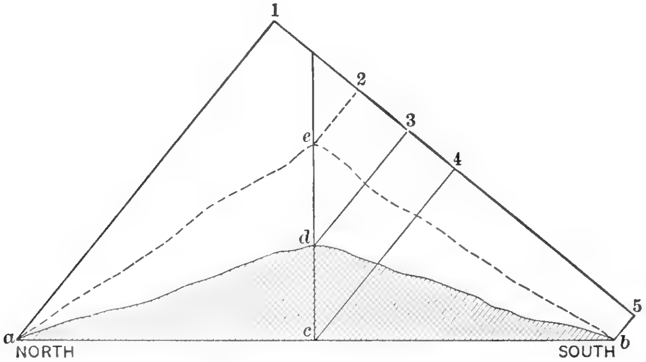

Fig. 8. — The influence of surface slope upon the amount of heat received per unit area.

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[1] H. E. Gregory (Gregory, Keller, and Bishop), Physical and Commercial Geography 1910, p. 105.

with strong local relief. It would be shown in the diagram by causing 1*a* — a ray of sunshine — to approach and finally to fall below *ad*. It is shown even in tropical situations close to the equator, though its expression in such a case is likely to be exaggerated by contrasts in rainfall derived from the trade winds. North of the equator these blow from the northeast and water the north or shadier (for most of the year) slopes copiously and leave the southern slopes dry; south of the equator the southeast trades produce a similar effect upon the southern or shady slopes.

The temperature of the soil will be affected also by its color. Sandy soils are light in color and to that extent are cool because they reflect a great deal of sunlight from their white or light yellow surfaces. Dark-colored soils like dark loams and humus, and dark-colored rocks such as basalt and other basic rocks are raised to a higher temperature under comparable conditions of water supply and insolation. Humboldt found that a black basalt sand on the island of Graciosa reached a temperature of 147° F. while white quartz sand in the same situation reached only 122° F. Dark soils cool more rapidly at night than light-colored soils, but do not become colder than the latter. Among all known substances charcoal absorbs and radiates the sun's heat rays most powerfully, so that its absorptive power is taken as 100. Gardeners and vine growers in the colder parts of Europe sometimes take advantage of the great absorptive power of carbon by spreading charcoal over the surface of the soil when early maturity is desired. The peasants of Chamouni hasten the melting of the snow by sprinkling slate powder over it.[1] A similar practice has been observed among the Ladakhis in the upper Indus valley, where the peasants dig up earth in the fall, store it in the stables and houses all winter, and in the spring hasten the late melting of the deep snow by scattering the stored earth over it.[2]

One of the most effective means of increasing the soil temperature is through warm percolating rains which displace the cold soil water below the root zone. Its effect may be understood by recalling that the specific heat of water is higher than that of any soil by four or five times and that if a pound of rain water at 60° F. carry ten heat units into the ground each heat unit raises the temperature of a pound of sand, not one degree as would be the case with water, but four or five degrees. Cold rains produce the opposite result, and one of the most important beneficial effects produced by proper drainage of a forest area is the

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[1] E. W. Hilgard, Soils, 1907, p. 304.

[2] E. Huntington, The Pulse of Asia, 1907, pp. 50–51.

removal of cold water from the soil during the spring. If the region is one which is subject to summer droughts, such rapid removal of even cold water may be harmful, for the cold rains of spring would have less effect on the vegetation in delaying the beginnings of seasonal growth than would the lack of moisture in the dry season.

A covering of vegetation, either living or dead, diminishes the soil temperature below that of bare fields. During different parts of the day these differences may rise to 4° or 5° F. a few inches below the surface and to far greater values at the immediate surface. The monthly averages of two localities rarely exceed 1½° F. The differences are greatest in the summer season, and when the covering of vegetation is thick the effect is more marked than when it is thin, so that forests exert a cooling influence and on the whole tend to diminish direct evaporation from the soil.

Temperature Variations with Depth

The effect of either extremely high or extremely low temperatures is felt in a surprisingly shallow layer at the earth's surface. In temperate regions the daily temperature variations affect only the surface two or three feet of soil or rock and vary according to the nature and condition of the soil material.

The monthly variations reach to greater depths and the annual variations affect a layer from 35 to 75 feet in thickness. Below the zone of change the same temperature is found year after year, and though there are many exceptions to the rule, yet it is in general true that the deeper the point of observation the higher the temperature.[1] In the Arctic regions the level of no variation in temperature is but little below the surface in spite of surface variations between – 40° and – 60° on the one hand and 80° and 90° on the other. This is due to the presence of ice a short distance below the surface, and ice is a very poor conductor of heat. In the tropics the annual temperature variation affects the surface layer to a depth less than 2 feet because of the very slight seasonal changes in temperature.

The temperature of the soil during the cold season generally exceeds that of the air; and the absolute minimum temperature of the soil is always higher than the absolute minimum temperature of the air during the cold season. During the warm season the soil temperatures in general exceed the air temperatures. In summer sandy soils are warmest, loam soils next in order, and clay coldest; in winter these conditions are reversed. It is to the fact that soil temperatures are higher than air temperatures in cold situations and in all situations in cold seasons that render inhospitable localities possible to plants.

Dew is sometimes derived from the soil owing to differences of temperature between soil and air. This occurs when the soil is warmer than

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[1] The mean temperature of the earth's soil is estimated by Tabert to be raised by conduction from the internal heat of the earth by the trifling amount of 0.225° F.

the air above it during a summer night. When the soil temperature falls to the proper figure dew is deposited within the soil to a depth at which the critical temperature is found. The daily repetition of this process at different depths exerts a considerable influence upon the distribution of moisture in the soil. It is probable that the formation of dew within the soil materially assists capillarity in distributing the soil moisture more uniformly.

Recently an investigation has been made of the rate of flow of heat through the soil under certain standard conditions of moisture content, specific volume, and effective specific heat.[1] The practical value of the work lies in indicating the nature of the soil control which should be exercised in order to secure a warm seed bed and good germination in the preparation of forest seedlings, the handling of cranberry marshes, etc. It has been found that heat will pass from a soil grain to soil water 150 times easier than from a soil grain to soil atmosphere, and this points to one reason why an air-dry soil shows such low heat conductivity.[2] Increase in heat conductivity due to the wetting of a soil is caused by a better contact between the soil grains. Coarse-grained soil has a lower heat conductivity than a fine-grained soil. A crumb structure in the soil causes the formation of air spaces, and the air acts as insulation against the passage of heat. When the soil crumbs are destroyed heat is conducted more rapidly and there is a more rapid rise of temperature.[3]

[1] H. E. Patten, Heat Transference in Soils, Bull. U. S. Bur. Soils No. 259, 1909, pp. 1–54.

[2] Idem, p. 49.

[3] Idem, p. 51.

CHAPTER V

CHEMICAL FEATURES OF SOILS

Relative Value of Chemical Qualities

A soil can be considered fertile only when it possesses certain necessary physical qualities. If the physical condition excludes water, air, and plant roots, its stores of chemical substances remain locked within it, as useless as if they did not exist. It is also true that a soil poor in plant food and yet richly endowed with favorable physical properties may support an abundant vegetal growth. It is for these reasons chiefly that many investigators consider physical properties as paramount in soil fertility. The chief objection to any rigid claims for either side of the contention regarding the relative value of physical and chemical properties is founded on the fact that physical and chemical conditions are often evenly balanced, and when the balance is destroyed it is as often because of unfavorable chemical as of unfavorable physical conditions. An ecologist would see in the distribution of vegetation in the Coalinga district, Cal. (p. 44), or in the Steilacoom Plains, Wash. (p. 43), strong physical control of both plant distribution and plant species. On the other hand the strong chemical contrasts afforded by the various types of igneous and metamorphic rocks in many parts of the Laurentian area of Canada have very close counterparts in the vegetative contrasts,[1] for the glacial and postglacial soils of the Laurentian area are thin and the rock character has equal opportunity with the soil character for vegetative expression. The almost universal abundance of moisture in the eastern part of the United States permits many variations in plant distributions based on chemical differences in soil and rock; in the West the general scarcity of water causes it to be as a rule the dominant factor in distribution. Chemical differences in soil have probably resulted in some cases in the development of new species of plants. *Viola calaminaria*, for example, is thought to have arisen from *Viola lutea* by the action of zinc in the soil.[2] In the Alps there appears to be a wide difference between parallel species occupying mountains of limeless slate on the one hand and mountains of limestone on the other.[3]

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[1] M. L. Fernald, The Soil Preferences of Certain Alpine and Subalpine Plants, Rhodora, vol. 9, 1907, pp. 149–193.

[2] A. F. W. Schimper, Plant Geography upon a Physiological Basis, Ox. ed., 1903.

[3] A. Kerner von Marilaun, Die Abhängigkeit der Pflanzengestalt von Klima und Boden, 1858. Quoted by Warming.

Each plant distribution is essentially the result of three groups of variable factors — physical factors, chemical factors, and biotic factors. All three groups of factors must be comprehended. Only exceptionally is a single factor a determining factor in plant growth or distribution. It is much more common to find these results controlled by combinations of factors, some physical, some chemical, some biologic. By physiologic adjustment and structural adaptation plants still further diversify their character, extend their distribution, and complicate the problem of tracing a given effect back to its fundamental causes.

Soil Minerals

All soils are based to a greater or less extent upon the existence and destruction of fragments of rock-making minerals. Practically all the common rock-forming minerals are to be found in any ordinary arable soil, but the relative amounts may vary widely from those in the rock from which the soil was formed and from each other. This conclusion is true even in such apparently homogeneous substances as brick clays.[1] Retgers found 23 different kinds of minerals in the dune sands of Holland.[2] Examinations by the U. S. Bureau of Soils show that some of the mineral species of the soil present clear and unaltered faces, although frequently, and especially with the feldspars, alteration products may be observed on the mineral fragments.

The composition of the chief minerals in the solid crust of the earth is shown in the following table.[3]

		Silica	Potash	Soda	Magnesia	Lime	Alumina	Ferrous Oxide	Ferric Oxide	Water
Quartz		100								
Feldspar	Orthoclase	64.2	17				18.4			
	Albite	68.6		11.8			19.6			
	Anorthite	43.1				20	36.9			
Mica		45 to 50	6 to 10	0 to 1.5			26 to 36			1 to 4.7
Hornblende Augite		39 to 49			10 to 27	10 to 15	3 to 15	3 to 20		
Olivine		41			49.2			9.8		
Talc		63.5			31.7					4.8

The soil minerals are all soluble to a certain extent in water, although the rate of solution may be quite slow and the actual amount dissolved

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[1] Cameron and Bell, Mineral Constituents of the Soil Solution, Bull. U. S. Bur. Soils No. 30, 1905, p. 9.

[2] L. V. Pirsson, Rocks and Rock Minerals, 1908, p. 280.

[3] A. D. Hall, The Soil, 1907, p. 16.

at any one time small. Many of the soil minerals are in a very finely divided or pulverulent condition and are therefore easily attacked by chemical agencies such as water, oxygen, and the various soil acids. Among the important chemical substances in the soil that may be classed as mineral are the zeolitic compounds (the hydrosilicates of alkaline earths and alkalies) easily decomposable by acids and capable of exchanging a part or the whole of their basic ingredients with solutions of other bases that enter the soil. The zeolitic compounds readily yield up a part of their ingredients to acid solvents and tend to fix a part or all of the soluble compounds that may be set free in the soil. The yielding up of their ingredients to acids is of great importance in that it enables plants to draw upon the reserve stores of food within the soil, the active solvent surrounding plant roots being water impregnated more or less with carbonic acid and possibly other acids.

Perhaps nowhere outside the arid regions are the mineral and rock particles of the soil in such a fresh condition as in glacial soils; and to the presence of large quantities of undecomposed material in such soils may be attributed their prolonged fertility, although their immediate fertility may be far below that of rocks in a stage of more complete decomposition.

Elements of the Soil

Of the nearly 80 elements that have been identified in the earth's crust but 18 occur in important amounts. These arranged roughly in order of abundance are as follows:

AVERAGE COMPOSITION OF LITHOSPHERE[1]

Oxygen	47.07%
Silicon	28.06
Aluminum	7.90
Iron	4.43
Calcium	3.44
Magnesium	2.40
Sodium	2.43
Potassium	2.45
Hydrogen	.22
Titanium	.40
Carbon	.20
Chlorine	.07
Phosphorus	.11
Sulphur	.11
Barium	.09
Manganese	.07
Strontium	.03
Fluorine	.02
All other elements	.50
	100.00%

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[1] F. W. Clarke, The Data of Geochemistry, Bull. U. S. Geol. Surv. No. 330, 1908, p. 32.

In the higher plants that have been investigated up to the present time the elements indispensable to normal development are invariably ten in number: oxygen, hydrogen, carbon, nitrogen, phosphorus, sulphur, iron, potassium, calcium, magnesium. If a single one of those substances is in a chemical form unavailable to the plant the plant enters into a pathologic condition or refuses to grow. Besides these ten substances all plants absorb various other substances whose utility is unknown.[1]

Relations of Soil Elements to Plants

While plants can not thrive in a soil that is without the substances noted above, the amount of each substance is found to vary according to the amounts of the others present; when a large percentage of lime is present, smaller percentages of potash, nitrogen, and phosphorus are required. But a soil entirely lacking in any one of these ingredients is an infertile soil. If the material of plants is burned the mineral residue contains potassium, calcium, magnesium, and a little iron among bases, and phosphorus, chlorine, sulphur, and silicon among non-metallic elements. Nearly all plants contain very small quantities of sodium and manganese; and radium, zinc, and copper have been found in traces in some plants.

Among these various elements carbon, hydrogen, and oxygen are drawn from the air or the water, while the other substances, equally indispensable to the plant, are derived chiefly by way of the roots from the soil. This fact makes it unnecessary to have a complete chemical analysis of the soil to understand certain aspects of its fertility, since the non-essential substances in the soil are simply the physical media in which plants grow; they therefore have no chemical importance. A chemical analysis of a soil is required to show the amount of nitrogen, phosphorus, potassium, and calcium in the soil besides other substances of less importance. The determination of the carbon compounds of the soil is of importance, and of the carbonates of calcium and magnesium which in most soils are active in neutralizing the acids that are harmful to bacteria.[2]

The degree of fertility of the soil, that is, the degree to which all the essential foods are present in available form, markedly affects plants in many ways, as, for example, the root habit of trees.[3] The more

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[1] E. Warming, Œcology of Plants, Ox. ed., 1909, p. 55.

[2] A. D. Hall, The Soil, 1907, pp. 128–129.

[3] J. von Sachs, Über den Einfluss der chemischen und der physikalischen Beschaffenheit des Bodens auf die Transpiration. Landw. Ver.-Sta., vol. 1, 1859, p. 179.

concentrated the nutrient solution of the soil the shorter the roots; and the poorer the soil the longer and more feebly branched are the roots; roots branch very copiously and form dense clumps in rich soil. In case of changing fertility with changing strata the roots display very marked contrasts in the degree of ramification within the different strata. In all such cases an unfavorable water supply in the otherwise richer medium will prohibit an exceptional root development in it.

The same species will absorb various substances from different soils in different proportions. Individuals of the same species contain much silica if they grow in granite soil and much lime if they grow in calcareous soil. Certain plants have the power of making both quantitative and qualitative selections of soil substances, and even when a desired substance is distributed in the soil in very small quantities such plants can in time absorb it in surprisingly large amounts. It is this selective power of root action combined with the fact that the substances indispensable to plants occur in nearly all soils in quantities so considerable that almost every plant may extract more than the minimum amount, that results in the distribution of a given kind of plant upon soils of very widely different character. Furthermore each plant community and each plant species has its own peculiar economy, its own peculiar root system and general demands, which make it possible sometimes for many species to live side by side on the same soil without competing for food.[1]

Characteristics and Functions of the Principal Soil Elements

OXYGEN

Oxygen is the most abundant of the elements, forming about one-half of all known terrestrial matter. It is a constituent of nearly all minerals in both soil and rock, and occurs in most rocks in amounts ranging between 45% and 50%. It is present in the soil as air, has an important effect as free oxygen in the oxidizing of various soil minerals and substances to form oxygen compounds, and plays a very prominent part in the many chemical changes which take place in both soil and vegetation. Without oxygen the nitrifying bacteria, which are of the utmost importance in maintaining the supply of soil nitrogen, can not live, earthworms are excluded, plants die, and some of the chemical changes important in maintaining the supply of plant food suffer a diminished rate of action.

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[1] E. Warming, Œcology of Plants, Ox. ed., 1909, pp. 56–58.

SILICON

Silicon occurs in both soil and rock in the form of silica (SiO_2) or quartz. It is one of the most indestructible of natural compounds and is the prevailing constituent in nearly all sands and soils because of its great resistance, so that soils from whatever source derived will differ from each other mainly in the relative proportions of the siliceous and clayey constituents.[1] Silica requires even in its most soluble form ten thousand times its weight of water for solution. Its relative indestructibility causes it to accumulate to such an extent in practically all soils that it is a matter of no concern. While it is not an essential plant food it is important to plants as a medium in which their roots are disposed and anchored. The amount of silica (SiO_2) in the parent rock determines to a large extent the rate of weathering, the rate decreasing with increasing quantities of this substance. Soil is derived from quartz schist, for example, with extreme slowness because of the resistance of quartz to weathering, and since this rock is composed chiefly of quartz its soil supplies but little plant food. Such a soil would be almost absolutely barren but for the frequent occurrence in the parent rock of accessory minerals that on decomposition yield important plant foods. Sandstone and sandy soils are usually poor because the sand almost always consists chiefly of quartz grains and the finer portions alone are of importance in plant nutrition. The oxide of silicon is the principal constituent of quartz sand; with it are usually associated however particles of other substances so that even a beach sand may have all the necessary elements for the limited growth of plants.

ALUMINUM

Next to oxygen and silicon the most important element is aluminum. It is the most abundant of all the metals and occurs chiefly in combination with silicon and oxygen, forming an important series of minerals known as aluminous silicates, such as feldspars, micas, zeolites, etc. Aluminum is so easily oxidized that (with the exception of the fluorides) only oxidized compounds of aluminum occur in nature. As a silicate, aluminum occurs as the principal constituent of all clays, and while insoluble in this form, soluble potash, lime, etc., are usually associated with it. Chemically pure clay is very insoluble and of little importance for it is the end product of the chemical decomposition of the soil minerals enumerated above, but it is very important in its capacity to retain soluble salts. The physical action of clay in producing flocculation and tilth has already been described (p. 37) and is of the highest importance.

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[1] Smith and McCalley, The Mineral Resources of Alabama, Geol. Surv. Ala., 1904, p. 74.

IRON

Iron gives a characteristic reddish or yellowish color to soils, occurs on the surface of the earth as an oxide and at greater depths or on fresh rock surfaces as a carbonate, sulphide, or silicate. Its principal forms are hematite, limonite, magnetite, pyrite, etc. It is essential to plants in the development of chlorophyll, without which there is improper nutrition. On account of its almost universal distribution in some form or other it is not a matter of concern in soil fertility.

CALCIUM

Calcium occurs in combination with carbon dioxide in great abundance in limestone; in the form of calcium carbonate it is slightly soluble in water containing carbonic acid and hence is an almost universal ingredient of all natural water. It is an important constituent of the principal silicates. It is one of the most essential substances in the soil because of its physical effects (p. 29) and because of its direct use in the formation of plant substances.

We have already noted the effect of lime, the carbonate of calcium, in promoting tilth, though it should be observed that an excess of 2% lime does not increase the tilth of the soil. Besides this it favors the important process of nitrification by prohibiting that acidity which excludes the nitrifying bacteria (p. 88). It seems to be an established fact that about 1% of lime is a high percentage of this ingredient in virgin soils.[1] In this connection it is important to see that when a large proportion of lime carbonate is present in the soil lower percentages of potash, phosphoric acid, and nitrogen are adequate. Among the other influences of lime in the soil are the rapid conversion of vegetable matter into black neutral humus and an increase in the nitrogen supply, an acceleration of the oxidation of carbon and hydrogen, a counteracting of the injurious effects of an excess of magnesia and of soluble salts in alkali lands, and a liberating effect upon the potash held in zeolitic compounds. An excess of lime, from 8% or more, disturbs nutrition, suppresses or diminishes the formation of chlorophyll and starch, and is in general deleterious to plant growth.[2]

The longleaf and shortleaf pine regions of the United States are poor in lime and have long remained almost uncultivated; the excess of lime in many of the chalk lands of Europe causes them to be equally infertile. The maritime pine and chestnut tree are both antagonistic to lime and any considerable amount of it will cause them to die or to

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[1] E. W. Hilgard, Soils, 1907, p. 346.

[2] For a discussion of lime effects see E. W. Hilgard, Soils, 1907, pp. 378–381 et al.

deteriorate, in contrast to the Corsican pine, which is a lime-loving tree.

The higher the clay percentage of a soil the more lime carbonate it must contain in order to exhibit the advantages of a calcareous soil. In sandy lands a characteristic lime growth may reflect the presence of only 0.10% of lime, while in heavy clay soils 0.6% is required to produce the same result. This explains the prominent color of dark-tinted humus in sand soils when very small amounts such as 0.2% of lime occur, whereas a comparable effect is produced in clay soils only when the percentage rises to 1%. A soil that effervesces with acids contains at least 5% of carbonate of lime, and percentages so small as to make the soil distinctly calcareous are not distinguishable by this mode of analysis.

In the study of the effect of lime upon vegetation a difference of opinion has arisen, probably due to the very different methods pursued and the different regions in which the students have worked. Hilgard, who has done the most extensive work of this character in America, concludes that the moisture of the soil is the point of first importance in the distribution and welfare of vegetation but that the condition next in importance is the amount of lime present. He grants, of course, that certain species are indifferent to lime, but holds that most species respond to lime in a marked manner and that on the whole the presence of lime tends to greater fertility except in the obvious case where it is present in excess. He finds that in Mississippi and Alabama there is a marked correspondence between the growth habit and types of trees and the geologic formations, so that a geologic map of the region would also be to a large extent a map of the various tree zones. The conclusions of Hilgard are of great value because they were formulated as early as 1860 after extensive study of native vegetation which grew in a soil that was almost undisturbed by man, hence a vegetation that represented a long term of adjustment to the soil. This is obviously an advantage over the conditions in Europe, where the observers of the vegetation have quite constantly to eliminate the influence of cultivation and other disturbing influences due to the long occupation of the land by man. It would not be fair, however, to dispose of the matter by merely stating the ground of Hilgard's conclusions. The contentions of the European students are cogent and interesting and deserve equal attention here.

Warming says:

> "Although the characteristics of the lime-flora are clear and distinct, yet in the past the influence of lime upon vegetation has been overestimated. Indeed, a distinction has been made between calciphilous and calciphobous plants. Recently it has been definitely established that the amount of lime in itself, in so far as it does not operate physically, can not be the cause of differences in the flora, for not only can calcicolous plants be cultivated in soil that is poor

in lime, but silicicolous plants, and even bog-mosses, which are regarded as preëminently calciphobous, can grow vigorously in pure limewater if the aqueous solution be otherwise poor in dissolved salts. It has been overlooked that nearly all lime soils are rich in soluble mineral substances, and this wealth excludes plants belonging to poorer soils; beyond this the important physical characters of calcareous soil, compared with granite soil, come into play."[1]

In general the disagreement of the conclusions as to the power of lime to control plant distribution appears to be due to the absence of a standard conception as to what constitutes a lime soil. By some a soil is regarded limey only when it effervesces with acids, yet not less than 4% of calcium carbonate in a soil will respond to the acid test, whereas 0.1% will have important effects on plants provided the soil is sandy. So far, most of the conclusions have been mere *obiter dicta*. The conclusions of American investigators, based on native and practically undisturbed vegetation, are essentially sound, though they require important modifications where the physical conditions become extreme.

MAGNESIUM

Magnesium forms an essential part of the rock known as dolomite and may exist as a silicate in such rocks as serpentine, talc, etc. In igneous rocks it occurs in the minerals pyroxene, mica, olivine, etc. Magnesia is invariably and rather abundantly found in the seeds of plants and is a very important plant-food ingredient, but must not occur in excess or it will cause, through chemical action, a pronounced change in the capacity for imbibition, and thus particularly disturb the functions of the plant. Magnesia is especially concerned in the transfer of phosphoric acid through the plant tissues; while magnesia predominates in the fruit of a number of crop plants lime predominates in the leaves, so that there is apparently a connection between the extension of leaf surface and the lime requirement.

SODIUM

Sodium occurs in largest percentage in the igneous rocks as a constituent of the soda-lime feldspars, amounting on the average to 2½% of the igneous rocks. These feldspars are more readily attacked by water and carbon dioxide than are the other common minerals save certain basic silicates, so that the whitening and the softening of feldspar is one of the first signs of rock decay. The sodium salts are so soluble, however, that they are leached away almost as rapidly as formed, with the result that soils are normally rich in potash but poor in soda. In poorly drained soils of arid lands, however, these qualities result in

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[1] E. Warming, Œcology of Plants, Ox. ed., 1909, p. 58.

a concentration of soda through the continued evaporation of ground water, where as carbonate, sulphate, and chloride it gives rise to alkali tracts poisonous to all but specially adapted species of plants. In northern Chile, one of the most arid tracts of the world, the sodium has become concentrated in nitrate deposits. These on account of the fixed nitrogen which they contain are extensively mined and shipped to many agricultural regions in humid lands as a fertilizer. Thus through its chemical properties — the extreme basicity of the element and the solubility of its salts — sodium causes the most arid deserts to add to the fertility of the garden spots of the world. Sedimentary rocks, the accumulations of the constituents of soils of former ages, are usually deficient in sodium and may be almost free from that element. Their soils, the result of a second cycle of leaching, tend to be still more barren in sodium. The use by land plants of potassium is doubtless an adjustment to the prevailing composition of soils; marine plants, living in an environment where sodium is dominant, show a parallel use of sodium in their tissues though they use potassium also, to some extent.

POTASSIUM

One of the most important elements of the earth's surface from the standpoint of plant growth is potassium, which in the form of a nitrate is found in nature (saltpeter). It occurs in small and large quantities in a great variety of igneous and metamorphic rocks, but may be absent from sedimentary rocks. It is present in mica, amphibole, and pyroxene, and when combined with silica is an important member of orthoclase and other minerals. Granite soils generally contain a good supply of potash on account of the common occurrence of potash feldspar in them. Granite soils may be deficient in lime, however, unless hornblende is present, since lime-feldspar is not likely to occur as an accessory ingredient of granite.

The amount of potash necessary for high soil productivity is about 0.5% and at this figure the addition of potash has but little effect upon the fertility. At 0.25% there is a deficiency that must be made up by fertilization. These figures do not apply, however, in arid or tropic lands. In tropic lands the prevailingly high temperature, the great rainfall, and the continuous leaching, cause a very rapid liberation of potash from its insoluble form as well as its rapid removal; smaller amounts are therefore necessary at any given moment. In arid regions the absence of rapid leaching allows the accumulation of earthy salts of many kinds, among which potash is prominent.[1]

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[1] E. W. Hilgard, Soils, 1907, pp. 354–355.

PHOSPHORUS

Of very high importance in soil fertility is phosphorus, found in the minerals vivianite and apatite, in the bones of animals, and in the seeds of plants. Apatite (phosphate of lime) is an almost universal constituent of granitic rocks, but occurs in very small quantities.[1] The amount of phosphoric acid (P_2O_5) contained in granitic rocks rarely exceeds 0.2% and may fall as low as 0.05%; but small as the amount is it probably is the main source of supply of phosphates existing in the soil. Phosphorus is most abundant in the basic eruptive rocks such as diorites and gabbros and deficient in such rocks as sandstone and slate.

Where the minerals vivianite and apatite are abundant in the country rock, as in the basaltic lavas of Hawaii, phosphoric acid may be present in the soil in exceptional amounts, — nearly 2%. Unfortunately in this particular case it occurs in the form of an insoluble basic iron compound, ferric phosphate, which is dissolved with such difficulty that it is wholly unavailable to vegetation and the soil containing it is actually phosphate poor. The same is probably true of certain ferruginous soils in California and the South. The lower limit of adequacy of phosphoric acid in the soil is about .05%. Exceptionally soils may contain as much as .30%, while .15% is regarded as adequate. In non-ferruginous lands the amount required is smaller than in the case of ferruginous lands because the iron renders phosphoric acid inert by forming ferric phosphate, an insoluble substance.[2]

Phosphate deposits are derived chiefly from animal remains, but animals derive it from plants, which in turn depend for their supply upon the alteration products of apatite. Commercially important deposits of apatite occur in Spain, Canada, and Norway. From the Norwegian deposits a commercial fertilizer is now manufactured, a phosphoric-chalk manure. Phosphorus is one of the rarest essential plant foods, and its conservation should be a matter of great concern. Sewage contains relatively high percentages of it, and the application of sewage to the land instead of its wastage in rivers and the sea is one of the most important though as yet limited uses of this neglected fertilizer.

SULPHUR

Sulphur plays an important part in the nourishment of plants, since it is an essential constituent of vegetable albumen and allied compounds,

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[1] The pure crystalline mineral apatite rarely occurs in large masses. Minute crystals of it are found widely scattered in many rocks, granite, basalts, etc. The largest deposits occur in connection with carbonate of lime in rocks known as phosphorites which closely resemble limestone. Extensive phosphate deposits are found in southern California, Florida, Alabama, Tennessee, Kentucky, Wyoming, Utah, Idaho, Montana, etc.

[2] E. W. Hilgard, Soils, 1907, pp. 393 et al.

hence a soil to be fertile should always contain sulphates in available form. The usual form of occurrence is in combination with the metals to form sulphides or with oxygen and a metal to form sulphates. It is an essential part of the mineral pyrite, and when combined with oxygen and calcium forms the valuable fertilizer gypsum. The amount of available sulphur existing in any soil is usually very small. The relative available amount in ordinary soils is indicated in the following table, in which it is assumed (1) that the mean dry weight of a surface foot of soil is 80 pounds, and (2) that the amount of soluble material is accurately represented by the results of a large number of analyses collected in the Tenth Census Reports.

RELATIVE AMOUNTS OF CERTAIN ESSENTIAL PLANT FOODS IN AN ACRE-FOOT[1]

Potash in surface foot, per acre	3.76	tons
Soda in surface foot, per acre	1.58	"
Magnesia in surface foot, per acre	3.92	"
Lime in surface foot, per acre	1.88	"
Phosphoric acid in surface foot, per acre	1.97	"
Sulphuric acid in surface foot, per acre	.91	"
Soluble silica in surface foot, per acre	73.40	"

In the decomposition of the various compounds of iron and sulphur, oxidation affects either or both the iron and the sulphur; when the iron alone is oxidized the sulphur or some part of it separates as hydrosulphuric, sulphurous, or sulphuric acid. The sulphur of the hydrosulphuric acid may be later oxidized to sulphurous or sulphuric acid through the action of water and oxygen with or without the assistance of bacteria, though bacteria are often the inciting cause of the oxidation. In the form of sulphuric acid sulphur is immediately available to plants, indeed sulphuric acid itself is found in the tissues of plants in small quantities. It is subject to steady depletion in this form by percolating water and by combination with bases in the formation of sulphates, in addition to the demands upon it by growing vegetation.[2]

Total Plant Food; Available Plant Food

The data concerning plant food are to be distinguished from those derived by mere chemical analyses of soils, which in themselves are of small value in understanding ecologic conditions. Almost all soils show on ultimate chemical analysis an abundance of the elements required for almost any given crop, but there is the widest difference between the forms in which the elements occur, so that it is the available plant food, and not the ultimate amount of plant food that may be produced on complete decomposition, that is a matter of chief interest

[1] F. H. King, The Soil, 1905, p. 102.

[2] C. R. Van Hise, A Treatise on Metamorphism, Mon. U. S. Geol. Surv., vol. 47, 1904, p. 468.

in the study of the chemistry of soils. The soil must be regarded as possessing most of its plant food in such a state of combination that it can not be utilized by the plant directly, but must by weathering slowly pass into the soluble, i.e., the available, form.

DETERMINATION OF SOIL FERTILITY

The approximate chemical nature of an ordinary soil may be ascertained in a direct manner by the determination of both the decomposed and undecomposed minerals present in it. The determination of its fundamental nature requires an examination of the undecomposed minerals only, since it is presumed that the decomposed part of the soil has been derived from the constituent minerals and since the undecomposed material forms by far the greater bulk of the soil. But such an analysis is of less value than direct qualitative and quantitative chemical analyses of the soil character. Even the latter analysis does not always furnish a reliable guide as to the productivity of the soil. The previous history of the land and the physical characters of the soil may be predominating factors.

In attempting to ascertain the nature and amount of the decomposed portion of the soil various working plans, which attempt to imitate plant action, have been tried. The water-soluble ingredients of the soil are only a portion of the total number of substances upon which plants may draw for food, because the plant roots act not alone through the medium of water but also through water charged with carbonic and possibly other acids. Clearly, then, the action of plant roots may be imitated more closely by employing in the analysis a weak acid solvent that will act upon the soil in a manner similar to the soil acids. The weak acid solvent employed is empirically determined, for no one has yet analyzed the soil about a growing plant in such a way as to ascertain under precisely what conditions the various soil acids act. The results of soil analyses by means of weak acid solvents must be compared with cultural experience and observations on natural plant growth; the results are thus empirical approximations, but they are the best that have been achieved. It has been found by such observations that all soils are continuously soluble to some extent but that the differences between the solutions derived from soils of low and of high productivity are very striking.

Plants differ very greatly in the energy and quality of their action upon reserve soil ingredients, so that no single solvent used in an analysis could properly represent the action of plant roots in general. Among the many solvents employed for the purposes of soil extraction and the determination of immediate soil productivity are citric acid (a 1% solution is most commonly employed) and aspartic acid, among the weak acids; and hydrochloric, nitric, and a few others, among strong acids. The hydrochloric acid is employed in densities ranging from 1.1 to 1.16, while a density of 1.115 has been found most convenient and satisfactory of all. From experience with acids of different strength it has been found that a five-day period of digestion with hydrochloric acid (density, 1.115) is sufficiently effective in showing what plant-food ingredients of the soil maintain its permanent productive capacity. This appears to be the natural limit of the action of the acid upon the soil and produces a maximum effect. There is much to justify the contention that the only legitimate solvent in determinations of soil fertility is carbonic acid, the commonest, the natural, and the most abundant acid in the soil.[1] The immediate soil requirements may also be empirically determined with a fair degree of accuracy by analyzing the ash of the vegetable growth and establishing a ratio between the normal ash ingredient and the actual soil ingredients. It has been found that in the case of a deficiency of certain kinds of plant food there is a disturbance of nutrition that manifests itself in the form or in the development of the plant and affords a direct basis for future determinations of a similar sort without the repetition of the full chemical analysis of the ash.

Unless extreme physical characters interfere with normal plant growth virgin soils showing high percentages of plant food as determined by extraction with acids[2] (hydrochloric, nitric, etc.) invariably prove highly productive. Hilgard states the law as follows: "The actual amounts of soil ingredients . . . rendered accessible to plants are . . . more or less proportional to the totals of acid-soluble plant-food ingredients present."[3] The natural condition which this result indicates may be stated thus: the larger the total amount of plant food in the soil and ultimately available the greater will be the immediate effect of the weathering agencies that produce available plant food. This conclusion appears to be rather well established and indicates how high a degree of importance should be attached to the chemical composition of soils despite the relatively higher importance of physical qualities in general. Neither group of qualities can be adequately applied to a soil type to the exclusion of the other group. All the field conditions must be evaluated before a soil analysis can be regarded as complete. It is in the highest degree unscientific longer to advocate the supreme importance under all circumstances of a single group of soil qualities.

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[1] A. D. Hall, The Fertility of the Soil, Science, n. s., vol. 32, 1910, p. 366.

[2] E. W. Hilgard, Soils, 1907, pp. 343–353, etc.

[3] Idem, p. 346.

HARMFUL ORGANIC CONSTITUENTS OF THE SOIL

In concluding this discussion of some of the chemical properties of soils it seems desirable to note an important recent result in one of the most complicated branches of soil chemistry, the identification of harmful organic substances that occur in the soil, the determination of their properties and the formulation of remedies to offset their effects. It has been found that many plants can possibly excrete, as the result of growth, organic compounds which are poisonous to the plants producing them. It has been found that these organic substances while inhibitory to the plants which produce them have little or no effect upon other plants. It is therefore concluded that they may be positive forces in producing a natural succession or rotation of wild vegetation not explained by any change of soil or climate.[1]

These harmful substances are constantly being added to the soil, and some of them are injurious in quite small amounts and are a cause of infertility even when the amount of plant food in the soil is abundant.[2]

The most markedly harmful bodies are found within the plant but are not apparently an essential part of the life of the plant. Of this class are arbutin, vanillin, heliotropine, terpenes, etc., all of which are very injurious. Tyrosine is injurious in quite small amounts, while some of the protein decomposition products are not only harmless but appear to act as plant nutrients; such for instance are asparagine and leucine.[3] The harmful substances have a toxic effect on the plants, but are destroyed or rendered harmless by other substances like soda and lime in coöperation with plant roots. Oxidation in a high degree converts some of these bodies into harmless substances, but a low rate of oxidation causes the organic matter to decompose incompletely and gives rise to organic compounds unfavorable to plant growth.[4]

Hall suggests that these so-called toxic substances may be normal products of bacterial action upon organic residues in the soil and that as such they may be as abundant in fertile soils rich in organic matter as in the sterile soils from which they were extracted. He points to the great power of the soil in precipitating soluble materials within it as a possible natural remedy for such toxic substances.[5]

It has also been found that tree roots have a toxic effect on the growth of wheat. The absence of grasses about certain trees is thus attributed not to depletion of plant food alone but to the toxic effects of the tree roots heightened by shade and the well-known injurious effects of washings from trunk and leaves.[6]

[1] Schreiner and Shorey, The Isolation of Harmful Organic Substances from Soils, Bull. U. S. Bur. Soils No. 53, 1909, pp. 1–3.

[2] Idem, p. 29.

[3] Idem, pp. 12–13.

[4] Schreiner and Reed, Certain Organic Constituents of Soils in Relation to Soil Fertility, Bull. U. S. Bur. Soils No. 47, 1907, p. 13.

[5] A. D. Hall, the Fertility of the Soil, Science, n. s., vol. 32, 1910, p. 367.

[6] C. A. Jensen, Some Mutual Effects of Tree Roots and Grasses on Soils, Science, n. s., vol. 25, 1907, pp. 871–874.

CHAPTER VI

HUMUS AND THE NITROGEN SUPPLY OF SOILS

SOURCES AND PLANT RELATIONS

THE nitrogen of the soil is a matter of paramount importance in forestry, especially in the maintenance of a proper forest growth and in efforts at reforestation, for as we have seen a supply of nitrogen in some form or other is absolutely indispensable to plants.[1] We shall therefore discuss it somewhat more fully than the other plant foods of the soil. To be available to plants nitrogen must be in soluble form, and it is therefore as a nitrate that it is used by the plant. The main source of nitrogen is humus, whence it is derived chiefly by bacterial action; although nitrogen exists in unhumified organic matter it is not in an available form. Other sources of nitrogen are (*a*) nitrogen-fixing bacteria that live in a free state in the soil and derive their nitrogen from the soil air, (*b*) nitrogen-fixing bacteria that live in symbiotic association with legumes and other plants, and (*c*) rain water. The amount of nitrogen contributed to the land in the last-named manner amounts to a half pound or a pound or more per acre with a rainfall of about 30 inches per annum.[2]

NITROGEN BROUGHT TO THE SURFACE OF THE EARTH BY RAIN

(Pounds per acre per annum.)

Locality	Nitrogen			Remarks
	Ammoniacal	Nitric	Total	
Rothamsted, England	2.823	0.917	3.74	In 1888–89
Barbados	1.009	2.443	3.452	5 years' average
British Guiana	1.351	2.190	3.541	7 years' average
Kansas	2.63	1.06	3.69	3 years' average
Utah	5.06	.356	5.42	Do.

Nitrogen is usually the first element to become exhausted in the soil because the nitrates are exceedingly soluble and no part of the soil has any special power of holding back nitric acid when it passes in aqueous solution through its pores, so that the nitric acid produced in the soil

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[1] A. D. Hall, The Fertility of the Soil, Science, n. s., vol. 32, 1910, p. 368.

[2] H. W. Wiley, Prin. and Prac. of Agri. Anal.: Soils, vol. 2, 1906, p. 448.

passes at once into the vegetation, or remains in store in dry periods, or passes into the drainage water and is lost.[1]

It is important that the forester retain the humus of the forest soil and increase it or make the amounts already there more useful, since the nitrogen which it yields is one of the rarest of the essential plant foods in the soil. The maintenance of humus in the soil requires a forester's constant attention to renewal of growth after cutting, proper drainage, a shaded surface, etc.[2] Different species of plants demand very different amounts of humus: some plants appear to require none at all, as those that develop on bare rock; some require a moderate amount, as is the case with certain grains; and others, notably the moorland plants, thrive only in rich humus, and have special methods of nutrition dependent upon the kind of soil in which they live.[3]

The great value of the birch and the aspen lies in their power of rapid dispersion and quick germination and growth in sterile soil or soil robbed of humus by repeated fires. They thus prevent excessive erosion, which is usually so destructive of the soil after fire has destroyed either or both the forest cover and the soil humus. In this manner and by their rapid growth they often afford an opportunity for the seedlings of longer-lived and more valuable trees to come in under conditions that insure their successful growth.[4]

As an illustration of the importance of humus in maintaining an original growth of vegetation may be cited the fact that a change in the forest vegetation is known to have occurred in Denmark during past millennia, owing in part to the action of the wind, which by blowing leaves out of the forest has reduced the amount of humus.

> "When a forest soil is exposed to desiccation and the fallen leaves are carried away by wind, the earthworms vanish, the soil becomes dry and hard, and the vegetation suffers. In acid soil (bog, heath) and dune, earthworms are wanting. Upon their presence or absence depends the occurrence of a humus soil or a raw humus soil in north temperate forest and heath. Conversely they disappear upon the production of raw humus and humous acids. Even upon the growth of rhizomatous plants in the forest do they exert an action; their presence or absence causes a series of variations in the kinds of soil that corresponds to a series of variations in the plants clothing it." [5]

It is noted also that a covering of leaves in a beech forest has a great influence upon ground vegetation in that it supports mosses and other plants, produces humus, and provides food for animals living in the

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[1] W. J. Spillman, Renovation of Worn-out Soils, Farmers' Bull. U. S. Dept. Agri. No. 245, 1906, p. 5.

[2] E. Ebermayer, Lehre der Waldstreu, etc., 1876, p. 206.

[3] E. Warming, Œcology of Plants, Ox. ed., 1909, pp. 62–64.

[4] C. S. Sargent, Manual of the Trees of North America, 1905, pp. 155–201.

[5] E. Warming, Œcology of Plants, Ox. ed. 1909, p. 78.

forest soil, among which earthworms are considered to be the most important.[1]

One of the most important qualities of humus that affects its value to the soil is its natural porosity, which renders it very absorptive of gases, especially aqueous vapor. Dry humus swells up when wetted and the volume of weight increases in the ratio of 2 or 8 to 1; in fact humus stands first in this respect among the soil ingredients.

Although in general the presence of the organic matter of plants increases the power of soils to hold moisture, some kinds of organic matter are known to cause a low water-holding power, as in certain California soils, a condition due to the peculiar and special qualities of the organic matter, which when extracted is found to have the properties of a varnish, repelling water to an extreme degree.[2]

The density of natural humus as compared with ordinary soil is about 1:4. It is the lightest soil material and greatly promotes tilth, aeration, water supply, etc. Besides nitrogen, humus contains mineral plant food ingredients which are capable of nourishing plant growth. These mineral ingredients are probably made available to plants largely through the direct and indirect action of the humus compounds; for it has been shown that the richer the soil is in humified organic matter the more rapidly the mineral matter of the soil is made available for plant nutrition. With an increase of soil humus there is a corresponding increase in the amount of mineral plant food extracted from the soil by a 4% solution of ammonia such as is employed in the Grandeau method of humus determination (p. 82).[3]

Organic Matter in the Soil

The difference between soil and a mere mass of sand or disintegrated rock is that soil contains some organic matter. Soil becomes arable and furnishes a medium suitable for the growth of higher plants when a certain amount of organic material has been accumulated in it from the growth and decay of lower plants. Animal remains, such as insects and worms, also have a prominent place as a source of soil organic matter. The accumulation of the remains of micro-organisms and of the vegetation which they modify is an important factor in the transformation of land waste into soil. The final product of these and other processes is a mixture of stuff fully as complex as the processes to which it owes its origin.

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[1] E. Warming, Œcology of Plants, Ox. ed. 1909, p. 74. For a very clear and comprehensive discussion of the chemical modification of forest litter and its value to the soil, see E. Ebermayer, Die gesammte Lehre der Waldstreu mit Rücksicht auf die chemische Statik des Waldbaues, 1876.

[2] Schreiner and Shorey, Chemical Nature of Soil Organic Matter, Bull. U. S. Bur. Soils No. 74, 1910, pp. 8–9.

[3] E. F. Ladd, Bull. So. Dakota Agri. Exp. Station, Nos. 24–32, **35**, **47**. Quoted by Hilgard, pp. 140–141.

The organic matter of both plants and animals is made up of protein, fats, and carbohydrates principally, but besides these substances there is a host of other compounds such as resins, hydrocarbons, and derivatives, that is, alkaloids, acids, etc. Furthermore, all living matter has as essential components some organic compounds that contain nitrogen, compounds which for the most part are those related to protein. When the complex molecules of proteins, fats, and carbohydrates break down into simpler bodies they pass through the same changes whether these changes are brought about through the agency of micro-organisms as in decay or through the agency of acids; and they are subject to still further decomposition through the same or other agencies. The secondary products are very numerous and of widely varying composition and structure, as well as chemical and physical composition and properties, so that the final products of decay are very different under different conditions.

When organic matter is contributed to the soil there is a continuous "building-down" process from the original complex molecule to simpler ones and these again to still simpler molecules, until in some instances the substances are reduced to their most elementary constituents.[1] All these chemical changes are affected by the temperature of the soil, the amount of air it contains and the amount of water, etc. Dry leaves, wood, and litter generally do not change in dry air or change very slowly; but if the ground is moist the process goes on rapidly.[2] In the absence of air bacterial transformations cease and the bacteria die. Extremely high or low temperatures likewise limit their activities (p. 86).

Soil Humus

AMOUNT AND DERIVATION

The chief source of soil nitrogen, as we have already noted, is the organic matter in the soil, and this occurs to a large extent in the form of "humus." The total amount of organic matter in ordinary soils is 2.06% for the soil and 0.83% for the subsoil, figures based on the analysis of thousands of samples from many different portions of the United States.[3] There is an average of 28 tons of organic matter in the soil per acre taking it to a depth of 8 inches, and 50 tons of soil and subsoil taking it to a depth

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[1] Schreiner and Shorey, The Isolation of Harmful Organic Substances from Soils, Bull. U. S. Bur. of Soils No. 53, 1909, pp. 9–11.

[2] E. Ebermayer, Die gesammte Lehre der Waldstreu mit Rücksicht auf die chemische Statik des Waldbaues, 1876, p. 202.

[3] Schreiner and Reed, Certain Organic Constituents of Soils in Relation to Soil Fertility, Bull. U. S. Bur. Soils No. 47, 1907, p. 10.

of 2 feet.[1] The amount of nitrogen is generally not far from 0.1%. In arid soils the average amount of humus is much lower, rarely exceeding 1% and frequently falling to or below 0.30%; but the nitrogen content of the humus of arid soils is very much higher than in the case of humid soils. Woodlands and old meadows as a rule show a high humus content in their surface soils. The humus content of peat and marshland is also high.

While figures for the amount of humus which may be derived from a given quantity of vegetable matter must vary greatly according to the conditions under which humification takes place, it may be said that in the humid regions roughly one part of normal soil humus may be formed from five to six parts of dry plant débris. This ratio is based upon the assumption that the average nitrogen content of plant débris is 1%. The ratio will vary according to the temperature, the degree of access of air and moisture, etc. In hot arid regions all vegetation may wholly disappear by oxidation at the surface of the ground, and the proportion of humus derived from the decaying vegetation of arid regions is in general very much smaller than that of humid regions where it is rather rapidly incorporated in the surface soil.[2]

The absolute amount of humus decreases rather regularly downward except in the case of depths that represent the maximum root development, at which level there is always a slight and often a notable increase in the humus content. Below this level decrease again takes place. The nitrogen percentage in the humus (which is to be distinguished from the total nitrogen content of the soil) exhibits a general decrease in the same direction, probably due to decrease in the amount of oxygen and a diminished rate of oxidation with increase in depth.

The humus content of soils has a very close correspondence in some cases with the root development and is large in the surface layer and small in the subsurface layer. In other cases, while the decay of organic material takes place chiefly at the surface, active animal agencies may carry the organic remnants downward into the soil and effect a somewhat uniform distribution. If both root penetration and animal agencies are restricted by the compactness of the subsoil only a light surface layer of mold will be formed and what little humus is found in the lower soil layers will be derived entirely from the decay of a very limited number of roots. Cultivation or timber cutting when followed by excessive erosion prevents the accumulation of vegetable matter, from which

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[1] Schreiner and Shorey, The Isolation of Harmful Organic Substances from Soils, Bull. U. S. Bur. Soils No. 53, 1909, p. 26.

[2] E. W. Hilgard, Soils, 1907, p. 128.

humus is chiefly derived, and allows the too rapid aeration and destruction of the humus.

In general it seems necessary to keep the nitrogen percentage of soil humus at about 4% to insure satisfactory results, and for the growth of grasses a nitrogen percentage in the humus of 1.7% is quite inadequate, no matter how much humus may be present. Different plants will accept this minimum, as might be expected from the differences of root habit, water supply, lime percentage, etc., which have an influence upon the rate of nitrification and of the leaching of nitrogen from the soil.

If a moderate amount of moisture is present in the soil and there is in consequence a relatively free circulation of the air, and if earthy carbonates are present, especially lime, so as to neutralize the acids of the soil as fast as formed, fungoid and bacterial growths effect the steady humification of organic matter. Oxygen and hydrogen are eliminated in the form of water and carbon dioxide, and there is an increase in the percentage of carbon and generally of nitrogen. When once humification is completed oxidation affects mainly the carbon and the hydrogen, so that the nitrogen content may for a time rise steadily and reach very high figures. Under unfavorable conditions the conversion of organic material to soluble nitrogen may be so slow that a soil containing as much as 40% of unhumified organic matter may contribute during a single year but a small quantity of available nitrate.

HUMUS DEFINED

Originally the term *humus* had no special significance and was only a name for dark-colored vegetable mold; later it came to be applied to this mold material when incorporated to a greater or lesser degree in soils. The term now has a more restricted meaning, at least among soil chemists, and is applied exclusively to the dark-colored organic matter extracted from soils by dilute solutions (usually 5% solutions) of sodium or ammonium hydrate.[1] The method of determination is purely empirical and ascertains the existence of only a portion of the organic matter of the soil.

Among agricultural folk and in general among foresters the term *humus* still retains its early meaning—partly decomposed organic material, dark in color, light in weight, and mixed with more or less mineral matter.

The amount of humus in the soil is sometimes determined by means of dry or wet combustion in which process the humus is calculated from the carbon dioxide formed and the nitrogen gas is measured directly. Obviously this measurement includes the entire organic matter of

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[1] Methods of Analysis, Humus in Soil, Bull. U. S. Bur. Chem. No. 107, 1907, p. 19; see also C. A. Davis, Peat, 8th Ann. Rept. Mich. Geol. Surv., 1906.

the soil whether humified or unhumified. To obtain the amount of actual functional humus in the soil (only humified organic matter can be directly nitrified) a solvent must be employed and discrimination between humified and unhumified material made. The accepted process is the method of Grandeau. By this method the soil is first extracted with dilute acid in order to set the humic substances free from their combinations of lime and magnesia and a subsequent extraction is made with moderately dilute solutions of ammonia. After the evaporation of the ammonia solution the humus is left behind in the form of a black substance somewhat resembling soot. This is then weighed and afterwards burned and the ash weighed. The amount of functional humus is considered to be the difference between these two weights. The nitrogen content of the humus may be determined directly by substituting in this process potash or soda lye for ammonia water and determining the nitrogen by the Kjeldahl method in the filtrate.[1]

The chemical composition of humus is indefinite because it itself is a variable mixture of substances of complex composition. It always contains more carbon and nitrogen and less oxygen and hydrogen than the substances from which it was formed. The following table shows the chemical composition of grass and of the top brown layer of turf in a peat bog, also the composition of peat of greater age, at 7 feet and 14 feet respectively.

CHEMICAL COMPOSITION OF VARIOUS TYPES OF ORGANIC MATTER.[2]

	Grass	Top Turf	Peat at 7′	Peat at 14′
Carbon........	50.3	57.8	62	64
Hydrogen......	5.5	5.4	5.2	5
Oxygen........	42.3	36	30.7	26.8
Nitrogen......	1.8	0.8	2.1	4.1

It should be remembered in the inspection of this table as well as in the general consideration of humus that vegetable matter consists, in addition to carbohydrates, of other carbon compounds containing nitrogen, and in some cases both nitrogen and phosphorus, which all break down under bacterial and acid action into dark-colored substances called humus. In the process of humus formation the nitrogen-containing bodies resist the action of bacteria longer than the carbohydrates, so that the later the stage of decay the greater the proportion of nitrogen the humus will carry. It follows that during the gradual depletion of the humus higher and higher percentages of nitrogen will be developed in that part not removed.[3]

Humin and *humic acid* are terms used in designating vegetable acids resulting from the decay of vegetable matter in the formation of peat, etc. The descriptions and formulæ for humic acid and related bodies

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[1] For a description of the Kjeldahl method see Wiley, Soils, 1906, p. 491 et seq.

[2] A. D. Hall, The Soil, 1907, p. 42.

[3] Idem, pp. 41–44.

are about as numerous as the number of investigators.[1] Certain elaborate experiments have resulted in the attempt to show that humic acid consists for the most part of an insoluble body of a protein nature, but this proves only that the humic acid examined by this investigator was either of a protein nature, a mixture of protein decomposition products, or probably both, together with some unknown body.[2]

Humic acid, ulmic acid, ulmin, etc., are commonly used as if they were definite bodies of well-established composition, but this is not the case, as their very existence has never been satisfactorily demonstrated. No attempt should be made to ascribe formulæ to acids of so complex and variable a nature. As commonly written the formulæ for the group are as follows:[3]

ULMIN AND ULMIC ACID

Carbon	67.1%	Corresponding to $C_{40}H_{28}O_{12} + H_2O$
Hydrogen	4.2	
Oxygen	8.7	

HUMIN AND HUMIC ACID

Carbon	64.4%	Corresponding to $C_{21}H_{24}O_{12} + 3\ H_2O$
Hydrogen	4.3	
Oxygen	31.3	

CRENIC ACID

Carbon	44.0%	Corresponding to $C_{12}H_{12}O_8$?
Hydrogen	5.5	
Nitrogen	3.9	
Oxygen	46.6	

APOCRENIC ACID

Carbon	34.4%	Corresponding to $C_{24}H_{24}O_{12}$?
Hydrogen	3.5	
Nitrogen	3.0	
Oxygen	39.1	

The ulmic, crenic, and apocrenic acid groups are therefore names for exceedingly complex and unstable compounds as yet but very little understood. Although they have never been isolated and their character definitely determined it should be remembered that there is reason for believing that they have at least a very short-lived existence in the soil. If they exist at all they pass quickly into the higher stages of oxidation and their final condition is CO_2; yet it is believed that during their supposed brief existence they may not only attack alkalies and alkali earths but also dissolve even silica.[4]

Clarke asserts that they have a very appreciable solvent power and advance the decomposition of rocks, but notes that their constitution is but little understood.[5]

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[1] Schreiner and Reed, Certain Organic Constituents of Soils in Relation to Soil Fertility, Bull. U. S. Bur. of Soils No. 47, 1907, pp. 14–16.

[2] Suzuki, Bull. Col. Agri. Tokio, vol. 7, 1907, p. 513. Quoted by Schreiner and Shorey in Bull. U. S. Bur. of Soils No. 53, p. 19.

[3] G. P. Merrill, Rocks, Rock-weathering and Soils, 1896, pp. 189–199.

[4] Sir Archibald Geikie, Text-book of Geology, 3d. ed., 1886, p. 472.

[5] F. W. Clarke, The Data of Geochemistry, Bull. U. S. Geol. Surv. No. 330, 1908, p. 409.

Hilgard says that an acid reaction is characteristic of the soils of many woodlands, as is notable of the soils of the long leaf pine region of the South as well as of many deciduous forests in northern climates. He believes that in the course of time oxidation converts the natural neutral humin and ulmin into humic and ulmic acids capable of combining with the bases. Still further action is thought to result in the formation of crenic and apocrenic acids, which are readily soluble in water and in part form soluble salts with lime, magnesia, and other bases.

"These acids act strongly upon the more readily decomposable silicates of the soil, and in the course of time may dissolve out, and aid in the removal, by leaching, of most of the plant-food ingredients . . . of the soil."[1]

It is conceived that this agency may be responsible for the almost complete absence of mineral plant food in the lower portions of peat beds and the subclays of coal beds.

Besides the uncertain humus compounds of ulmic, humic, crenic, and apocrenic acids, there are others of similar derivation the action of which is not yet understood; among them are xylic acid, saccharic acid, and glucinic acid, and a black humus acid containing 71.5% of carbon and 5.8% of hydrogen.

In the old forests of northern climates there is sometimes formed at the surface a partially decomposed peaty layer or vegetable remains which retards the full production of the land both while occupied by forests and for some time after being cleared.[2] In the case of such arrested humus development the soil becomes sour. The sourness is thought to be due to the presence of the above-named acids.

Raw humus or unhumified organic material consists of incompletely decomposed plant remains, and may be found so rich in such remains from 50% to 60% organic matter as to be employed as fuel. It has free vegetable acids in abundance, earthworms can not penetrate it, and by itself it is of no value to plants. Raw humus appears in the forest in poorly drained places or in places exposed to wind, while ordinary humus with its earthworms, insects, etc., occurs in fresh, sheltered places. Ordinary humus or vegetable mold contains many fungi, besides earthworms and insects, and is an excellent nutritive substance for plants: the rapid production of humus in the forest is therefore a kind of natural manuring. When ordinary humus in the beech forests of Europe is displaced by raw humus because of timber falls, etc., the beech is no longer capable of regeneration and disappears, being replaced by a heath.[3]

Unhumified organic material has a potential value through the possibility of its nitrification into active humus. It also lightens the soil by rendering it more pervious to air and water, and by progressive decay gives off carbon dioxide, which is the basis of carbonic acid so important in soil decomposition.

[1] E. W. Hilgard, Soils, 1907, p. 126.

[2] Muller, Natürliche Humusformen.

[3] E. Warming, Œcology of Plants, Ox. ed., 1909, pp. 62–63.

ACTION OF BACTERIA

We have as yet only briefly mentioned the action of bacteria in relation to soil nitrogen. Further discussion is required in order that the conclusions concerning the control of bacterial action may be adequately understood. Since the growth of bacteria is a large factor in maintaining the supply of some of the most important plant foods, the conditions which promote the activity of such bacteria are matters of serious interest to those engaged in the production and care of plants.

Bacteria are plants that form the simplest group of fungi and are lacking in chlorophyll. They are very minute. The largest forms may reach a diameter of 0.008 mm. (0.000352 inch), and the majority are not more than 0.005 mm. (0.000197 inch) in diameter. It is believed that some bacteria are too small to be seen even with the most powerful microscope. Though they are of small size they are concerned with almost every phase of our daily life and overcome their apparent insignificance by their incredible numbers and ceaseless activity. A fertile soil has from 500,000 to 10 million bacteria to the gram, or from 15 million to 300 million to the ounce.[1] In a drop culture of one cubic millimeter an experimenter found that one-tenth the total volume was composed of bacteria. In 24 hours, 48 generations will produce 281,500 billions of organisms.[2] They are most numerous near though generally not at the surface, decrease in numbers rapidly downward, and generally vanish at seven or eight feet. Water drawn from deep wells does not show any bacterial growth.

The functions and value of soil bacteria are variable, but the kinds that thrive in the soil are chiefly beneficial. Their action in the soil is affected by moisture, temperature, degree of comminution of soil particles, aeration, drainage, etc., besides which bacteria have associative relations with each other whose reactions may be either beneficial or harmful. Some of them decompose dead plant and animal matter into simpler compounds, reconstruct various inert materials, and thus constantly renew certain elements in the soil and maintain its fertility. It should be remembered, however, that if the conditions of food supply and environment are unfavorable harmful groups of bacteria may destroy the fertility of the soil.[3]

Humus is essentially a product of bacterial action, but this action should be carefully distinguished from the later action, called nitrification, which transforms the nitrogen of the humus into available nitrates. The formation of humus is accomplished mainly by the breaking down of carbon compounds, especially the carbohydrates of plant tissues, with the production of marsh gas or hydrogen, carbonic acid, and humus. With a surplus of air the humus-forming fermenta-

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[1] K. F. Kellermann, The Functions and Value of Soil Bacteria, Yearbook U. S. Dept. Agri., 1909, pp. 219–226.

[2] Grandeau, Ann. Sci. Agr., vol. 1905, p. 456.

[3] For Winogradsky's classification of nitrifying organisms see H. W. Wiley, Prin. and Prac. of Agri. Anal.: Soils, vol. 1, 1906, p. 557.

tion is replaced by one which results in the complete combustion of the organic matter to carbonic acid. It is largely for this reason that more humus is found in a pasture or a forest than in a continuously tilled field.

Most aerobic (oxygen-consuming) bacteria require for their well-being, or even in some cases their existence, some carbon compounds of nitrogen, and will begin to break down proteids and other nitrogen-containing materials. The products of their action, Fig. 9, are successively peptones (like leucin and tyrosin), eventually ammonia, and probably free nitrogen, but the formation of ammonia is the most characteristic effect of the bacterial fermentation of a proteid. When organic matter has decayed to the stage of such simple compounds as ammonia, nitric acid, carbonic acid, etc., it is no longer organic matter and much of it may escape from the soil altogether.[1]

Ammonia is not directly assimilable in the soil when delivered to it by the air or when occurring as the product of plant decay. The ammonia of air and soil is converted into nitrous acid by bacteria or by the oxidation produced under the influence of the catalytic activity of ferric hydroxide. The latter process takes place at a temperature of 15° to 25° C., and under its influence a certain amount of available nitrogen is developed in the soil independently of the activity of the nitrifying ferments. The conversion of ammonia into nitrates is, however, chiefly accomplished by two groups of organisms, (1) nitrosomonas or nitrosococcus and (2) nitrobacteria. The action of the first group is limited to the formation of a nitrite; the action of the second group is the oxidation of the nitrite to a nitrate. Both groups are active only upon humus and its products, and are to be distinguished from the ammoniacal bacteria (such as *Bacillus mycoides*) that effect the reduction of the carbohydrates and the oxidation of proteid compounds to humus and ammonia. The latter have wholly different habits. In general the nitrifying organisms require both organic and mineral substances for proper growth. Indeed some forms of nitrifying organisms have the power of subsisting wholly upon mineral substances.[2]

The proper conditions for both groups of organisms are somewhat definite. A fairly high temperature, 75° F., is most favorable, and there must be a certain amount but not an excess of moisture present in the soil. If the temperature is low and water is present in excess, bacterial action may be incomplete in its effects or cease altogether. This is illustrated by the preservation of leaves, stems, and seeds for thousands of

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[1] Schreiner and Shorey, Chemical Nature of Soil Organic Matter, Bull. U. S. Bur. Soils No. 74, 1910, p. 45.

[2] H. W. Wiley, Prin. and Prac. of Agri. Anal.: Soils, 1906, pp. 522–526 et al.

years in peat bogs, and by the well-known antiseptic properties of sour humus or peat. Free oxygen in large quantities is required, and there must be present a base or its carbonate, such as lime, with which the acids due to oxidation immediately unite. Sour soils exclude nitrifying bacteria through the action of the organic acids that have not been neutralized.

The neutralizing salts favorable to bacterial development are not restricted to the carbonates. Potassium chloride acts favorably up to 0.3% but suppresses nitrification at 0.8%. Earthy and alkaline sulphates act favorably up to 0.5%. Among the latter gypsum is most beneficial and accelerates the process more than any other substance known. Common salt inhibits nitrification to a notable degree, and to this fact is due in great part the absence of nitrates in low-lying seacoast tracts. Arranged in the order of their value to the nitrifying process the various substances stand as follows, taking gypsum at 100% (after Pichard).

Gypsum	100%
Sodic sulphate	47.9
Potassic sulphate	35.8
Calcic carbonate	13.3
Magnesic carbonate	12.5

The value of thorough aeration in nitrification is shown by the experiments of Deherain in which a cubic meter of soil was left undisturbed for several months while a similar mass was agitated in air once a week for the same period. At the end of the experiment it was found that the ratio of nitrogen content in the two samples was 1: 70 respectively.[1] It has also been shown[2] that the brown substances of humus and analogous compounds are directly oxidized to some extent under the influence of air and sunlight, thus forming carbonic acid. The process is purely chemical, has no relation whatever to bacteria, and is rendered more effective by cultivation, principally through the better aeration thus effected. The succession of changes through which organic matter passes in the processes of nitrification and denitrification is shown in the accompanying diagram, Fig. 9. It presents in summary form the principal changes that have thus far been described.

The immensely important conclusion has recently been established that all soils contain groups of protozoa which feed upon living bacteria and restrict their numbers, thus acting as beasts of prey.[3] Their predatory activities seriously restrict the limits of nitrogen production even when the amount of organic matter in the soil is greatly increased. Happily a remedy has been found in heating or in treatment with antiseptics. Crop increases of 30% have been effected by a 48-hour treat-

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[1] E. W. Hilgard, Soils, 1907, p. 147.

[2] Berthelot and Andre, Comptes Rendus Academie de Paris, 114, 1892, pp. 41–43.

[3] A. D. Hall, The Fertility of the Soil, Science, n. s., vol. 32, 1910, pp. 370–371.

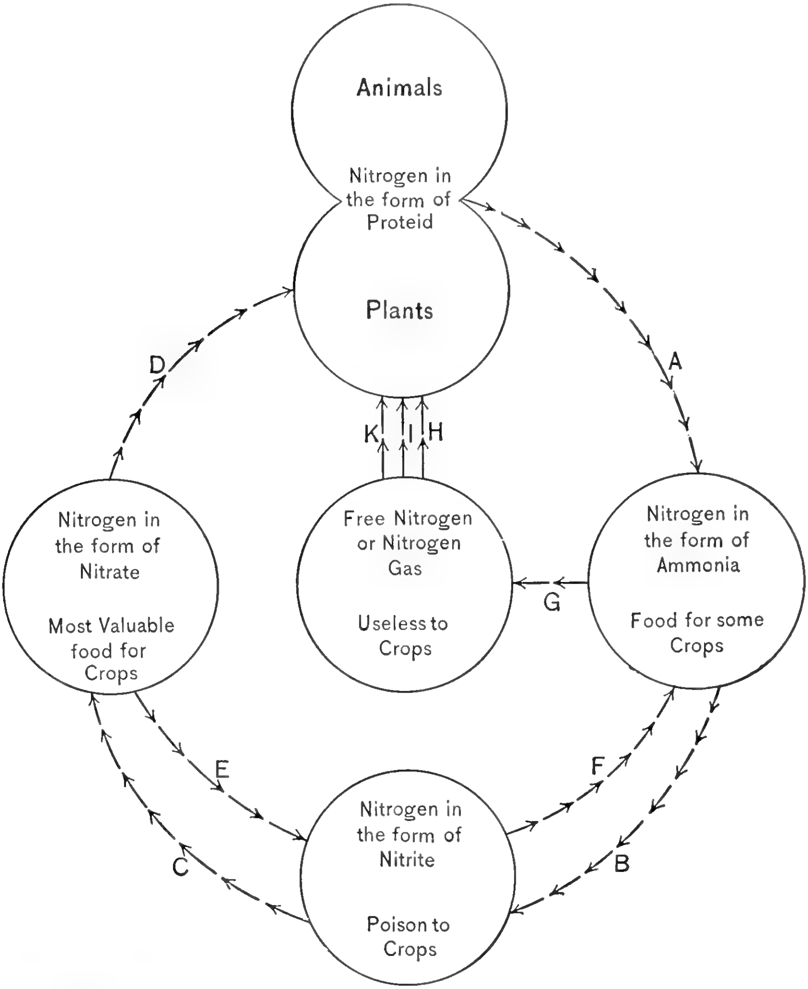

Fig. 9. — Diagram indicating the nitrogen changes in the soil produced by the action of bacteria. The arrows indicate the course of the changes which various groups of bacteria may produce in the nitrogen compounds of the soil. A, action of ammonifying bacteria which change organic nitrogen to ammonia; B, action of nitrifying bacteria which change ammonia to nitrite; C, action of nitrifying bacteria which change nitrite to nitrate; D, assimilation of nitrate by green plants; E, action of denitrifying bacteria which change nitrate to nitrite; F, action of denitrifying bacteria which change nitrite to ammonia; G, action of denitrifying bacteria which change ammonia to nitrogen gas; H, action of bacteria which change nitrogen gas into proteid nitrogen; I, action of bacteria which in symbiosis with leguminous plants change nitrogen gas into proteid nitrogen; K, action of bacteria which in symbiosis with certain non-leguminous plants change nitrogen gas into proteid nitrogen.[1]

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[1] Yearbook, Dept. Agri., 1909, p. 222.

ment of the soil with vapors of toluene, chloroform, etc., followed by complete volatilization of these antiseptics. Analyses of the plant material so produced shows an assimilation of greater amounts of other plant foods as well as of nitrogen. It follows that the extra growth does not represent mere temporary stimulation but an absolute increase in the available stores of plant food. While great numbers of bacteria also succumb in the application of the remedial measures, some of them escape, and these, immune from attack, increase at a prodigious rate and almost at once increase the soil fertility.[1]

Several species of bacteria have the power of direct fixation of nitrogen from the soil air. Some of the most important of these bacteria are *Clostridium pasteurianum, Bacillus alcaligenes, Bacillus tumescens, Pseudomonas radicicola,* Granulobacter and several species of Azotobacter.[2] The abundance of these bacteria in the soil seems to indicate the measure of the natural nitrogen-recuperative power of the soil. In the coastal-plain soils the genus Azotobacter occurs only in the surface layer of a few inches; in the deep and almost exhaustless soils of certain sections of the West the same genus is found in active condition even down in the fifth foot below the surface. While most investigators attach considerable importance to the direct fixation of nitrogen, Hall considers that it is yet to be ascertained if the direct fixation of nitrogen by bacteria has any very important part in re-creating the store of uncombined nitrogen in the soil.[3]

An interesting and elaborate series of experiments by Lipman[4] makes it seem likely that *Azotobacter chroococcum* has the power of fixing atmospheric nitrogen when in symbiotic association with certain green algæ with which it is commonly found and which develop with great rapidity upon limestone soils. It has also been shown by Lipman that *Azotobacter vinelandii* does not require symbiosis with algæ to fix atmospheric nitrogen, but that a mixture of it and another bacillus (No. 30) caused a doubling of the nitrogen development.

Certain bacteria have nitrogen-fixing power when in symbiotic association with various legumes such as clover, etc., and accumulate large amounts of soluble nitrates which are ultimately used by the host plant.

[1] There are also present in the soil anaerobic or denitrifying bacteria whose life functions are not dependent upon the presence of air since they are able to avail themselves of combined oxygen by reducing the oxides present in the soils. Some of them cause the reduction of nitrates to nitrites and finally to ammonia as shown in Fig. 9. Such reductive processes are carried on by *bacillus denitrificans* I, and occur chiefly in soils rich in organic matter or badly aerated. The result is a loss of nitrogen and a depletion of the plant food in the soil.

[2] Yearbook Dept. Agri., 1909, p. 225.

[3] A. D. Hall, The Soil, 1907, p. 171.

[4] Rept. Agri. Exp. Station, New Jersey, 1903–1904.

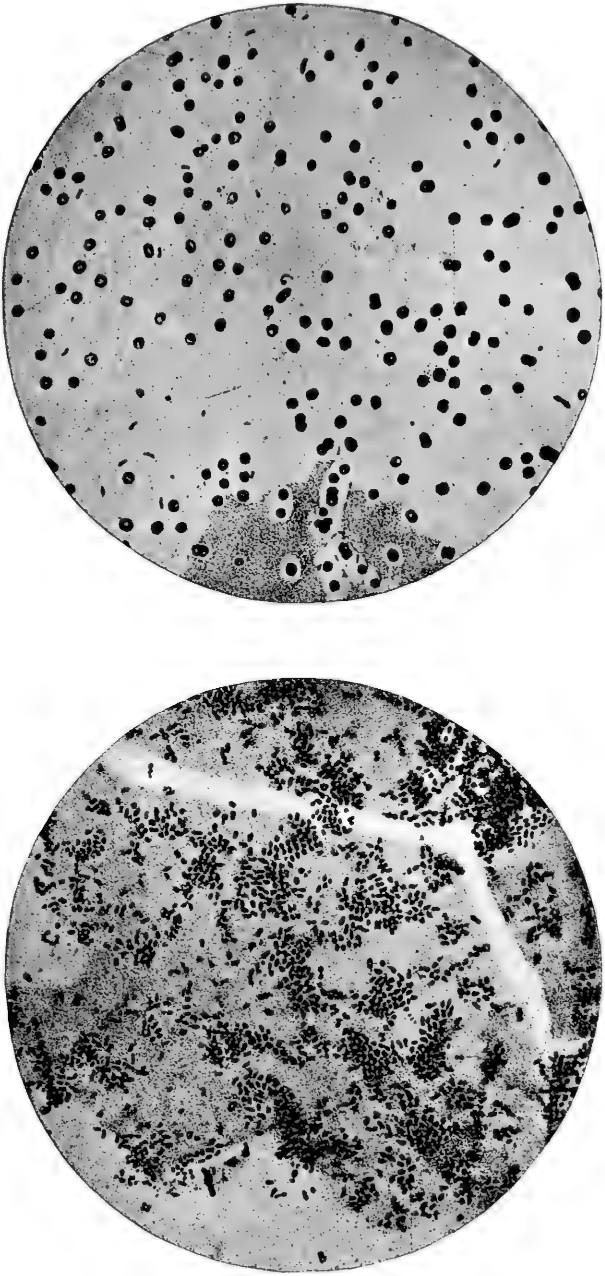

Fig. 10. — Upper figure represents nitrous ferment prepared by Winogvodsky from soil from Cito Lower figure represents nitric ferment from the same source. (Wiley Soils.)

The bacteria live as parasites within the roots of the host plant from which they derive their carbohydrate food supply. The presence of the parasites stimulates the development, by the root, of the peculiar swellings known as root nodules or root tubercles. These become filled with a bacterial mass consisting principally of swollen and abnormal (hypertrophied) "Bacteroids" having forked outlines, but in part also of bacteria which remained in their normal condition.[1] For a time the nodule increases in size and the bacteria continue to furnish a steady supply of nitrogenous material to the host plant. Ultimately the nodules cease growing, the Bacteroids degenerate, and their substance is absorbed by the host. Normal bacteria, however, remain and provide for future reproductions.

When the root nodules cease growing the larger group of bacteria, called also bacteroids, gradually collapse and are then depleted of their nitrogenous substance. The bacteria capable of this action draw their supply of food largely from the plant with which they grow in symbiotic relationship. It follows also that when the plant becomes seasonably inactive the bacteroids also become inactive for a season; they are found only upon actively growing roots and not upon the roots of dead legumes.

A fourth process of nitrogen fixation is by symbiosis, in which the plant involved is one other than a legume. Whether this process has any practical value remains to be determined, but bacterial nodules have been found upon at least one species of Alnus (alder), upon *Ceanothus americanus* (red root, New Jersey tea), *Ceanothus velutinus*, *Elaeognus argentea* (silvery berry), *Shepherdia argentea* (buffalo berry or rabbit berry), *Podocarpus macrophylla*, and several genera of the cycads, though the nodules of the latter group of plants are quite different in some ways from the nodules of legumes.[2]

One investigator concludes that the property of utilizing atmospheric nitrogen belongs to many other plants than the legumes.[3] He contends that in all the plants examined by him structures were found which are capable of absorbing it from the air and transforming it into the organic state. The chlorophyll cell seems to possess this power to a high degree. It absorbs free nitrogen and transforms it into organic compounds. Certain organs, called producers of nitrogen, occur in the tender parts of very young leaves or their petioles. But the whole matter of such utilization by non-leguminous plants requires much further work before these broad conclusions can be accepted.

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[1] Strasburger, Noll, Schenk, and Karsten. A Text-book of Botany, 3d Engl. ed., 1908, p. 232.

[2] K. F. Kellermann, The Functions and Value of Soil Bacteria, Yearbook Dept. Agri., 1909, p. 226.

[3] Jamieson, Rept. Agri. Research Assn. of the Northeastern Counties of Scotland, 1905, p. 16.

It has been fairly well demonstrated that forests are able to appropriate free nitrogen by means of their trichomes.[1] In a large number of chemical tests conducted in such a manner as, it is believed, to exclude all other sources of nitrogen than the atmosphere it was found that nitrogen is always present in the trichomes. Among the forest trees that have been tested are *Acer campestre, Tilia europaea, Ulmus campestris, Sorbus Aucuparia, Fagus silvatica,* and *Abies concolor.* The process is one of unusual interest, for it adds one more to the very brief list of means by which nitrogen is made available as a plant food. This statement should not be taken to indicate that plants in general are capable of fixing nitrogen. The experiments of two Rothamsted (England) investigators, Lawes and Gilbert, and of Boussingault in the middle of the nineteenth century are very conclusive in their determination of the inability of cultivated plants to fix atmospheric nitrogen except in symbiosis with nitrogen-fixing bacteria.[2] The decay of forest litter and its transformation into nitrates by bacterial means are the chief processes that supply nitrogen in forested areas.[3]

ACTION OF FUNGI

Contributing to the general store of humus in the soil are a large number of fungi among which are Penicillium, Mucor, Aspergillus, Oidium, etc.[4] They take a prominent part in the conversion of vegetable matter into black neutral insoluble humus, a process that is always marked by the formation of carbon dioxide. It is always found that both the fungous tissues and the humus resulting from their decay are notably richer in nitrogen and carbon than the higher plants. These organisms are found about decaying roots and plants, though they are not confined to this occurrence. Their tiny fibrils or hyphæ are scattered through the ground much more thoroughly than even the tiniest rootlets with which they are associated. It is this thorough distribution that makes their presence so important in soil fertility, for it results in a correspondingly wide dissemination of the humus to which the fibrils contribute. Their life functions are dependent upon air, so that thorough aeration promotes their activity and increases their number; it follows that they will be most numerous near the surface and that

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[1] T. Cleveland, Jr., Forests as Gatherers of Nitrogen, Science, n. s., vol. 31, 1910, p. 908.

[2] A. D. Hall, The Soil, 1907, p. 162.

[3] Warming suggests mutual reactions between plants as possible sources of nitrogen. "Experience has shown that where *Picea excelsa* has been planted in Jutland it flourishes better in company with *Pinus montana* than without it. It is probable that in this case the mountain pine provides the spruce with nitrogen."

[4] A. D. Hall, The Soil, 1907, p. 182.

the nature of the soil drainage will determine their maximum depth or even their very existence.

From the standpoint of the forest it is fortunate that these growths are not confined to decaying vegetation. They infest the roots of a large number of trees and shrubs and enable the latter to assimilate indirectly the decaying organic and inorganic matter that would otherwise be unavailable. They are in symbiotic association or coöperation with pines, firs, beeches, aspens, and many other forms, all of which appear to depend very largely for their healthy development upon such association.[1] The degree of dependence of the host plant upon the fungoids that inhabit it is emphasized by Frank, who says that some host plants are so dependent upon this relation to obtain the necessary carbon from the humus that they possess no green carbon-assimilating foliage, a condition illustrated by the *Neottia nidusavis* or Bird's-Nest Orchid found among beech underwood in England. The action requires close association of host plant and fungus, and in some cases the fungus penetrates the cortical tissue of the root or forms a sort of cap on the ends of the smallest and shortest rootlets.[2] The association, when it results in the supplying of the host plant with mineral substances, is especially characteristic of plants that grow in soils subject to drought or poor in mineral salts or rich in humus. In general those plants that have feeble transpiration capacity are well supplied about their roots with fungus through which they obtain food of many kinds from the soil. Such plants have also a very limited starch development in the leaf. Fungi may be harmful in their action when they rapidly transform the plant food into available form and produce such large amounts as to cause the excess to be removed by solution, so that a luxuriant but short-lived growth occurs, as in the "faery rings" common in poor pastures.[3]

[1] E. W. Hilgard, Soils, 1907, p. 157.

[2] A. D. Hall, The Soil, 1907, p. 183.

[3] Idem, pp. 184–185 and 219.

CHAPTER VII

SOILS OF ARID REGIONS

General Qualities

The rainfall of arid regions is insufficient to leach out of the soil the salts that tend to form in it during the progressive weathering of the rock. In humid regions where the rainfall is abundant these salts are leached out and pass in very dilute form through springs and streams into the sea, and relatively small portions of the salts formed by weathering are retained in the soil and utilized by plants. It follows that when the degree of aridity is variable the salt of the soil will be variable in kind and amount and that in extremely arid regions practically the entire mass of salts contained in the rocks remains in the soil.

We have already seen that arid soils are potentially more fertile than humid soils, for abundant rainfall in the latter case leaches the soil of valuable fertilizing elements that are easily soluble. In arid regions these elements are retained in the soil and many of them are very productive. To this advantage is added the greater number of bright clear days in arid regions and a maximum of insolation. The favorable features of arid soils are illustrated by the bench lands about San Bernardino, which are fertile, warm, equable in temperature, free from alkalinity, and, where water can be directed upon them for irrigation, among the most valuable agricultural lands in the United States.[1]

The most striking characteristic of the soils of arid regions is the uniformly high percentage of lime and, as a rule, of magnesia, no matter what the underlying geologic formations happen to be. This condition is all the more apparent in the United States because of the general absence of limestone formations in the more arid portion of the country west of the Rocky Mountains and the wide distribution of such formations east of the Rocky Mountains. No matter what the formation is, whether it is the granite of the Sierra Nevada foothills, the eruptives of the coast ranges of California and Oregon, or the great basalt sheets of Idaho and Washington, they are all alike in producing soils with a high lime content.

It is largely to the high percentage of lime that the flocculated condition of arid soils is due. This is one of their notable characteristics,

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[1] W. C. Mendenhall, The Hydrology of San Bernardino Valley, Cal., Water-Supply Paper, U. S. Geol. Surv. No. 142, 1905, p. 17.

and is related to the great depth of root penetration and easy tillage in arid lands.

While in humid regions the average nitrogen content of soil humus is less than 5%, in the upland soils of arid regions the percentage rises as high as 22%, with a general average between 15% and 16%. This is probably due both to the presence of the lime which keeps the acids that tend to form in the soil completely neutralized, and to the deficiency of vegetable matter which allows more complete nitrification than when an excess of such matter is present. The absence of an abundance of vegetable matter in the surface soil and of other qualities that differentiate it from the subsoil is a distinguishing character of arid-region soils. Subsoil and surface soil have no sharp line of separation either in fertility or general appearance or composition. The decomposed state of arid subsoils, the absence of that rawness that characterizes humid subsoils, and the possibilities of their utilization are shown by the manner in which quick growths of yellow pine (*Pinus ponderosa*) appear in the placer mines of the foothills of the Sierra Nevada of California where the subsoil was thrown out years ago and became the surface soil. The timber growth is now of sufficient size to be used for mine timber and a second young forest is springing up on the red earth which once appeared as barren as the desert.[1]

In the case of the relatively insoluble ingredients of the soil such as quartz or silica, the substance making up the greater part of sand, the humid region contains the larger amount, 84%, as compared with the 69% of the arid region where other substances exist in greater proportions. So that while sand of humid regions ordinarily consists of a collection of quartz grains with relatively clean surfaces, in arid regions it consists of a great variety of minerals in a partially decomposed condition. Mixtures of fine and coarse particles at the surface are also more common in arid than in humid soils, due to the absence of thorough sorting in water. Thus the soils of arid regions often have uniform physical and chemical characters to a great depth.

Scantiness of rainfall in arid regions effects a great retardation in the rate at which clay forms from feldspathic rocks and the sediments derived from them. This is shown in the distribution of two broadly different soil types in the eastern wet and western dry portions of the country. The soils of the Atlantic slope are prevalently loams and contain considerable clay; the soils of the arid region are generally sandy or silty with a small amount of clay unless derived directly or indirectly from clay or clay shales.

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[1] E. W. Hilgard, Soils, 1907.

The amount of phosphoric acid contained in the soils of arid regions is not different from that contained in the soils of humid regions. Phosphorus is a substance tenaciously retained by all soils and appears to be independent of leaching. On the other hand the leaching process has such a marked influence upon the compounds of the alkaline metals, potassium and sodium, which are readily soluble in water, that the ratios of their percentages show a marked difference in humid and in arid regions. The average ratio for potash is .216% to .672%, the ratio for soda is .140% to .420%. Potash occurs in greater abundance than soda in all soils because it is tenaciously held through reactions effected by zeolitic compounds in which soda is wholly or partially displaced when brought into solution with a potash compound, so that soda accumulates only where the rainfall or drainage is insufficient to effect proper leaching; in such places it results in what is generally known as an alkali soil. Potash is therefore relatively abundant in arid soils and is one of the last substances added to them for increasing their productivity. They rarely contain much less than 1% of acid-soluble potash, occasionally rising as high as 1.8%.

Among the most notable differences in the composition of arid and humid soils is not only the smaller amount of humus found in arid regions but also the relatively higher nitrogen content of the arid-soil humus. On the average, the humus of arid soils contains about 3½ times as much nitrogen as the humus of normal soils and in extreme cases the amount may be 6 times as great, in which case the nitrogen percentage in the arid humus considerably exceeds that of the albuminoid group, so that in arid regions a humus percentage which in humid regions would be considered quite inadequate may be considered entirely sufficient for all crop demands.[1] In arid regions the substance that first requires replacement is phosphoric acid, the second is nitrogen.

ALKALI SOILS

For reasons already stated in connection with the higher percentage of soluble salts in arid regions, certain tracts may under special topographic and drainage conditions develop alkalinity, a condition due to the presence of three compounds which usually form the main mass of the salts — the sulphate, chloride, and carbonate of sodium. Among these, calcium sulphate is nearly always present, magnesium sulphate (Epsom salt) is in many cases very abundant, and calcium chloride is present occasionally. The composition of a more or less typical alkali soil in California is shown in the subjoined table.[2]

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[1] E. W. Hilgard, Soils, 1907, p. 138.

[2] Hilgard and Weber, Bull. Cal. Agri. Ex. Sta. No. 82, p. 4. Quoted by Wiley

TABLE SHOWING COMPOSITION OF ALKALI SALTS IN SAN JOAQUIN VALLEY

	Tulare County					
	Goshen	People's Ditch	Near Lake Tulare	Visalia	Lemoore	Tulare Expm't Station
	Surface Soil	Alkali Crust	Surface Soil	Surface Soil	Alkali Crust	Alkali Crust
Soluble salts in 100 parts soil	1.40	....	0.83	1.26	....	....
Potassium sulphate	....	....	....	....	....	small
a Potassium nitrate	....	....	....	....	....	small
Potassium carbonate (saleratus)	....	....	....	18.80	....	....
Sodium sulphate (Glauber's salt)	44.24	1.22	31.30(*n*)	13.4	chiefly	32.8
Sodium carbonate (sal soda)	32.98	88.09	18.2	45.3	....	13.16
Sodium chloride (common salt)	16.74	1.00	....	4.4	little	31.16
a Sodium phosphate	1.97	....	0.22	10.4	....	....
Calcium sulphate (gypsum)	....	....	....	....	little	....
Magnesium sulphate (Epsom salt)	....	....	....	8.1	moderate	....
Organic matter	1.97	9.21	7.5	....	....	5.37

a Very generally present, but not always in quantities sufficient for determination.

Alkali lands are so widely distributed in the desert regions of the world[1] that the problem of their improvement and utilization for agriculture is of great importance. These lands when properly treated have great fertility on account of the many soluble plant foods in them, and they may in many places be turned from waste lands to fertile oases. Their natural vegetation is of little value except in a few cases, as the salt bushes and wild clover of South America and Australia, which form valuable pasture. Considerable areas of alkali lands are either destitute of vegetation or bear resistant growths of little value as forage. The effects of sodic carbonate on plants grown in alkaline regions are seen in a scant leafage, short growth of shoots, and a deadening of the roots. The cortex assumes a brownish tinge just above the surface in the case of green herbaceous stems, and, in the case of trees, the outer bark assumes an almost black tint and the green layer underneath turns brown. The maximum injury is usually at or near the surface, where there is a maximum accumulation of salts, due to evaporation at the surface. The vertical distribution of the alkali salts in a California soil is shown in the diagram below, Fig. 11.[2]

Certain native plants that live upon alkali soils have adapted their root systems to a very interesting condition. Figure 11 shows that down to a depth of 15 inches there is practically no alkaline content; and it is within these 15 inches of soil that the native plants develop their roots

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[1] The total area of the arid lands of the world computed from the total area of interior basin drainage is given by Sir John Murray as 11½ million square miles, or one-fifth of the total land surface of the globe — The Origin and Character of the Sahara, Science, vol. 16, 1890, p. 106.

[2] E. W. Hilgard, Soils, 1907, p. 432.

and develop their growth. The bulk of the salts accumulate at the greatest depth to which the annual rainfall of seven inches reaches, where it forms a hardpan. It is above this hardpan that the seeds of the shallow-rooted plants germinate and extend their roots. The soil moisture of the surface layer is so thoroughly consumed by the plants that no alkali is brought up from below by evaporation and the life cycle begins the following season. It is in this manner that the luxuriant vegetation of the San Joaquin plains is maintained except where occasional alkaline spots occur. The horizontal distribution of alkali is variable and the location of the salts changes from year to year, especially in irrigated lands, so that the cultivation of alkali lands, the determination of their position, etc., must be carried on with great care.

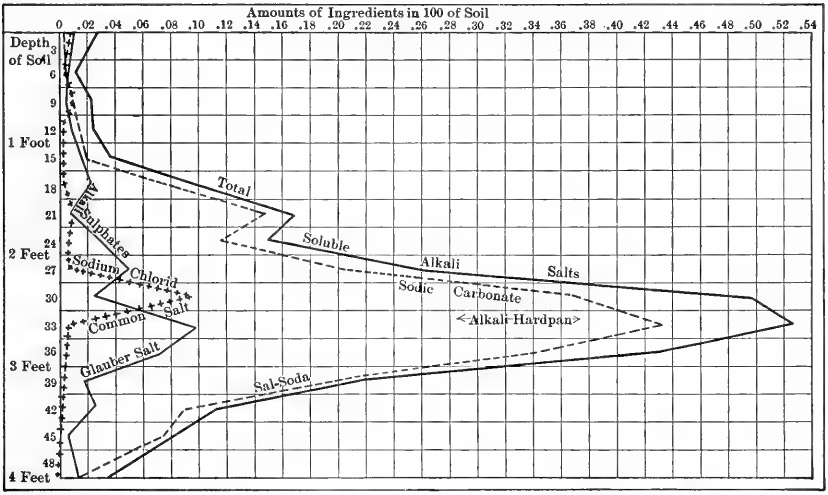

Fig. 11. — Amounts and composition of alkali salts at various depths in black alkali lands covered with native vegetation. (Hilgard, Soils.)

Two types of alkali soils are noticeable: the one is due to the presence of carbonate of soda and is called black alkali; the other is due to the presence of the sulphates and chlorides of sodium, and is called white alkali. The latter is much milder in its effect on plants. In California, outside the main valleys no important amounts of alkali salts are found at depths exceeding four feet. The total amount found in alkali lands which show saline efflorescences at the surface in the dry season is from one-tenth of one per cent to as much as three per cent of the weight of the soil taken to a depth of four feet. Alkali lands also have a high lime content and a high potash content — higher than the average amount of phosphates; while nitrates are usually scarce or altogether absent, though nitrates may occur along the margins of the alkali spots.[1]

In sloping valleys or basins where the central lowest portion receives the salts leached out of the soils of the adjacent slopes, occur belts of variable width in which the alkali impregnation may reach to a depth of 10 or 12 feet. Such areas are, however, quite limited and irreclaimable, and the predominating ingredient is usually common salt, as is illustrated in the Great Salt Lake basin of Utah, in the Antelope and Perris valleys of southern California, and the Yellowstone Valley near Billings, Montana.[2] The salts of alkali lands are not permanent in their vertical position but follow the movement of the moisture, descending in the rainy season to the lower limit of the absorbed rainfall, and reascending in response to surface evaporation, so that at the end of the dry season a saline efflorescence may occur or the entire mass may be found within a few inches of the surface.

Carbonate of soda exercises a puddling action on the soil, destroys its crumb structure, and renders it almost untillable and impervious. It also tends to form a tough impervious hardpan as resistant to roots as to implements. Hilgard has shown that the proper treatment of alkaline soils is leaching (after treatment with gypsum in the case of black alkali), together with subdrainage. Flooding alone is not sufficient, for if the process is carried on generally the alkali spots grow larger to the destruction of adjacent lands. If coöperative subdrainage is carried out the salts may be entirely removed by an excess of irrigation water or be carried down to so low a level as to have no injurious effect upon plants. The amount of alkali in the soil may be diminished also by cultivating plants that take up considerable amounts of salt, — a notable property of the greasewoods (Sarcobatus, Allenrolfea), which contain from 12% to 20% of alkaline ash. When grown upon the land and then cut and removed, such plants will markedly diminish the amount of alkali in the soil. A few such salt-consuming plants are fit for pasture, such as the Argentine plant (*Atriplex chachiyuyun*) and the Australian salt bushes (*Atriplex halimoides*), Vesicaria and Leptocarpus, and a Chilean plant (*Modiola procumbens*). The results of the reclamation experiments of the U. S. Bureau of Soils are surprisingly good and indicate the range of possibilities in regard to the use of alkali lands.[3] Tracts originally covered with a white crust of alkali and

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[1] E. W. Hilgard, Soils, 1907, pp. 439, 444, 448.

[2] Farmers' Bull. U. S. Dept. Agri. No. 88, 1899.

[3] For specific descriptions of the localities where alkali soils have been experimentally improved and reclaimed, see C. W. Dorsey, Reclamation of Alkali Soils, 1907, and Reclamation of Alkali Land in Salt Lake Valley, Utah, Bull. U. S. Bur. Soils No. 43, 1907.

supporting a scanty growth of greasewood were sweetened by flooding and drainage and then sown to alfalfa, various vegetables, grains, etc., with very beneficial results.

The accumulation of mineral salts at or near the surface has given rise to the formation in most arid regions of a characteristic deposit known as "caliche." It often consists of a variety of substances, but the most common constituent is nitrate of soda. The greatest deposit of this sort is found in Chile in the province of Tarapacá, where nitrate of soda is produced on a very large scale, practically the whole of the world's supply being derived from this desert region. Smaller tracts are found in many other deserts, notably in the Southwest as in Death Valley, California, but the scale of production in all these cases is decidedly limited. In general the layer of caliche is covered with a deposit of earth from a few inches to a few feet in thickness. It may consist in part of wind-blown material, in part of water-laid material deposited since the caliche was formed. The largest beds of caliche are probably due to the crystallization of mineral salts from bodies of water which have disappeared either through a change of climate or a change in the level of the land or both. The origin of this class of material is, however, still in doubt, and although the result is closely allied to aridity it is not yet clear what combination of arid conditions with topography, drainage, and chemical character of rock and vegetation brings about its existence.

CHAPTER VIII

SOIL CLASSIFICATION

It has been generally agreed among soil investigators that because of the predominating influence of physical characteristics in soil fertility, physical and not chemical qualities shall be made the basis of soil classification. This decision is strengthened by the immemorial custom among agricultural folk of designating soils principally by their physical character. The terms *sand*, *gravel*, *clay*, etc. (or their equivalents), are common non-technical words which convey a fairly definite meaning the world over. When, however, a soil is to be scientifically investigated, its characters strictly defined, and its value and its needs formulated, somewhat precise terms must be employed, careful experiments conducted, and conventional symbols devised which have stricter meanings than the colloquialisms of the farmer. Hence a relatively refined classification has been elaborated, based primarily upon physical character. In examining the accepted classification we should not lose sight of the fact that while the forester must acquaint himself with it in order to make the literature of soil investigators serve his purpose, he generally requires for ordinary field work a somewhat rougher scheme of classification. Gravel, sand, silt, clay, and peat or muck are the main types he is required to recognize, modifying his choice of terms by mention of such secondary qualities as the soil of a particular locality exhibits. He will also be required to distinguish between various grades of gravel, sand, etc., as coarse, medium, and fine, and it is obviously to his advantage to employ for these subdivisions the basis employed by soil specialists, in so far as this is possible.

In determining the sizes of soil grains a number of methods may be employed; the three principal ones are (*a*) sieving the soil samples, (*b*) elutriating them, and (*c*) separating the various grades by the subsidence method.

(*a*) The sieves used for soil analyses have round holes of carefully determined diameter. The unit employed may be fractions of an inch, but the smaller units of the metric scale (millimeters) are decidedly preferable both because of their international acceptance and their easy use in computations. The soil samples are sifted after being rubbed so as to destroy the lumps or soil crumbs composed of both fine and coarse material that behave in some respects as large individual particles the size of the lumps. Separation may be more easily accomplished by playing water on the sieve; without it the clay particles and even the silt particles tend to cling to the sand as soon as the grain sizes in the latter fall much below ½ mm.

(*b*) The elutriator, Fig. 12, is an instrument employed to separate soil grains of different sizes (after removal of the clay by subsidence) by an ascending current of water at various fixed velocities. The soil grains are carried off in exact conformity to their several sizes or volume weights. The maintenance of the current at a fixed velocity for a long enough period will result in the practically complete removal of all grains below a certain size. The different velocities are adapted to certain desired grain sizes, and the volumetric determinations that follow elutriation form the basis for classification.

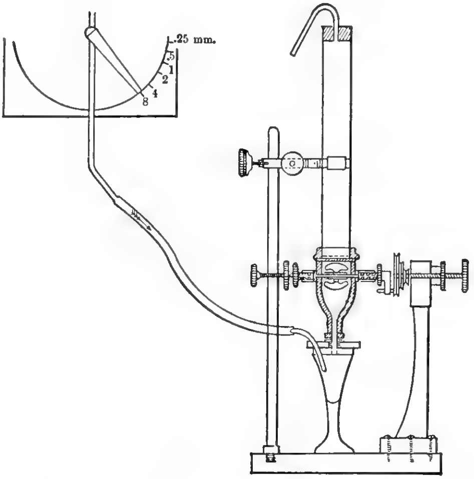

Fig. 12.—Elutriator (Hilgard's) in position for soil analysis.

(*c*) The subsidence method is based upon the assumption that if a soil sample is thoroughly mixed in water the different grain sizes will settle according to their weights. A successful outcome requires the removal of the clay by repeated sedimentations of the non-clay material, the decantation of the water in which the suspended clay particles are held, and the final sedimentation of the coarser grades. The necessity for the removal of the clay is due to the greater viscosity of the water in which the clay is suspended and its interference with normal and accurate sedimentation. The clay itself is determined from the several clay waters by evaporation of the water. Precipitation will not suffice, for the finest colloidal clay will not subside for years,—a condition thought to be due to a change in its physical and possibly in its chemical nature.[1] A defect of the subsidence method is the impossibility of abstracting all the clay, a defect the more serious because of the high importance of the

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[1] W. H. Brewer, On the Suspension and Sedimentation of Clays, Am. Jour. Sci., vol. 29, 1885, p. 1.

clay constituent of soils (p. 35). Some clay particles are invariably carried down by heavier constituents and deposited with them. A similar result does not occur in elutriation because of (1) the agitation (which prevents flocculation into heavy aggregates) of the ascending current and (2) the grain sizes are expelled in reverse order, the finest first, and so on.

PURPOSE OF A SOIL ANALYSIS

The physical analysis of a soil is not alone for the purpose of finding a name for it in the series proposed in the table, Appendix A. This is the least of its purposes. It aims, in addition, clearly to present the controlling constituent among the soil grains. Soils are not generally composed of grains rather equally distributed among the several sizes. Some particular size usually predominates, and gives the soil its strongest individual character. This is clearly illustrated by the Volusia soils spread over some 10,000,000 acres of western Pennsylvania, southern New York, Ohio, and West Virginia. They are poor in their present condition, yet nothing in their chemical nature suggests poverty. Their unproductiveness is due largely to improper drainage, for their physical composition is such that the natural drainage is not adequate; acid therefore forms and accumulates and makes the soil sour. Their improvement is not to be sought in the use of fertilizers alone, for the fine-grained fertilizers by themselves would still further clog the soil pores. It is suggested that adequate drainage and deep aeration would prove remedial.[1]

The remedies proposed are particularly interesting because they are among the relatively small number which the forester finds it possible to apply to economic advantage over large areas. The forester can not fertilize the ground by the application of manures or mineral fertilizers; the very scale of his work makes it impossible to do more than enable a forest soil to improve itself by encouraging processes already in action. This he is able to do in many ways. Proper cutting and seeding or replanting are almost always possible in both the physical and the commercial sense of the term, and by maintaining shade the drying of the surface soil, in which seedlings make their first growth, is prevented. Proper drainage is also feasible and is at once a means of partly controlling the kind of growth and the rate of growth.

It is fundamental in drainage to ascertain the nature of the subsoil as well as the soil. If the subsoil is open and porous it is likely to be dry; if clay forms the subsoil it will probably be wet and by capillarity

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[1] M. E. Carr, The Volusia Soils, Bull. U. S. Bur. of Soils No. 60, 1909, pp. 21–22.

supply the surface soil with water in the dry season. Not only for this reason, but also because so important a part of the root systems of trees occurs in the subsoil, is it necessary to secure data as to its nature and its effects upon the surface soil in different seasons.

Different Bases of Soil Classifications

It is unfortunate that no general scheme of classification has been universally adopted by soil physicists. In Appendix A the scheme of the U. S. Bureau of Soils is described because the literature of this Bureau is now both extensive and valuable and reference to it indispensable on the part of any one beginning the study of the soils of a given region. Nevertheless it should be noted that many other bases of subdivision of soil types are in vogue. It has been proposed by Hilgard and others, that all constituents of soils that are too large to pass through a sieve with meshes 0.5 millimeter in width should be called the "soil skeleton" and that the remaining constituents that pass through the sieve should be called "fine earth." He regards the fine earth as having a special relation to plant life as food material and through its physical attributes. For the purposes of ecologic studies Warming distinguishes six different kinds of soil as follows[1]:

Rock soil.
Sand soil.
Lime soil.
Clay soil.
Humus soil.
Saline soil.

Soils may be distinguished also by classes, as rigid, stiff, mellow, lax, loose, and shifting, in order to express various grades of compactness. Hilgard suggests the use of broad types such as sand, clay, and humus.

Considered in reference to their origin, soils may be classified as sedentary and transported. A sedentary soil may then be either residual where it remains upon the rock from which it was derived or colluvial where it is subject to slow down-hill movement on hill slopes. Transported soils may also be divided into alluvial where the soil is deposited on bench lands or flood plains, and eolian where it is deposited by the wind. The most common classification is based on texture, as gravel, sand, silt, clay, and their subdivisions and derivatives. Again, soils may be called humid or arid according as they are formed in one or the other of these climates. Or a soil may be classified according to its chemical properties. Thus, we have a lime soil with its lime-loving vegetation, or a magnesium soil, or a soil exceptionally

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[1] Œcology of Plants, Ox. ed., 1909, p. 60.

rich in potash or gypsum. A classification based on the distribution of vegetation is often helpful but the soil requirements of plants are not rigid except in the case of extreme types of soils and plants. Doubtless the physical classification has the widest practical importance since physical features most commonly have a fundamental control over vegetation and are the most unchangeable. The ideal classification would be adaptable to, and would take cognizance of, all important soil characters. It is at least certain that no single scheme is applicable to all kinds of soils in all kinds of climates.[1]

With this brief suggestion of the nature of other classifications in mind the student is referred to Appendix A for a description of a suggested outline of a soil survey with such description of the field methods required as bear on soil studies practicable in forestry.

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[1] Hilgard and Loughridge, The Classification of Soils, Verh. der II Int. Agrogeologen-conferenz, Stockholm, 1911.

PART TWO

PHYSIOGRAPHY OF THE UNITED STATES

CHAPTER IX

PHYSIOGRAPHIC REGIONS, CLIMATIC REGIONS, FOREST REGIONS

INTRODUCTION

PHYSIOGRAPHY is indispensable to the environmental study of organisms of every kind, whether trees, or men, or bacteria. Soil, topography, and climate are positive forces in the development of forests and the harvesting of forest products. They underline the main possibilities as well as the main limitations of nature. We have already seen that soil in at least small amounts is a necessary condition of tree growth; of the same order of importance are the facts that the broader forest distributions depend upon climate, while the accessibility of forests depends to a large extent upon topography. It is doubtful, for example, whether some of the best timber of the Sierra Nevada will ever be harvested because of topographic difficulties — steep canyon walls, sharp spurs, and remoteness from transportation lines. Climatic conditions exclude trees from the larger part of the arid and semi-arid West and from the higher, colder, and windier parts of the western mountains. Forests are excluded also from great areas of bare rock outcrop in regions of glacial denudation or from soils rendered infertile by extreme physical or chemical properties. The forester must take account not only of these relations but also of the larger relations of forests to stream flow and soil erosion. Each soil type has its own peculiar water-holding or water-shedding capacity, each topographic province has certain slopes upon which either agriculture or forestry can or can not be conducted, each natural region has its own climatic possibilities and restrictions, a study of which enables the forester to improve natural conditions and repress harmful forces to the benefit of mankind.

It is our purpose in these pages to present the physical basis of forestry in the United States. No attempt is made, however, to discuss either regional ecology or the principles of ecology. The ecology of the forest is regarded as a subject which possesses a body of facts and laws of its own. The single object of this book is to acquaint the forester with the geographic basis of his work, with such references to the forest as point the direction of his more special subjects.

This attitude should be appreciated here, lest the organization of the following chapters be misunderstood. For example, a forester requires a certain group of physical data in developing, let us say, the forests of the Black Hills. It is our object to discuss not the silvicultural or lumbering methods best adapted to the Black Hills and the relations of these to the physical geography of the region, but to make the student so familiar with the geography that a knowledge of it may be assumed when he begins a study of the forestry.

Physiographic Regions

The description and explanation of any large and varied portion of the lands proceed naturally by subdivisions, each subdivision embracing a tract in which the topographic expression is in the main uniform. Since uniformity of topographic expression is achieved only when geologic structure, physiographic process, and stage of development in the geographic cycle are also uniform, each subdivision has an essential uniformity or unity of geologic and physiographic conditions. It is customary to speak of each subdivision as a natural region or province, and to bound each region by lines which represent the limits of unity. In some cases the boundary lines are very precisely located, as along the eastern edge of the Allegheny Plateau in Pennsylvania, or the western edge of the Colorado Plateaus in Arizona, where great scarps mark out sharply defined borders; in other cases the transition zone between provinces is relatively wide and has characteristics which partake of the nature of both adjoining provinces, as between the Columbia Plateau of southern Oregon and the Great Basin south of it.

It must not be supposed that the idea of physiographic unity is applied in an absolutely rigid manner. Some of the physiographic provinces appear to have great topographic variation and but little unity. In such cases it appears at first sight impossible to group the forms in a rational manner until soil, climate, topography, and geologic structure are all examined, when prevailing or group characters always become apparent. Exceptions to group qualities are often observed, and in some cases these are of great importance, but on the whole they affect only the minor physiographic features. Thus the northern Rockies of Montana and Idaho are in striking contrast to the high plains on either side, — the Columbia lava plain of Washington on the west and the Great Plains of Montana on the east. This contrast between a belt of high, rugged mountains and gently rolling, bordering plains forms a primary basis for subdivision. Nevertheless the traveler in crossing the northern Rockies finds the landscape changing continually. Everywhere the ranges trend in the same general direction, but the kind of rock, the structure and hardness of the rock, and the kinds of dissection affecting the range masses vary from point to point; everywhere the major valleys have a distinctive trough-like cross section, but the minor valleys are of many varieties. No two ranges, therefore, are alike in detail, but all are alike in being rugged and high, while the bordering lands are smooth and low (relatively). Some of the mountains are dissected plateaus, as the Clearwater Mountains of Idaho; others are dissected anticlines and synclines, as the Lewis and Livingston Mountains of Montana; yet they are all alike in being *deeply* dissected.

The broad *similarities* among the features of a physiographic province are frequently expressed in the name of the province, as "Prairie *Plains*," or "Colorado *Plateaus*," or "Great *Basin*"; yet the Prairie Plains are locally rough, as where high and irregular morainic belts cross them, the Colorado Plateaus are diversified by volcanic mountains like Mt. Taylor and San Francisco Mountains, whose summits reach above timber line, and the Great Basin consists of many independent basins broken by, and mutually separated by, mountains of marked height and ruggedness. The *dissimilarities* among the features of a region may be classified and grouped by subregions. The Older Appalachians (Chap. XXVIII) for example have certain very distinctive and uniform features over a great belt of country from Maine to Alabama, such as their great geologic age, their highly complex structure, their prevailingly crystalline character, and the tremendous erosion which they have suffered. But throughout the region marked dissimilarities also occur which require recognition. The scenery about Asheville, North Carolina, is quite unlike that about New Haven; the mountain basin in the first case falls in the Appalachian Mountains, a subdivision of the Older Appalachians, the valley lowland of the second case lies in the glaciated New England subdivision of the same province.

Many of the physiographic regions of the United States are of great size. The Great Plains are as extensive as European Russia; the Lower Alluvial Valley of the Mississippi is at least half as large as Italy; the Alps are less extensive than that part of the Rockies south of the international boundary. Many individual topographic features are developed on a large scale. Hurricane Ledge, an eroded fault scarp in the Colorado Plateaus, is 700 miles long, the Great Valley of the Newer Appalachian region extends with but local interruptions from Alabama to Quebec, the Grand Hogback of western Colorado is a bold escarpment of erosion which extends unbroken for over 200 miles.

In addition to the great size of individual provinces and features is the great variety of physiographic features which the country exhibits. The physiography is also in many respects unique. Exploration has not revealed anywhere else on the earth structures and forms like those of the Colorado Plateaus, either in respect of scale or perfection of development. The Newer Appalachian ridges and valleys are so perfectly developed that "Appalachian structure and topography" has become a technical phrase. The till sheets of the upper basin of the Mississippi, in the heart of the continent, are so extensive and their succession so complete that the history of the glacial period was first worked out to partial completeness in America. The Columbia lava flows constitute one of the few really great basalt fields of the world.

We should ascribe to the great variety of physical conditions in the United States no small share of the general interest in American forestry, for the forests and forest problems are almost as varied as the relief upon which, either directly or indirectly, they so commonly depend. The vital relation of the forests of the arid West to the general welfare of the people has given western forestry a scientific interest not exceeded elsewhere. Man's control of the desert had its beginning in his control of water. At first that control was in the nature of art; now it is in the nature of science. As much care was at first bestowed upon the ritual of rain as upon the construction of a dam; we now study the laws of rainfall, measure its several dispositions, exercise control over it in measurable degree, relate cause and effect, and know the limits of irrigation enterprises before they are begun. Throughout the West the problem of water control has been found to be also a problem in forest control and grass control. Irrigation, forestry, and grazing are parts of one scientific problem. Of lesser but still of great importance are the relations of run-off and forests in the humid East, where over large areas a mountainous relief diminishes the value of the land for agriculture and increases its value in relation to forests and stream flow. Mountain influences are extended out upon the plains, where resides a dense agricultural population whose commerce and towns and fertile valley lands are often largely dependent upon the behavior of the mountain-born streams.

Climatic Regions

The determining *factors* of climate are chiefly latitude, the relative distribution of land and water, the elevation of the land above the sea, and the prevailing winds; the most important climatic *elements* are temperature, moisture, wind, pressure, and evaporation. The climatic elements are shown graphically on the accompanying series of maps for North America. Among them temperature and rainfall are of most importance in relation to forests, and a brief discussion of these elements of our climate is therefore presented in this chapter. In Plate I, representing the climatic provinces which correspond with the life regions of Merriam,[1] they are combined in such a way as to show their effect upon the life of the continent.

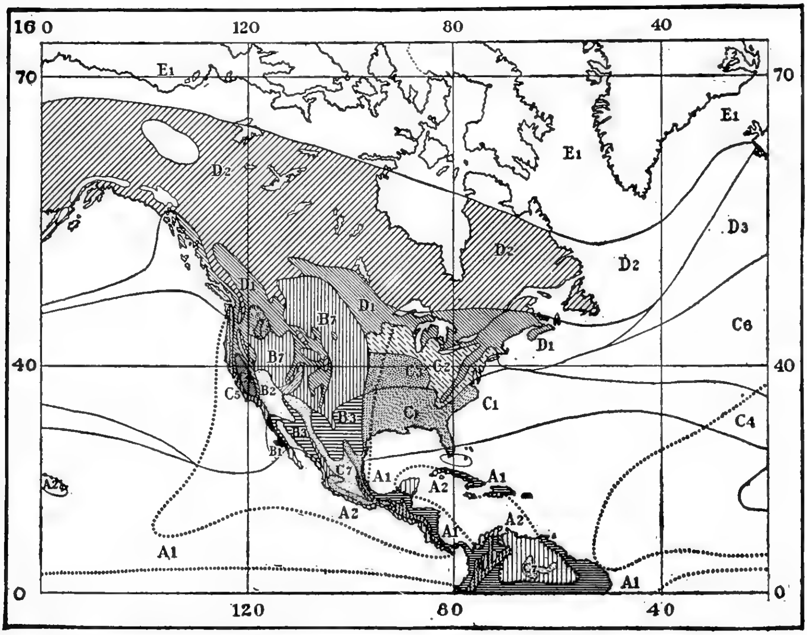

Fig. 13. — Köppen's classification of climates in relation to vegetation. Tracts enclosed by broken line have distinct dry seasons (rain probability < 0.20). A_1, Liana; A_2, Baobab; B_1, Garva; B_2, Simoon; B_3, Mesquite; B_7, Prairie; C_2, Hickory; C_3, Corn; C_4, Olive; C_5, Heath; C_7, High Savanna; D_1, Oak; D_2, Birch; E_1, Arctic Fox. (Ward, Climate.)

TEMPERATURE

The temperature map, after Köppen, Fig. 14, is peculiarly useful to a forester, since on it temperatures are not reduced to sea level and the

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[1] C. H. Merriam, Life Zones and Crop Zones of the United States, Bull. Div. Biol., U. S. Dept. Agri., No. 10, 1898. The fourth edition of this map forms the basis for Plate I.

boundaries of the various belts have certain definite relations to tree growth.

> "A normal duration of a temperature of 50° for less than a month fixes very well the polar limit of trees and the limits of agriculture. Near this line are found the last groups of trees in the tundras. A temperature of 50° for four months marks the limit of the oak, and also closely coincides with the limits of wheat cultivation."[1]

The greater part of the United States lies in the belt of westerly winds, hence we should expect marine temperature influences to be felt farther inland on the Pacific or windward coast than on the Atlantic or leeward coast. However, the Pacific coastal tract has a relief including high mountain ranges trending at right angles to the prevailing winds, hence marine influences affect a belt of country sharply limited on the east. They do not extend farther inland than the Sierra Nevada in California and the Cascades in Oregon and Washington, except along the valley of the Columbia (which cuts across the Pacific mountains), where unusually high temperatures prevail for some distance east of the Cascades. Washington, Oregon, and California have strikingly equable temperature conditions. On the Atlantic coast marine influences do not extend so far inland as a rule nor are they so pronounced. They are, however, distinct, as is shown both by the lower absolute and mean monthly temperatures at a shore station like New London as compared with a station like Middletown, Connecticut, 20 miles inland. Southern species of birds and plants follow the Atlantic coast in narrowing belts surprisingly far toward the north. The northernmost occurrence of persimmon trees, a southern species, is at Lighthouse Point, New Haven. The temperature contrasts between the two coasts are shown in the following table.

CONTRASTS BETWEEN ATLANTIC AND PACIFIC COAST TEMPERATURES[2]

Stations	Latitude		Annual Mean	Winter Mean	Summer Mean
Savannah, Ga.	32°	5′	66° F.	52° F.	81° F.
San Diego, Cal.	32	43	61	55	68
Cape May, N. J.	38	50	54	36	72
San Francisco, Cal.	37	18	56	51	59
Nantucket, Mass.	41	17	49	33	65
Eureka, Cal.	40	48	52	47	56
Chatham, N. B.	47	3	39	13	63
Fort Canby, Wash.	46	17	50	42	58

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[1] R. DeC. Ward, Climate, 1908, p. 28.

[2] A. J. Henry, Climatology of the United States, Bull. Q, U. S. Weather Bureau, 1906, p. 26. The statistical data in the section on climate have been derived chiefly from this source.

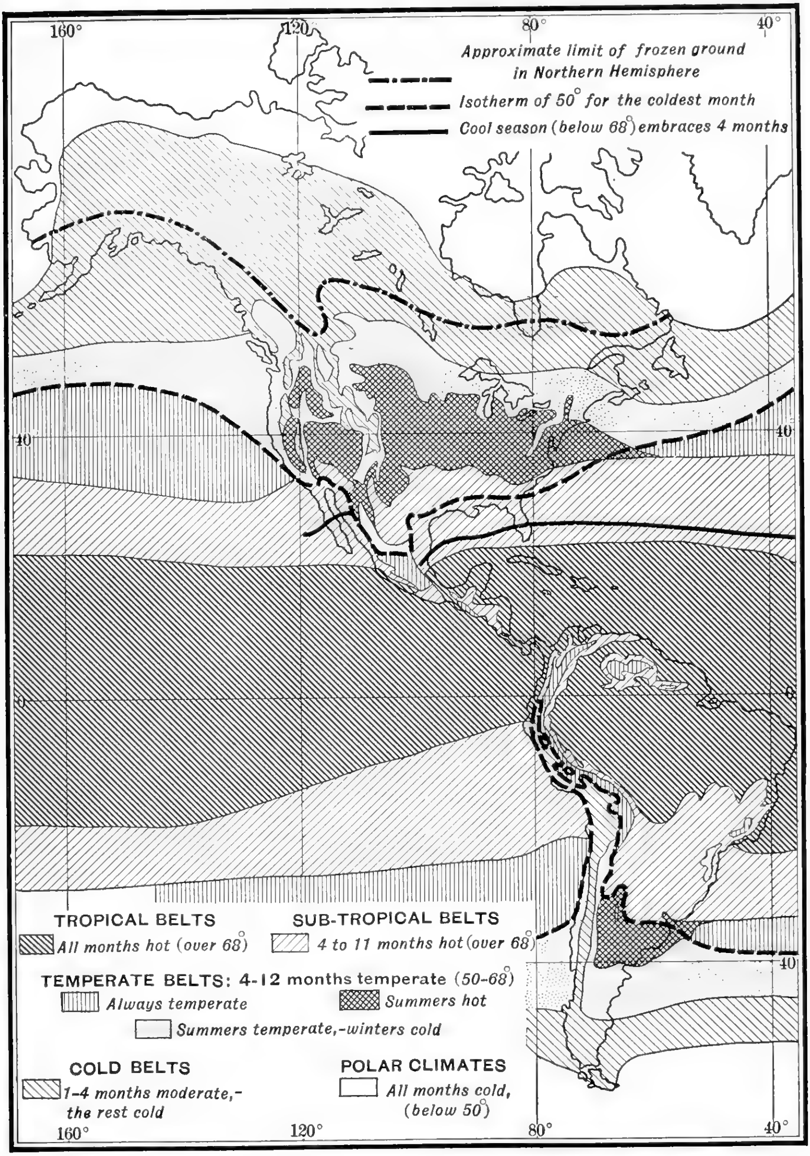

Fig. 14.—Temperature zones of the western hemisphere. (Ward, adapted from Köppen.)

It will be noted from the table that the winter means on the Atlantic coast are regularly lower than those on the Pacific, since, being on the leeward side of the continent, continental influences are more strongly marked than marine. The summer means are all higher for the same reason: the land is always warmer in summer and colder in winter than the sea.

The greatest extremes of temperature are experienced in the interior of the country far from the influence of the oceans, where the continental type of climate prevails. The valleys of eastern Montana experience the lowest absolute temperatures; −65° below zero was recorded at Miles City, Mont., January, 1888. The whole plains region in the latitude of the international boundary is subject to great and sudden variations of temperature, since its open and vast expanses are exposed both to the cold winds from the mountains and the north, and to hot winds from the south. The 100° maximum at times extends into the Canadian Northwest. The northerly winds are sometimes of great velocity and in winter are often attended by light, dry snow, conditions which reach their culmination during a blizzard, when the wind may attain a velocity of 60 miles an hour. High winds in summer are often attended by dust and give rise to the "dust storms" of the plains.

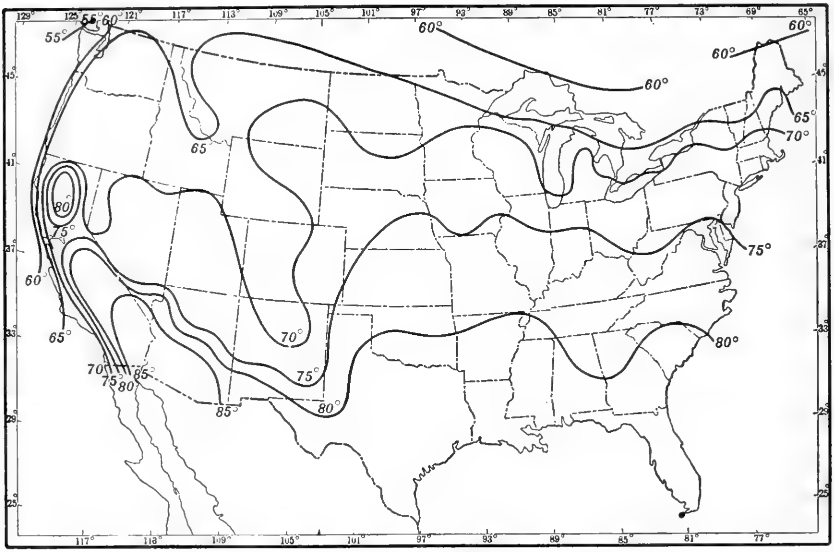

Fig. 15.—Normal surface temperatures for July.

When they are marked by high temperatures they may be even more harmful to crops than the winter blizzards are to livestock.

Maximum temperatures of 100° and over are experienced in all parts of the United States except in the higher portions of the Atlantic and Pacific Cordilleras, the immediate coasts of both oceans north of 40°, in the peninsula of Florida, along the Gulf coast, and in portions of the Great Lake region. The highest recorded temperature in the entire country is 130°, recorded in the Colorado Desert in southern California. Maximum temperatures of 112° to 115° are frequent in southwestern Arizona and southern California. The only Weather Bureau stations

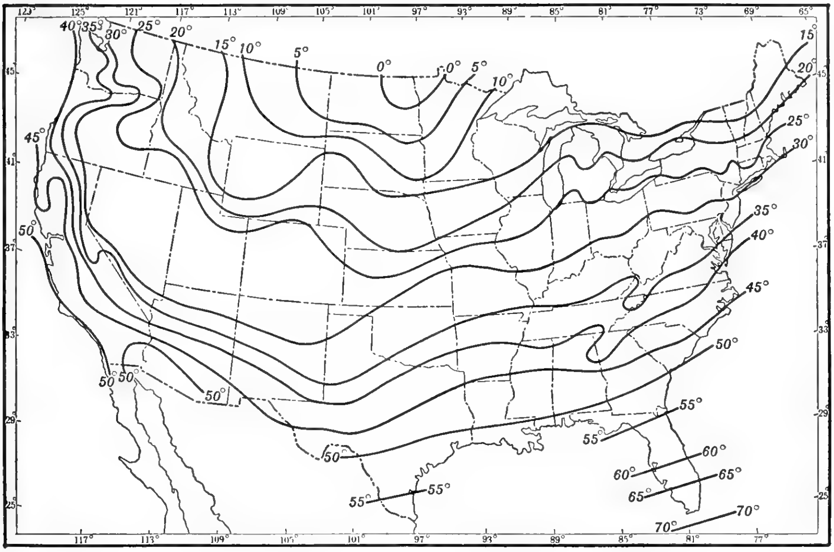

Fig. 16. — Normal surface temperatures for January.

in the United States where a minimum temperature below freezing has not been experienced are Key West, Fla., and San Diego, Cal., with absolute minima of 41° and 32° respectively. South of the mouth of Chesapeake Bay the Atlantic coast has never experienced a temperature below zero, nor have zero temperatures ever been recorded along the Gulf coast, at any point on the Pacific coast, or in the Great Valley of California. The mountain summits of both the Atlantic and the Pacific Cordilleras have minima comparable to those experienced on the north-central Great Plains and in the Arctic regions. The lowest recorded temperature on Mount Washington, N. H. (6293 feet), is – 50°, the lowest on Pikes Peak, Col. (14,134 feet), is – 37°.

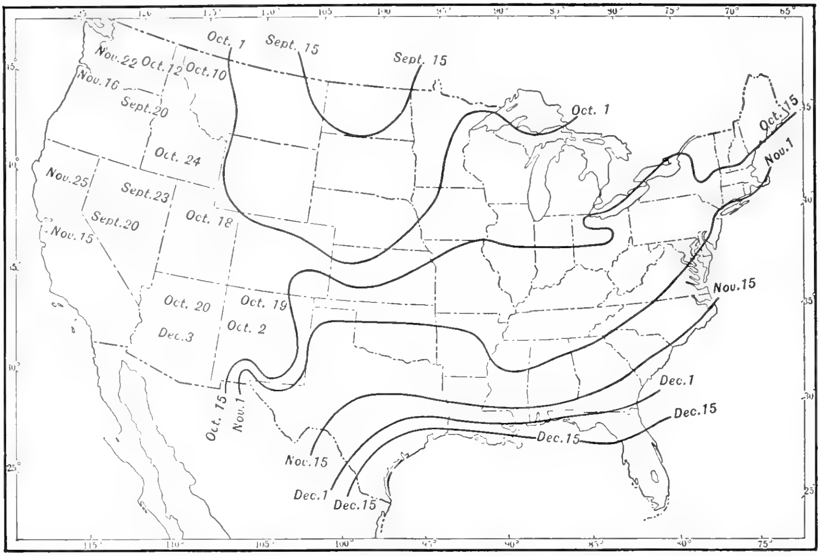

Fig. 17. —Average date of first killing frost in Autumn.

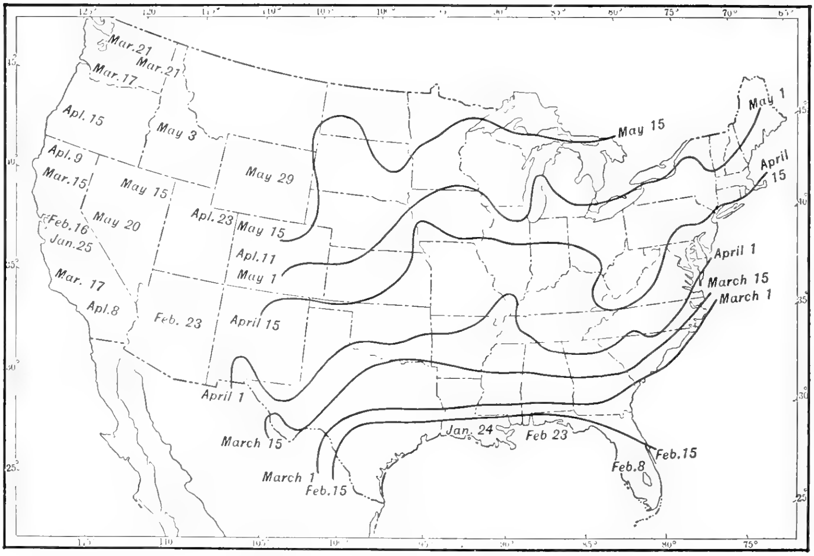

Fig. 18.—Average date of last killing frost in Spring.

The mean annual range of temperature is about 30° in the states of the Gulf and Atlantic Coastal Plain, 40° to 50° in the interior valleys, Rocky Mountain region, and Middle Atlantic States, and from 55° to 65° over the northeastern Rocky Mountain slope and eastward to Lake Superior. The greatest daily range occurs in the arid and semi-arid Southwest on account of the prevailingly clear skies and the lack of vegetation; the greatest mean daily range (30° to 35°) is in the Plateau region, the least (8° to 12°) is along the Pacific and Gulf coasts. East of the Mississippi Valley the mean daily range is generally less than 20°.

PRECIPITATION

The chief causes of an abundant rainfall are (1) nearness to the ocean or other large body of water such as the Gulf of Mexico or the Great Lakes in the United States, (2) location within or near the track of cyclonic storms, and (3) mountain ranges athwart the rain-bearing winds. The western slopes of the Coast Ranges of Oregon face the ocean and run at right angles to the westerly winds, and their rainfall exceeds 100 inches a year; the Ohio Valley lies in the track of the more or less regular cyclonic storms that move northwestward from the Gulf, and receives a rainfall of 40 to 50 inches a year; nearness to the sea gives the greater part of the Atlantic and Gulf coasts a higher rainfall, 50 to 60 inches, than is enjoyed by any portion of the eastern half of the country except the mountains of western North Carolina. By contrast the mountain-rimmed parks of Colorado, and the Great Basin of Nevada, are regions of diminished rainfall; the coast of southern California owes its dryness chiefly to its position outside the belt of cyclonic storms; the dryness of North Dakota is chargeable chiefly to remoteness from the sea, although in this, as in the other cases cited, the rain-producing or rain-resisting forces commonly operate in combination with other forces, so that the influence cited should be understood to be the predominating and not the sole influence.

Rainfall is always due to the cooling of the air to and below the point of saturation. This may be accomplished (1) by the rise of air on a mountain flank—the air expands on rising and since the heat of the air supplies the energy for expansion, the air is cooled to and beyond the point of saturation and rain falls; (2) by convectional air currents produced by a local overturning of the lower air as during a summer thunder shower; and (3) by radial inflow and ascensional movement, as in cyclonic storms, with expansion and cooling to the point where rain falls.

The seaward slopes of the Coast Ranges of Oregon and Washington receive the heaviest rainfall in the United States, from 60 to 150 inches a year. Rains are frequent during the entire year, but most frequent during the winter season, from November to May. The rain-bearing winds change from southeasterly to westerly with the approach and passage of cyclonic storms. The rain begins with the southeast wind and ends with the westerly wind. The result is that the leeward or eastern slopes of the mountains are also well watered, though the fall is lighter than that on the windward or western slopes. Northerly winds bring fair weather at all seasons. Southward from the well-watered strip along the northern part of the Pacific coast the rainfall decreases rapidly, falling from 67 to 22 inches between the northern boundary of California and San Francisco. Toward the south it continues to decrease and falls to a minimum of less than 10 inches at San Diego, in the horse latitude belt of light uncertain winds between the westerlies and the trades. The Pacific coast thus exhibits a range in rainfall of about 100 inches.

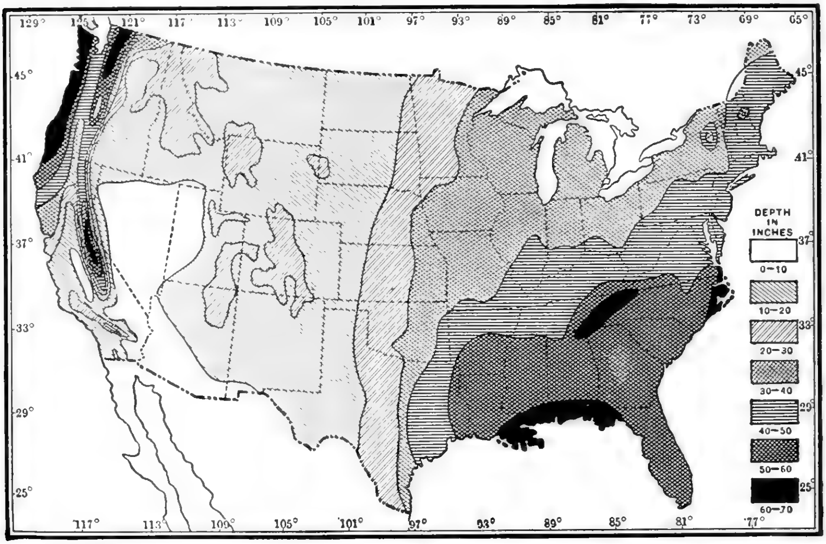

Fig. 19.—Mean annual precipitation in the United States reduced to inches of rainfall. Note the Adirondacks, White Mountains, and Black Hills islands. (U. S. Geol. Surv.)

The main Pacific coast valleys, embracing the Great Valley of California, Salton Sink, the Willamette Valley, and the Puget Sound depression, have a much lighter rainfall than the rain-obstructing Coast Ranges, since they lie in the lee of the latter. The valley of southern California is an extremely dry desert. In the Great Valley the rainfall varies from about 10 inches at Fresno in the south to 25 inches in the north; the

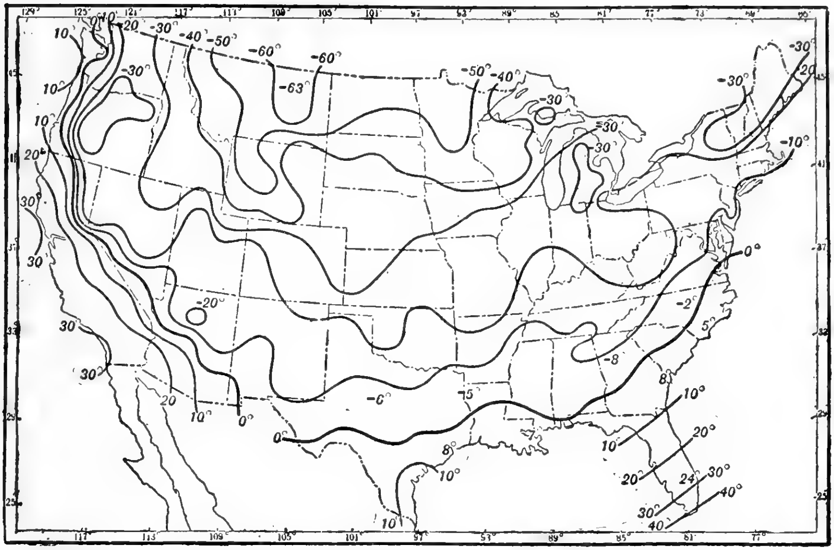

Fig. 20. — Absolute minimum temperatures.

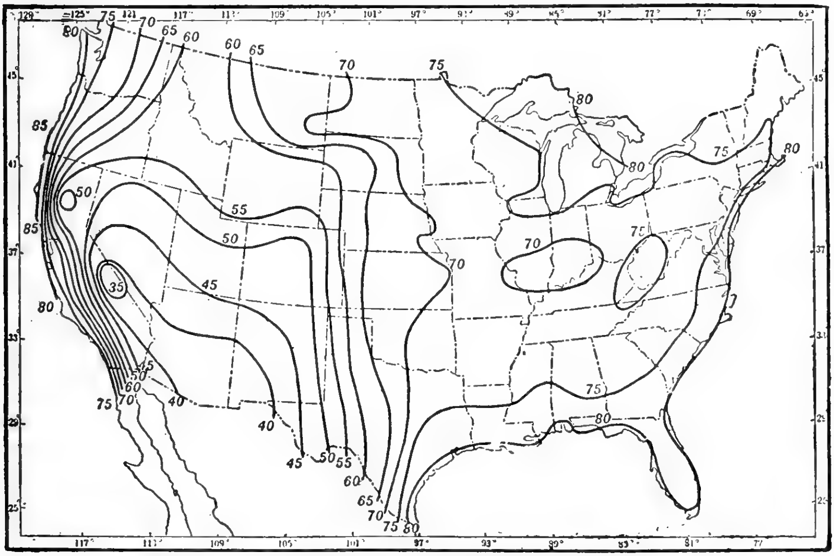

Fig. 21. — The average annual humidity of the air in the United States.

rainfall of the Willamette Valley varies from 25 inches in the south to 45 inches in the north; while the Puget Sound region has an average rainfall of about 45 inches. The precipitation increases rapidly eastward as the winds ascend the western slopes of the Sierra Nevada and the Cascades. It reaches a maximum of about 100 inches in Washington and Oregon, and from 40 to 80 inches in California at elevations between 3500 and 5000 feet. Beyond this point the precipitation diminishes again toward the summit and becomes insignificant at the eastern base of the mountains.

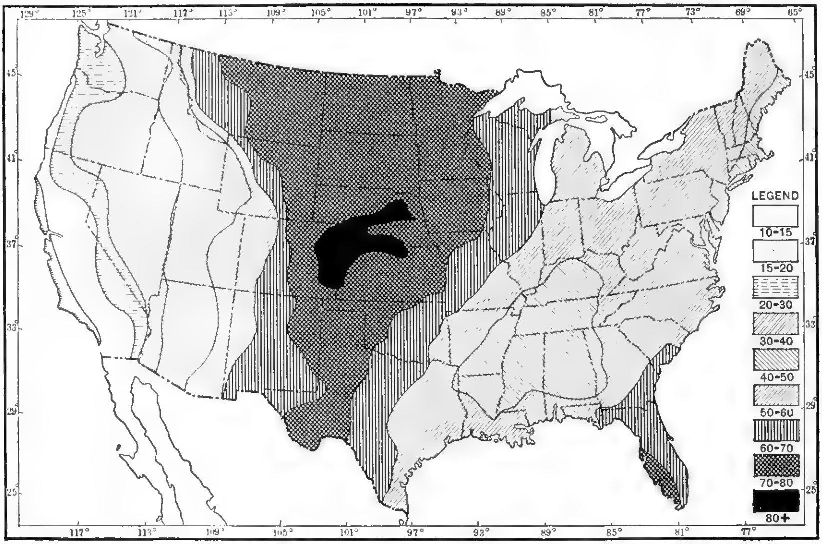

Fig. 22. — Percentage of annual rainfall received in the six warmer months, April to September inclusive.

The great height and continuity of the Sierra Nevada and the Cascades cause these mountains thoroughly to obstruct the westerly winds in respect of moisture, with the result that great stretches of country east of them are arid wastes. Where ranges of exceptional height occur in the country east of the Cascades and the Sierra Nevada the rainfall may exceed 25 inches a year, but by far the greater part of the region has less than 12 inches a year. Southwestern Arizona and southern California are the driest regions in the United States, and the rainfall of the lowlands is almost wholly confined to the winter months. In the rain shadow of the Sierra Nevada the mean annual rainfall is between 5 and 6 inches and locally as low as 3 inches. It is characteristic of the region that occasionally some portion of it receives a rather abundant rainfall. About once in six years the greater part of the rainfall of a locality comes in a single month. In 1891, for example, 2.5 inches or 93% of the annual rainfall of the lower Colorado Basin fell in January. In January, February, and March, 1905, 8 inches of rain fell at Yuma, Arizona, whereas the average annual rainfall of that place is but 2.7 inches.

The Rocky Mountain region rises to such a height as to provoke a heavier rainfall than the plateaus and basins on the west, though the remoteness of the region from the sea gives it a much lighter rainfall than occurs in the southern Appalachians of far lower elevation, or the relatively low Coast Ranges of Oregon. During the winter the western windward slopes of the Rockies are more heavily watered than the eastern, but the reverse is true for portions of the system during the spring and summer. In New Mexico and western Texas the mountains of the Trans-Pecos region have a greater rainfall than the surrounding plains and basins, but it is never heavy in an absolute sense. It comes in July and August and appears to be rather evenly distributed on all sides as if due to local updraft of air from plains to mountains. Nowhere does more than 50 inches of rain occur in the Rockies and the average amount is far smaller. The rainfall is very unevenly distributed, as might be expected owing to the irregular trends of the intermont basins and mountain ranges and the variable dispositions and heights of the mountains. The maximum precipitation occurs probably in northern Idaho; the minimum is between 6 and 8 inches and falls in San Luis Park in south-central Colorado.

Eastward of the Rockies as far as the Atlantic coast the topographic features lack great height, hence the rainfall distribution is controlled chiefly by the frequency and direction of movement of the rain-bearing cyclonic storms. The greater height of the Unakas, Great Smokies, and associated ranges in western North Carolina and South Carolina and northern Georgia cause their rainfall to exceed that of any other region east of the Pacific mountains. It is more than 70 inches a year. The rugged and high eastern portion of West Virginia, the Adirondacks, and the White and the Green mountains are other centers of heavy rainfall that owe their influence upon climate to their greater height. A heavier rainfall depending not on elevation but on nearness to the sea and on position within the track of frequent cyclones occurs in southern Louisiana and Alabama, — 60 to 70 inches.

The Great Plains region has a diminished rainfall owing to its position in the rain shadow of the Rockies and its remoteness from the sea.

Fortunately such rain as falls comes chiefly in the summer or growing season. From the 101st meridian to the Rockies the rainfall is from 10 to 15 inches. Eastern Colorado is a region of small precipitation, with an average fall of about 12 inches and a maximum yearly fall rarely in excess of 20 inches. In western Kansas the precipitation of the driest year was 9.9 inches; of the wettest, 33.7 inches. The last-named illustration is typical of the wide differences between the extremes of rainfall in the arid and semi-arid portions of the West. The wettest years have a rainfall sufficiently great for agriculture; the means and minima are far below the necessary amount.

Of the seven climatic and life provinces of North America, Plate I, but four fall within the limits of the United States, except that the southernmost or tropical province touches southern Florida and the lower valley of the Colorado, and the northernmost or Arctic province is developed on a few of the highest summits like Shasta in northern California and Blackfoot Mountain, Montana.

The Boreal province is developed in the southern Appalachians of western North Carolina, eastern West Virginia, the Catskills, the Adirondacks, the White and the Green Mountains, and in the Superior Highlands of northern Michigan and Wisconsin and on all the main divisions of the Pacific Cordillera, where its upper limit coincides with the timber line. It is marked by a low mean annual temperature, generally between 32° and 40°, by long, cold winters, and in general by a heavy snowfall. Its forest growth is spruce and pine in New England, spruce and balsam in North Carolina, chiefly white pine in Michigan and Wisconsin, and spruce, fir, and cedar in the Pacific Cordillera.

The greater part of the mountain forests of the United States is found in the Transition province which includes the cool temperate portions of the country with a generally high mean annual precipitation. The mean annual temperature is about 45°, but the temperature is in general marked by frequent and sudden changes. Snow falls throughout the entire province, though it is variable in amount owing to differences of elevation, exposure, etc.

In the northern portion of this province both broad-leaved deciduous trees and conifers grow; similarly in the west, scattered growths of oak, piñon pine, and sycamore of the lower mountain slopes mingle or shade into the spruce and yellow and white pines of the upper slopes. The province as a whole has few distinctive plants; it is marked rather by the mingling of southern species that here find their northern (on the mountains their upper) limit and of northern species which find their southern (or lower) limit of occurrence.

PLATE I

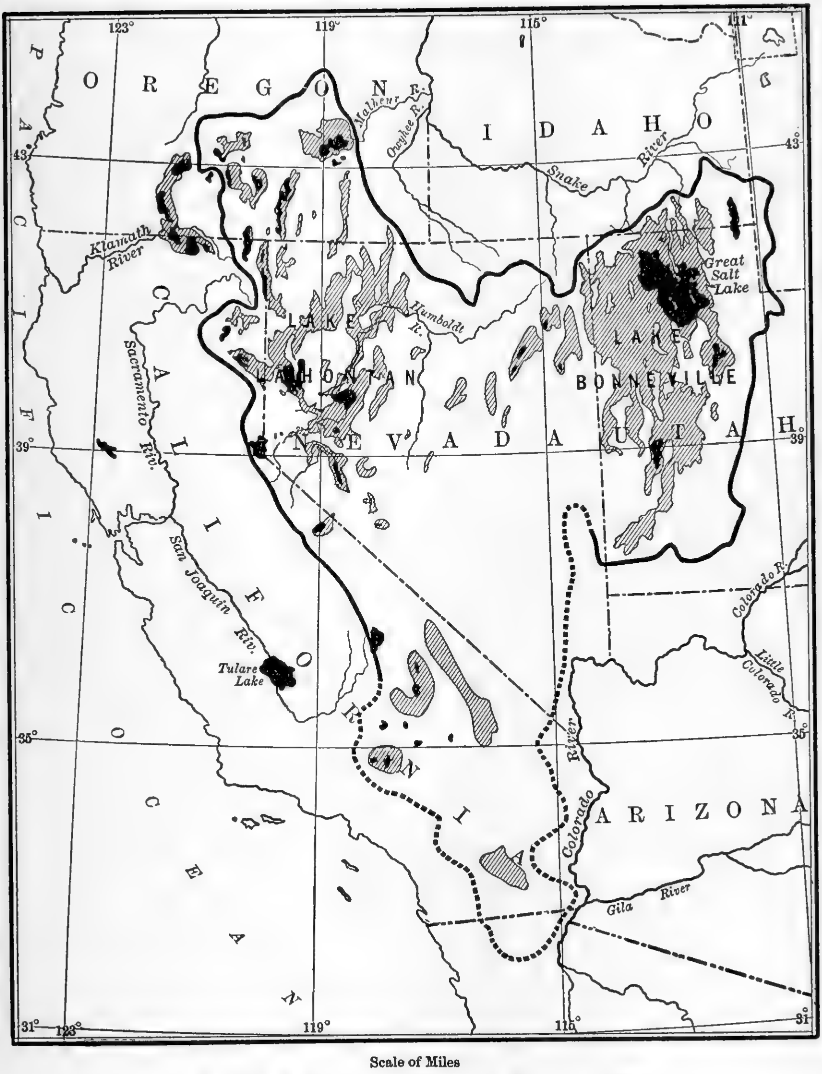

Plate I. — Climatic and Life Provinces of North America.

The western division of the Upper Austral province is so dry that agriculture without irrigation is impossible and tree growth is limited to the heads of the better watered alluvial fans and the banks of streams. The eastern portion of the province was originally covered with a varied and dense forest of hickory, maple, oak, and chestnut, as in the Ohio Valley and the Piedmont and the Appalachian Plateaus. The climate is warm temperate, with a long summer season.

The Lower Austral province resembles the Upper in the western part of the country in its general treelessness except along the streams. East of the 100th meridian the climate is wetter, and throughout the entire Gulf and Atlantic Coastal Plain the temperature and rainfall are favorable to the growth of great forests of southern species of pine and of cypress. The winters are very mild, snowfall is absent, and the long, hot summers have an abundant rainfall. The mean winter temperature is 40° to 52°, the summer temperature from 75° to 80°.

FOREST REGIONS

A single unbroken forest belt extends across North America, the spruce forest of Canada. Its northern border, a timber line determined by cold and physiological dryness, extends from Hudson Bay northwestward to the head of the Mackenzie delta, thence westward and southwestward across Alaska. Its southern margin is the 60th parallel in the Canadian Northwest and the 50th parallel in the Great Lake region. Black and white spruces, poplar, canoe birch, aspen, and tamarack are typical growths; the presence of only a few species of trees is characteristic. The spruce forest includes a large part of the lake region of North America with an abundance of lakes and swamps (p. 565). The spruces and the gray pine grow on the uplands between lakes and swamps; poplar, dwarf birch, willow, and alder occupy the cold wet bottom lands. While the trees attain fair size on the southern portions of the belt in which they occur, they are never large, and decrease notably in size toward the north, where they finally become so stunted as to be of little economic importance.

Southward from the broad transcontinental forest belt are an Atlantic forest, a Pacific forest, and a Rocky Mountain forest. The two intervening belts of country — the Great Plains and the Great Basin — are forestless though not treeless. This distribution is controlled largely by rainfall, though the distribution of species within each region is also controlled by insolation, temperature, wind velocity, water supply, and geographic relation to postglacial centers of dispersal. By the same token the forests are not distributed evenly over a given region,

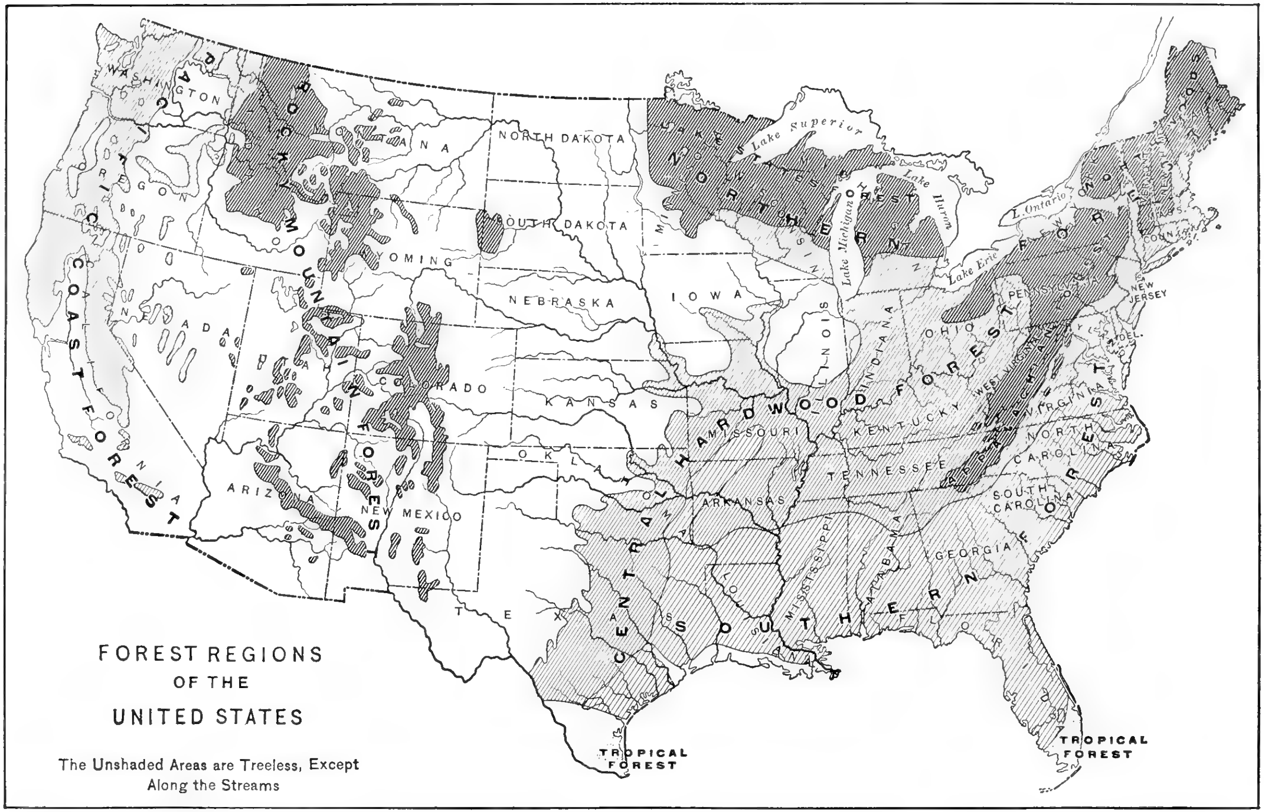

Fig. 23. — The effects of rainfall are clearly shown in the forest contrasts of East and West; the effect of elevation on rainfall and forests is shown in the Blue Mountains of Oregon, the Black Hills of South Dakota, the Trans-Pecos ranges, etc.; the effect of elevation on temperatures and forests is shown in the long arm of northern forest that extends south along the Appalachian system; the effects of high temperatures in low latitudes is shown in the tropical forest of southern Florida and southern Texas; the effects of ground water are most apparent on the western border of the central hardwoods area where finger-like extensions project westward along the river bottoms; the exclusion of the forest (1) by an excess of water is shown in southern Louisiana, (2) by a deficiency of water, in the unshaded portions of the West. (Map from U. S. Dept. of Agri., Bur. of For.)

but vary from windward to leeward slopes, from warm southern to cool northern slopes, and from dry to wet situations as controlled by more local conditions.

The eastern or Atlantic forest tract consists largely of hardwoods, though large tracts of conifers are also found; the western forests are principally conifers of unrivaled size and beauty and hardwoods are comparatively rare. The great variety and in some cases the great size of the trees of the Atlantic forest are distinctive features. The primary divisions of the Atlantic forest belt are (1) a belt of conifers, (2) a hardwood belt, and (3) a belt of southern pines.

The belt of conifers in which the white pine is the most important species extends from southeastern Canada and Massachusetts westward to northern Michigan, Wisconsin, and Minnesota. It reaches its best development in the light, dry, sandy soil of the glacial drift in the northern part of the southern peninsula of Michigan. White cedar, hemlock, fir, larch, and spruce are other conifers of minor importance in the tract.

South of the white pine belt is a belt of hardwoods which extends through the Great Lake states and the larger part of the great Appalachian region. The most notable types of trees are many species of oaks, several kinds of hickory, the chestnut, basswood, magnolia, tulip tree, and cottonwood. In this belt the hickories reach their greatest size in the Ozark region, the oaks in the central and southern portions of the eastern United States, the tulip tree in Kentucky. Among the exceptions to the characteristic growths of this division may be mentioned the spruce and hemlock forests on the summits of the Pisgah and other ranges in western North Carolina, where boreal conditions prevail.

The Atlantic and Gulf Coastal Plain is occupied by longleaf, shortleaf, loblolly, and slash pines. The first two occupy dry sandy uplands for the most part; the loblolly pine grows best on the drier portions of the moist lowlands of eastern Texas.

Among the trees of the Pacific coast forests in the United States the red or Douglas fir is the most important. It has its best development in the wet Puget Sound region, where it grows to a height of several hundred feet. It is associated with the tide-land spruce, hemlock, and red cedar. This portion of the Pacific forest is one of the densest and commercially one of the most valuable in the country. Southward and eastward the forest changes in character. In northern California, where the rainfall is heavy, the redwood is the most important forest tree, and between it and the fir forest on the north is a tract occupied by the Port Orford cedar. The dry and nearly treeless Great Valley of California divides the Pacific forest into an eastern and a western section. The well-watered Sierra Nevada in the east has a heavy forest growth of sugar pine, red fir, yellow pine, and hemlock besides the famous *Sequoia gigantea.* The dry Columbia Plateaus have a discontinuous forest in which pine and larch are the most important types. The Great Basin region is still drier and supports an even more limited growth of pine and juniper at the lower elevations, and a scanty growth of fir and spruce at the higher elevations.

The Rocky Mountains forest extends from the borders of the surrounding plains and the intermont basins up to elevations of 9000 to 11,000 feet and is much broken into forest islands by the restricted areas of mountain land which are sufficiently high to provoke an adequate rainfall from the prevailing westerly winds. Spruce grows luxuriantly at elevations ranging from 8000 to 10,000 feet, and at lower altitudes yellow pine, red fir, and white fir are abundant. This growth is characteristic of the Rockies as far south as New Mexico, where the lower elevations of the mountains of the Trans-Pecos region cause the forest to disappear or to become restricted to a few higher ranges such as the Sacramento and Davis Mountains of western Texas and eastern New Mexico.

Two small forest tracts of exceptional character deserve mention in even this brief description. In Florida the subtropical climate has given rise to an Antillean type of flora among which mahogany, royal palm, and mangroves are of chief interest. The second tract is in southernmost Texas, where vegetation occurs whose affinities are with the Mexican flora.

CHAPTER X

COAST RANGES

THE relief of the relatively dry western half of the United States has a high importance in the distribution of the forests because of the effects of relief upon two of the controlling factors of forest growth — temperature and rainfall. We shall therefore begin our consideration of the physiography of the United States by a study of the West. Of the 190 million acres of national forests, more than 185 million occur west of the eastern front of the Rockies, a fact that further increases the forester's interest in the topography, drainage, soils, and rainfall of this vast region.

SUBDIVISIONS

The Coast Range System of mountains in the United States extends from southern California to the Straits of Juan de Fuca. The mountains of the system do not have uniform topographic qualities throughout but consist of four somewhat dissimilar sections. The southern section extends from southern California to the 40th parallel; farther north are the Klamath Mountains, which extend from the 40th to the 43d parallel; the third section embraces the low Coast Ranges of western and northwestern Oregon; the fourth includes the Olympic Mountains, which rise to heights of over 8000 feet and are the highest mountains of the system next to those in southern California.

COAST RANGES OF CALIFORNIA

The Coast Ranges of California terminate on the northern margin of Humboldt County (p. 141); beyond them to the northeast lie the Klamath Mountains, which are more closely allied to the Sierra Nevada Mountains than to the Coast Ranges in rock character and geologic history though not in geographic position. The Coast Ranges of California are sometimes regarded as ending on the south in Santa Barbara County, there giving way to the mountains of southern California. We shall here include the mountains of southern California with those of the coast of California to the 40th parallel in a single coast group because of (1) the extension of the tectonic lines of the northern mountains into the mountains of southern California and (2) the closely related fact that the movements along these lines — movements to which the larger topographic features are due — date in both cases from the close of the Tertiary. A unity of both structural and topographic characters is thus given the entire group of ranges. The group is divided, however (largely on the basis of trend), into three subgroups: (1) the Coast Ranges proper; (2) a broad chain extending from Santa Barbara County to the eastern and southeastern side of the Colorado desert, with a general trend west-northwest, and including the San Rafael, Santa Ynez, Santa Susannah, Santa Monica, and San Gabriel ranges, a chain parts of which are known locally as the Sierra Madre, though the application is neither uniform nor clear; and (3) the mountainous country of the Valley of southern California. The principal ranges of this group are the northwestward-trending Santa Ana and San Jacinto mountains, sometimes called the Peninsular chain.[1]

On both the north and the south the Coast Ranges are from 5000 to 8000 feet high; the elevations of the central portions are from 3000 to 4000 feet. San Lucia Peak, the highest peak of the central Coast Ranges, is less than 6000 feet high. In general the crests range from 2000 to 4000 feet.

The eastern margin of the Coast Ranges of California rises abruptly from the floor of the great central valley of California as a well-marked continuous mountain front. At its southern end it is a dissected fault scarp; elsewhere a smaller amount of faulting has taken place, but everywhere the eastern border represents a line of strong deformation. In a broad view the western margin of the Coast Ranges is not at the shore line but at the edge of the continental platform on the 600-foot submarine contour, where the sea bottom changes its slope abruptly from a previously gentle incline and plunges steeply down to depths of 8000 feet and more.[2] At the foot of this steep decline the sea bottom again assumes low gradients. The slope constitutes a notable mountain front rising from the floor of the Pacific and forming the natural western boundary of the coast system of mountains. It is interpreted as a great submarine fault scarp or series of fault scarps comparable to those that form the eastern front not only of the Coast Ranges of California but also of the Sierra Nevada. At the base of the steep submarine scarp, dredgings (Tuscarora explorations) at the depth of 12,000 feet have brought up fragments of bituminous shale which are con-

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[1] A. C. Lawson and others, Section on Geology, The California Earthquake of April 18, 1906, Carnegie Inst., vol. 1, pt. 1, pp. 2, 3 et al.

[2] Andree's Handatlas, bathymetric chart, No. 157.

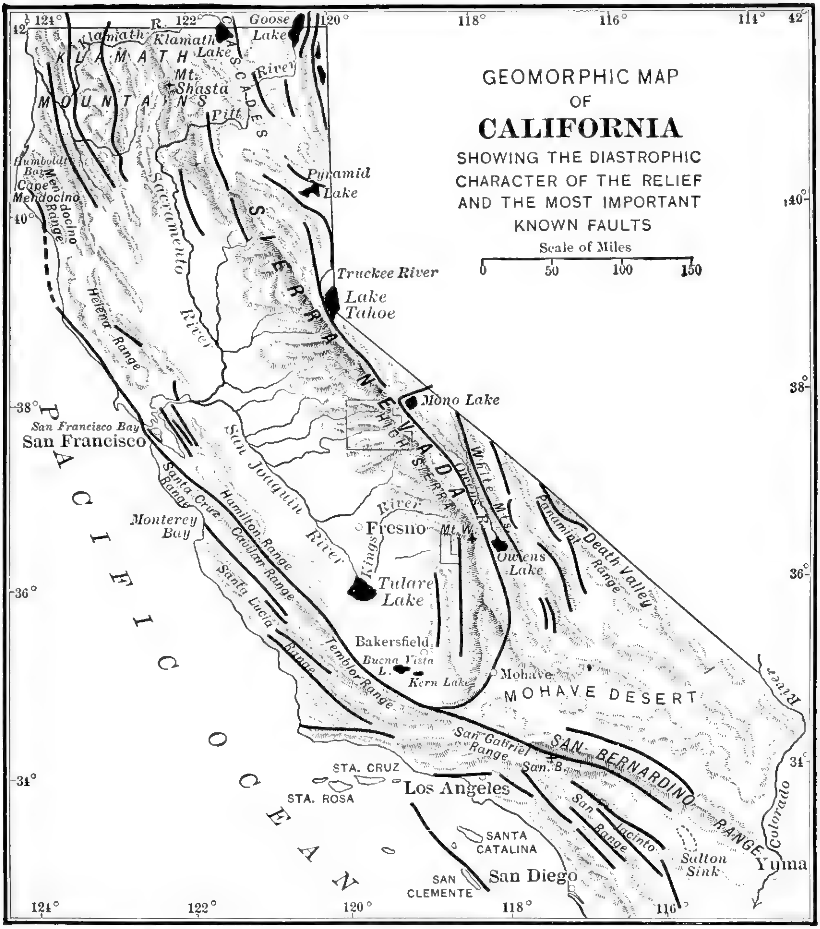

Fig. 24. — Map of California. The heavy lines indicate the principal faults.

sidered to be talus débris of so recent origin as not yet to have been buried by oceanic sediments.

The coastal scarp above sea level is not everywhere regular in development; the most noticeable interruption is the Bay of Monterey and adjacent slopes, which form parts of a synclinal trough whose axis is at right angles to the trend of the coast and of the Coast Ranges as a belt. A second interruption of the continuity of the coastal scarp is at the Golden Gate and is due to a depression of the Coast Ranges which resulted in the drowning of the lower portions of land valleys that formerly crossed the coastal mountains. The Point Rees peninsula is a third important break in the continuity of the coast line of California and is due to the manner in which the depression east of the ridge forming the peninsula has been drowned; the northern end of the valley is occupied by Tomales Bay, the southern by Bolinas lagoon.[1]

The Coast Ranges of California consist on the whole of a series of parallel ridges composed of sedimentary strata (Cretaceous[2] and later) that have been deformed on broad lines by deep-seated causes. There has been crumpling of the strata besides a certain amount of igneous eruption, but the major features are due to the effects of great dissection and later block faulting on a large scale, attended and followed by erosion. The character of the relief is in many cases markedly diastrophic and the relief features commonly have the rectilinear quality associated with pronounced faulting, which also explains to a large degree the parallelism of the ridges. Examples are Castle Rock Ridge, Cavilan range, the Santa Cruz range, and many others whose borders are marked by the San Andreas fault, the Castle Rock fault, etc., which during the California earthquake of 1906 were the loci of maximum earthquake intensity.[3]

The most important line of faulting in the Coast Ranges of California is the Rift, as it has been termed, or the San Andreas Rift, a name taken from the San Andreas valley of the peninsula of San Francisco. The Rift is a continuous topographic depression for at least 190 miles from Point Arena to San Juan, and in this part of its course is nearly straight, following an old line of seismic disturbance which has a much greater extent — that is to say, from southwest of the Point to southern California, or about 600 to 700 miles. Indeed the Rift may extend much farther to the south and may be associated with the origin of the

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[1] Lawson, loc. cit., pp. 12–15.

[2] For geologic time names consult Appendix D.

[3] Atlas of maps and seismographs accompanying the Report of the State Earthquake Investigation Commission upon the California Earthquake of April 8, 1906, Maps 1, 22, and 23. Also the Santa Cruz quadrangle, U. S. Geol. Surv.

Colorado desert and the Gulf of California. The physical habit of the Rift valley, for example in the Bolinas-Tomales section, is that of a remarkably straight depression, with the southwestern wall steep, the northeastern wall gentle. The character of a pronounced topographic depression, however, is not everywhere sustained.

The southern end of the great Rift may be traced for an unknown distance along the base of the mountains bordering the Salton Basin upon the northeast, where it probably dies out gradually. It is coincident with long and narrow valleys whose orientation is controlled by faulting along the Rift but whose detailed features are in large measure determined by erosion upon the exposed edges of formations of varying hardness. The depressions which constitute the major Rift along the southern margin of the Mohave desert appear to be almost wholly diastrophic. The steep northern flank of the San Rafael and San Gabriel ranges on the south side of the Mohave desert are degraded fault scarps, the walls of the great Rift valley. The exact share in all these various sections of the Rift valley that may be ascribed on the one hand to crustal deformation of the fault block type and on the other to erosion has not been determined. For miles at a stretch the earth on one side or the other of the fault in the southern part of the Coast Ranges has sunk in such manner as to give rise to basins and cliffs measured in terms of several hundred feet.

The individual ridges of the Coast Ranges of California have a pronounced parallelism in a direction somewhat oblique to the main trend of the coast, so that they tend constantly to emerge upon the coast in the form of northwestward-trending peninsulas. The courses of the longitudinal valleys correspond either to the strike of the rocks or the trend of the fault lines and are oblique to the general trend of the coast range belt. The general drainage is therefore termed subsequent, for the streams have extended themselves along belts of weak rock or along fault depressions at the expense of an earlier drainage crossing the region in a westerly direction or transverse to the structure. Short sections of the streams cross the ridges in steep-sided valleys or gorges, and these only may be termed antecedent.[1]

The tops of the ridges in some respects are more or less flat and present the character of a rolling, mature upland; but more commonly they are determined by the intersection of the slopes of adjacent valleys; even in the latter case, however, it is generally true that the ridge crests over wide areas reach about the same altitude and in a broad view give the impression of an upland with fairly uniform elevations and gentle

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[1] Lawson, loc. cit., p. 20.

slopes. The stream valleys, cut below the level of the dissected upland, are usually wide-bottomed in the softer and narrow-bottomed in the harder rocks.[1]

The Santa Lucia Range illustrates many of the general features of the region. It is the dominant mountain range of the coast of California for over 100 miles between latitude 35° and 36°30′ N., Fig. 24. For much of this distance it rises boldly from the Pacific Ocean and forms the most picturesque portion of the California coast. In places the spurs of the range terminate in cliffs several hundred feet high; in other places the range is bordered on the seaward side by a gently sloping platform or terrace which is from 40 to 80 feet high on its cliffed outer margin and 100 feet high on its inner margin. This platform is primarily a wave-cut terrace, though its surface is thinly covered with wash from the bordering hills.[2] The Santa Lucia Range has an even sky line many miles long, and a summit from 2 to 4 miles wide. Its regular front is a bold, compound, fault scarp. The range is traversed by narrow canyons which open out headward into broad valleys in an advanced stage of topographic development. In this respect the range resembles many others among the Pacific mountains. An earlier surface, in some places softened and subdued with moderate waste-covered slopes, in other places a true peneplain, was deformed by faulting. The summit levels of the uplifted fault-blocks (the present ranges) display remnants of the ancient smoothly-contoured surface in strong contrast to the steep borders of the ranges sharply outlined by more recent faulting and now in process of vigorous dissection.

Large portions of the Coast Ranges are unknown even through reconnaissance surveys. Among the known portions the Santa Cruz section between San Francisco Bay and the Bay of Monterey presents features of special interest. Here the parallelism of the valleys and ridges is apparent in the larger features of the topography but is less marked or absent in the minor relief. The main ridges have a steep northeast slope bordered by a series of valleys lying along the San Andreas Rift. The lines of the major folds of the Santa Cruz region are marked by more or less continuous valleys, and in the case of both these larger valleys and the main ridges the topographic and geologic features are in sympathetic relation.[3] The hillsides of the region are generally covered with a deep coating of soil, and cliffs are rare, owing both to the friability of most of the rocks and to the advanced state

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[1] Lawson, loc. cit., p. 20.

[2] H. W. Fairbanks, San Luis Folio U. S. Geol. Surv. No. 101, 1904, p. 1.

[3] Branner, Newsom, and Arnold, Santa Cruz Folio U. S. Geol. Surv. No. 163, 1906, p. 1.

of topographic development which was reached before the last and recent uplift. An unusual feature of the topography of the Santa Cruz region is the occurrence of very steep yet soil-covered hillsides; 35° to 40° slopes are not uncommon, and in one place is found a soil- and vegetation-covered hillside with a slope of 50° from the horizontal. There is a dense growth of timber and underbrush over much of the area, which does not prevent the thick covering of soil from being frequently involved in landslides in the belts of greatest faulting and folding.[1]

The Coast Ranges of northern California include, besides the mountains proper, a coastal tract which was eroded (Pliocene) to the form of a peneplain. The coastal peneplain was then uplifted and its streams intrenched; it now forms a dissected plateau with long and roughly level-topped ridges separated by equally long, narrow valleys. The ridges are remarkably constant in general altitude, and the sky line is essentially level. In a general perspective the view is that of a plain or sloping plateau of low relief. The peneplain was uplifted to an elevation of 1600 feet above the sea on the seaward margin, and to 2100 feet on the inner margin. The mountainous tract adjacent on the east participated in the same movement. In Humboldt County several sharp peaks rise abruptly above the general level of the dissected plateau to 4000 or 5000 feet, but they are clearly encircled by remnants of the plateau which give to the mid-slopes of the peaks a distinctly terraced aspect. The peneplain may be followed in among clusters of mountain peaks and ridges and extends at least as far as the Bear River ridge. That the present dissected plateau was once a peneplain is inferred from the facts that the rocks composing it are of varying ages and of varying degrees of hardness, and that the general surface of the region bevels rather evenly across the deformed strata. On the summit of some of the ridges of the plateau numerous water-worn pebbles have been found, at 1600 feet, which are reasonably interpreted as remnants of larger bodies of stream gravels formed upon an erosion surface.[2]

The coastal peneplain grades into a region of stronger relief on the east where the stream courses were still completely under the control of geologic structure at the end of the first erosion cycle and flowed in mature subsequent valleys which were inherited by the streams of the second or present cycle of erosion. The abrupt coastal margin of the uplifted peneplain of northern California has given rise to a youthful

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[1] Branner, Newsom, and Arnold, Santa Cruz Folio U. S. Geol. Surv. No. 163, 1906, p. 10.

[2] A. C. Lawson, The Geomorphogeny of the Coast of Northern California, Univ. Cal. Bull., Dept. Geol., vol. 1, pp. 242–244.

topography along the coast; the coastal canyons are narrow and precipitous, and V-shaped profiles predominate. In the middle stretches of the streams degradation is less intense and the topography appears somewhat less rugged.

Recent events following the uplift and dissection of the coastal peneplain of California are a subsidence of at least 370 feet at the mouth of the Sacramento River which flooded the lower portions of that valley and gave rise to the magnificent harbor of San Francisco. The drowned mouth of the river once discharging across the Coast Ranges at this point is known as the Golden Gate. The last episode in the region has been a slight uplift in the vicinity of the Straits of Carquinez.[1]

Fig. 25. — Coastal terraces produced by wave erosion, west of Santa Cruz, California. (U. S. Geol. Surv.)

The uplift of the coastal peneplain of northern California was not accomplished in a single continuous movement but was interrupted by many halts. During these periods of relative stability there were formed well-developed ocean terraces which are among the most prominent features of the coastal topography. Such terraces were always involved in later uplifts and now stand at high levels, the highest representing the algebraic sum of all coastal changes whether of uplift or depression since the beginning of the last series of changes in the level of the land. The highest terrace of northern California is about

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[1] A. C. Lawson, The Geomorphogeny of the Coast of Northern California, Univ. Cal. Bull., Dept. Geol., vol. 1, pp. 270–271.

1500 feet above sea level. Below this are prominent terraces at 1400, 1180, 760, 440, 350, and 280 feet, respectively, above sea level, with many less prominent terraces at intermediate levels. The lower terraces have all the characters associated with wave and current origin, such as a rather regular seaward slope, upturned strata smoothly planed off, residual stacks, beach bowlders, and sea cliffs with horizontal base lines. The higher ones are usually not so clear, though even the highest have sufficient definition in the form of sea cliff, sloping terrace, and bowlder beach to make its character certain.[1]

MOUNTAINS OF SOUTHERN CALIFORNIA

In the southernmost division of the coastal mountains of California (see p. 127) faults have also played a very important part in the topography. Both the northern and southern sides of the San Gabriel range are determined by a profound fault; the range may be interpreted as a horst thrust up between two bounding faults. Since uplift the range has been thoroughly dissected and older surfaces of erosion destroyed.

> "One seeks in vain for horizontal lines along the San Gabriel tops; a confusion of peaks and ridges of discordant and seemingly unrelated heights makes up the mountain mass. . . . [They] present a labyrinth of canyons and ridges and peaks, with no level areas of any size. The ridges have narrow summits; the peaks are sharp; the streams are all evenly graded from source to mouth." [2]

The Santa Ana Mountains are a tilted, seaward-sloping mountain block with a very straight and abrupt fault scarp that faces the northeast and overlooks the Perris plain. The block is an elevated and as yet but little dissected peneplain (Cretaceous) with remnants of younger (Tertiary) deposits upon it, indicating that it has in part at least been resurrected in recent times from a buried condition. It is thought that the same tilted block structure extends beyond the Santa Ana Mountains southward to the international boundary and even beyond. Both sides of the San Jacinto Mountains are precipitous and probably determined by faults, so that the ridge has very bold margins.

Among the drainage features of these mountains are the interesting valleys of the Santa Ana and Santa Margherita rivers which are antecedent to the tilting of the region; they persisted in their southwestward courses during the development of the fault scarps, and now cut squarely across the range, draining the valley lands on the northeast.[3]

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[1] A. C. Lawson, The Geomorphogeny of the Coast of Northern California, Univ. Cal. Bull., Dept. Geol., vol. 1, pp. 246–247.

[2] W. C. Mendenhall, Ground Waters and Irrigation Enterprises in the Foothill Belt, Southern California, Water-Supply Paper U. S. Geol. Surv. No. 219, 1908, p. 17.

[3] A. C. Lawson and others, The California Earthquake of April 18, 1906, Carnegie Inst., vol. 1, pt. 1, pp. 23–24.

SAN BERNARDINO RANGE

The San Bernardino range of southern California is a distinct topographic unit and does not have a close genetic relationship with the other members of the Coast Range System in southern California. It is much younger than the San Gabriel range and appears to have had a history different from that of the San Jacinto range south of it. The relief of the mountains is outlined upon an uplifted fault block once of somewhat more regular development than at present. Remnants of an old surface of moderate relief, broad elevated valleys, plateau-like ridges, and several interior basins like those in the Mohave desert on the north, are the principal secondary topographic elements. At its western end is displayed a long even sky line at elevations between 5000 and 6000 feet above the sea.

Fig. 26. — Redlands and San Bernardino and San Gorgonio Peaks, San Bernardino Mountains, California. (Mendenhall, U. S. Geol. Surv.)

> " . . . there are many wide upland valleys, forested and grassy glades, and lakes or playas like Bear Lake and Baldwin Lake. Where these upland levels are attained it is difficult to realize that one is actually in the high mountains. The surrounding topographic forms are rounded and gentle, the level areas are extensive, the streams meander placidly through broad meadows, and the topographic type is that of a rolling country of moderate elevation. But as the edge of these interior uplands is approached the streams plunge into precipitous canyons, the slopes are as steep as earth and rock can stand, the roads and trails twist and turn and double to find a devious and precarious way to the valleys below."[1]

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[1] W. C. Mendenhall, Ground Waters and Irrigation Enterprises in the Foothill Belt, Southern California, Water-Supply Paper U. S. Geol. Surv. No. 219, 1908, p. 17.

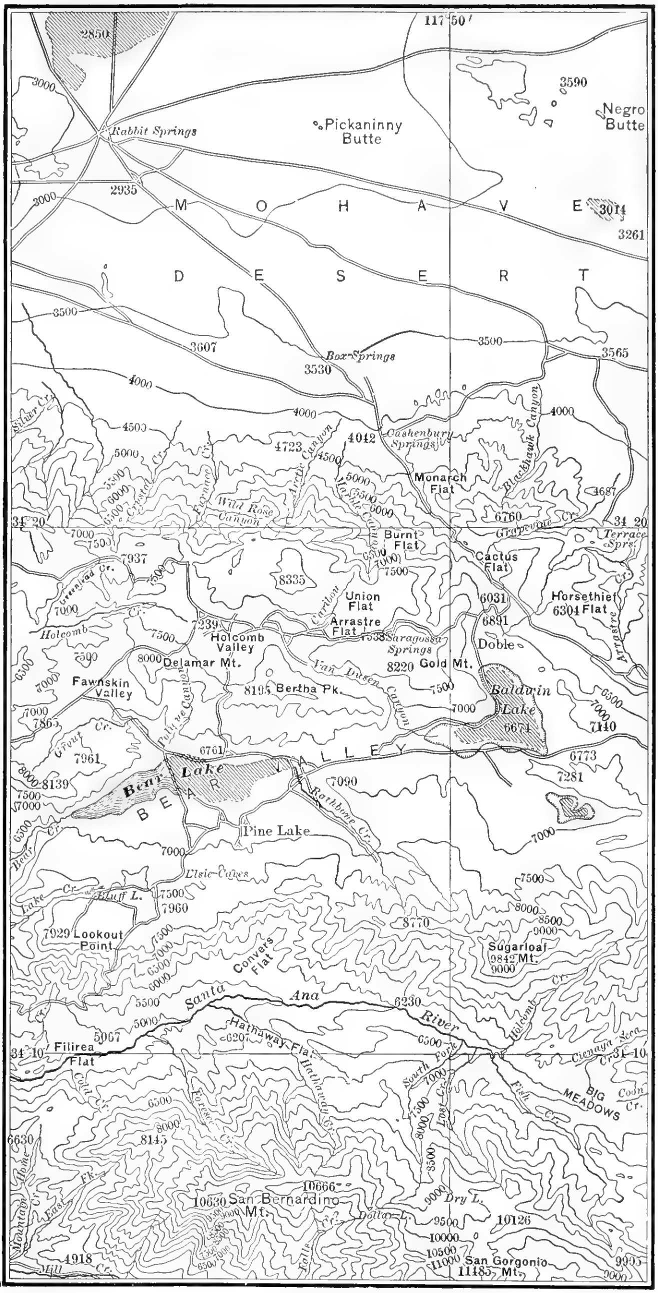

Fig. 27. — Bear Valley and the adjacent country exhibit the subdued relief characteristic of the interior of the San Bernardino Mountains. The parallel of 34° 20′ coincides with a fault scarp on the northern border of the range; the southern edge of the map represents a part of the southern border of similar origin. Both borders are deeply dissected. Note the withering streams, foreland plain, and playa of the Mohave desert. (San Gorgonio quadrangle, U. S. Geol. Surv.)

The mountain mass was blocked out of a portion of the earth's crust that was at one time continuous with the Mohave desert region and the San Bernardino Valley. The highest portion of the range is a rather sharp ridge about six miles long culminating in San Bernardino Mountain (10,630 feet) on the west and San Gorgonio Mountain (11,480 feet) on the east.

A surprising feature of the topography of the range is the occurrence of glacial cirques, moraines, and basin-like depressions. The southern limit of glaciation in this longitude has until lately been thought to be somewhat farther north, so that this occurrence of glacial features is one of the southernmost in the country.[1] Both the northeast and the northwest slopes of the main ridge appear to have been glaciated, the snowy accumulations having been formed in alcoves near the summit where drifted snows still gather. At the head of Hathaway Creek are five semicircular terminal moraines a mile and a half below the cirque-like basin close under the crest. Of interest in this connection is the fact that the summit of the range still supports a distinctly boreal fauna and flora.[2]

The Klamath Mountains

In the second major division of the Coast Ranges dominated by the Klamath Mountains and designated the Klamath sub-province there are three well-marked subdivisions: (1) a narrow coastal plain, (2) high marine terraces, and (3) a well-dissected plateau.

The coastal plain is from one to five miles wide, and its inner margin stands several thousand feet above the sea. Swamps border the expanded lower courses of the streams where lagoons have been formed back of the sand reefs that fringe the coast. An interesting feature of portions of the coast is the variable position of the stream mouths through the year; the south and southwest storms of winter produce a coastal drift northward and the inlets through which the rivers discharge are moved in this direction; but when the northwest winds of summer prevail the movement is southward. In many places the winds have blown the reef sands into dunes whose shifting character may long prevent tree growth. There appears to be a natural limit to this action, however, for each locality, so that ultimately lower forms of vegetation take hold of the sand and bind it, allowing the trees to come in. The

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[1] Other southerly localities where glacial features have been found are (*a*) near Santa Fe, (*b*) on San Francisco Mountain, (*c*) near Nogales, etc. For a résumé of these occurrences see D. W. Johnson, The Southernmost Glaciation in the United States, Science, n. s., vol. 31, 1910, pp. 218–220.

[2] Fairbanks and Carey, Glaciation in the San Bernardino Range, California, Science, n. s., vol. 31, 1910, pp. 32–33.

action is well illustrated along the inner margin of some of the dunes near Coos Bay, Oregon. Locally dunes have been driven inland so far from the source of sand supply, a mile or more, as at last to make little progress and to become covered with a forest growth.

On its inner margin the coastal plain has been moderately dissected; the outer margin of the plain still bears marks of extreme youthfulness in the form of coastal lagoons and recent marine sediments. Occasional rock stacks persist, of which Tupper Rock is a conspicuous illustration; they represent harder or more favorably located rock masses that withstood the wave erosion which carried away the softer surrounding rocks. Although the coastal plain of this part of Oregon is narrow it contains by far the greater part of the people of the region, a fact due to its flat tillable surface and the dark, rich loam which favors the interests of agricultural people.

The ascent from coastal plain to high-level plateau is made by a series of terraces sculptured upon the prominent spurs that define the interfluves. Ancient sea cliffs with ancient beaches at their foot alternate with long gentle slopes marking the wave-cut terraces that once extended seaward from the cliff as a submarine platform. The terraces range in height from 500 to 1500 feet. At the latter elevation is a well-marked, though discontinuous, sea cliff which has been traced for many miles along the coast. The preservation of these old cliffs and benches of a former shore line at such high elevations above the sea are suggestive of the rapidity that characterizes uplift on these shores.

The Klamath Mountains proper embrace all those peaks and ridges lying between the 40th and 43d parallels. Some of their most conspicuous members are the Salmon, Trinity, and Scott mountains of California and the Siskiyou and Rogue River mountains of Oregon. The mountains are composed in large part of rocks similar to those found in the Sierra Nevada, — limestone, sandstone, shale, schist, diabase, etc., — with traces here and there of lavas having a close relationship to those of the Cascade Mountains; in late physiographic history and in geographic position, however, they are related to the Coast Ranges.[1]

The dominating physiographic feature of the Klamath sub-region is the Klamath plateau. From one of the higher summits a general view of the landscape may be obtained which shows that while there are many small irregularities, the summit levels approximate a general plane with moderate inclination toward the sea. The elevation of the plateau is from 2000 feet on the west to 4000 and 5000 feet and more on the east. In many places decidedly flat summits may be noted, so that in a

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[1] J. S. Diller, Roseburg Folio U. S. Geol. Surv. No. 49, 1898, p. 1.

general view the surface appears to be a practically level-topped plateau deeply trenched by streams. The South Fork range in Trinity County, California, has an even sky line more than 40 miles long at an elevation exceeding 5000 feet in spite of its variable structure. Such a relation of surface to structure is indicative of a long erosion period in which rocks of diverse altitudes, hardnesses, etc., were brought to essentially the same level; in short, that the region was peneplaned, that is, reduced by long-continued erosion at one level to the form of an almost featureless plain. Uplift is indicated not only by the relatively high level at which the plain, once formed at sea level, now stands, but also by deep dissection.

The fact of early peneplanation and later dissection is also well shown by a comparison of the upper and lower valley slopes. The lower portions of the valleys are in general narrow and canyon-like, with prevailingly steep descents, while the upper portions of the valleys are wide and the slopes gentle. The upper gentle slopes are the slopes of an early valley system which is now being destroyed by the present drainage cut far below the old level since the uplift of the region. One of the best preserved of the early valleys is the Pitt River valley. The level of the broad, shallow, old valley of the Pitt is but 500 feet below the flat backbone of the ridges across which its course is directed, and is in very strong contrast to the deep, narrow, canyon-like valley of the present river. Traces of earlier valleys may also be found on the uplands along the McCloud and Little Sacramento valleys.

An interesting fact which bears upon the origin of the older valleys and the former existence of a peneplain is the occurrence at Potters Creek cave of the bones of some forty species of animals of which at least seventeen, including the mastodon, elephant, and tapir, are extinct. The character of the fauna indicates low relief and a condition quite out of harmony with the present topography.[1] The low relief that must have existed here when the peneplain was nearing its latest stages of development is also indicated by the fine character of the corresponding sediments (Ione formation) which like the characters of the fossil flora and fauna suggests a flat coastal region whose climate was not notably different from that of Florida to-day.[2]

The Klamath peneplain in an uplifted and deeply dissected state has been traced southwestward to the head of the Sacramento Valley, California, where the slopes of the mountains become gentler as they approach the

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[1] J. S. Diller, A Preliminary Account of the Exploration of the Potters Creek Cave, Shasta County, California, Science, n. s., vol. 17, 1903, pp. 708–712.

[2] J. S. Diller, Redding Folio, Cal. U. S. Geol. Surv. No. 138, 1906, p. 10.

highest summits. These flattish crests approximate a general plain and indicate that the region was one of gentle relief before the last uplift.

Turning now to the more rugged interior portions of the Klamath district we find that the main ranges fall into two rather well-defined systems which cross each other nearly at right angles. The most prominent ranges have an east-west trend, as the Rogue River, Siskiyou, Scott, and Trinity; on the other hand the Yallo Bally, Bally Choop, South Fork, and Salmon River mountains and many less important ridges run approximately in a northerly direction. Even in the central

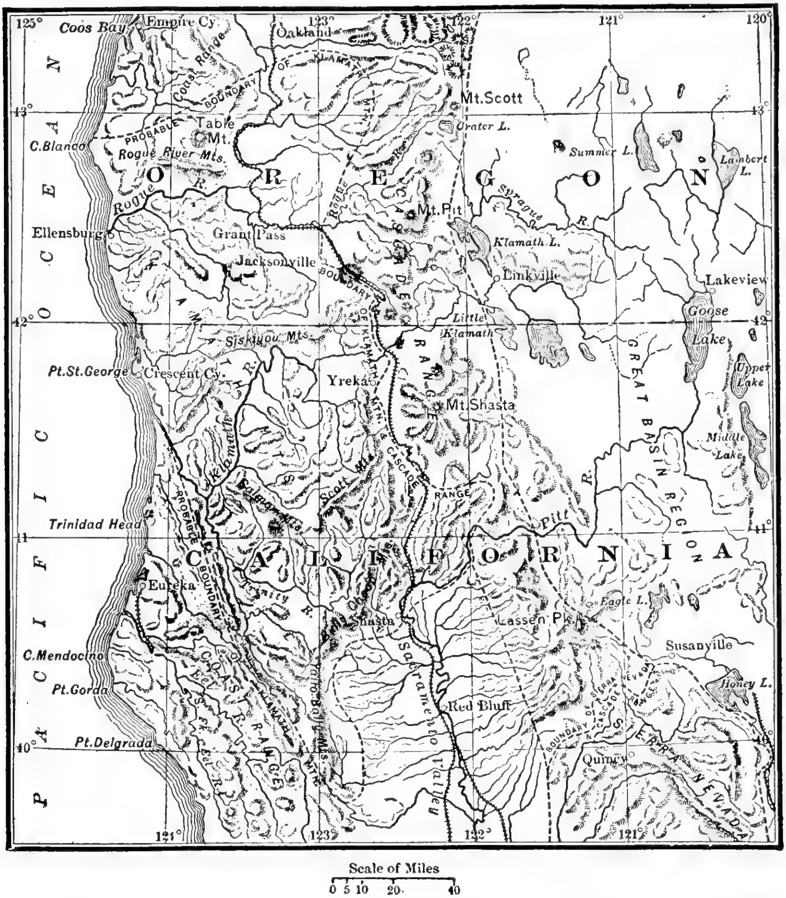

Fig. 28. — Boundaries between the Sierra Nevada, Cascades, Coast Ranges, and the Klamath Mountains. The Lassen Peak volcanic ridge extends from the Pitt River on the north to the North Fork of the Feather River on the south. It is the southern part of the Cascade Range. Goose Lake discharges into Pitt River only at long intervals. (After Diller, U. S. Geol. Surv.)

portion of the group, as between the Rogue River and the Trinity valleys, the north-south trends are apparent.

The mountain-rimmed basins of the region have two characteristic features; all receive the drainage of comparatively large areas, and each is drained by a main stream that leaves the basin to cross a bordering range through a deep canyon. Scott Valley, for example, 8 by 25 miles in extent, has a nearly level floor, and an extensive system of centripetal tributaries; it drains through an almost impassable canyon more than 20 miles long. Other interior valleys of this type are Hay Fork, Trinity, and Illinois.

It seems clear from the persistent manner in which the ranges lie athwart the main drainage lines that the ranges were developed after the drainage had become well established. It is conceived that the eastward-trending ranges had been developed, peneplanation had been accomplished, and the streams by gradual development had gained courses westward to the sea when elevation along north-south axial lines deformed the peneplain and gave rise to a system of cross ranges with intervening structural valleys and valley basins.[1]

The deformations of the Klamath peneplain were sufficiently acute to cause the north-south ranges to stand well above the general level of the broadly uplifted portions of the peneplain. The east-west ranges in the higher and more rugged portions of the Klamath group have a residual relation to the uplifted and dissected peneplain about them. They represent unreduced elevations and display a boldness of form and an irregularity of relief in sharp contrast to the plateau character of the marginal tracts of the region. They are nowhere lofty, however, nor does their ruggedness in any place have alpine characteristics. In general their elevation exceeds the elevation of the bordering peneplain from 2000 to 4000 feet.

Coast Ranges of Oregon

The Coast Ranges of Oregon constitute the third member of the Coast Range System of mountains. Their geology and geography have not yet been studied in sufficient detail to make generalization very profitable. It is known that they consist in part of sandstones (Eocene) and in part of volcanic rocks, the latter type constituting a considerable part of the ranges south of the Columbia River.[2] In the Coos Bay region a portion of the Coast Ranges of Oregon has been described as

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[1] F. M. Anderson, The Physiographic Features of the Klamath Mountains, Jour. Geol., vol. 10, 1902, pp. 144-159.

[2] Willis and Smith, Tacoma Folio U. S. Geol. Surv. No. 54, 1899, p. 1.

exhibiting somewhat flat though narrow hill and ridge crests from which steep slopes descend to the valley floors.[1] Farther north similar qualities are exhibited, and in addition there are a number of rather flat-topped tablelands which represent remnants of an elevated peneplain. The even summits rise to maximum heights from 1200 to 1700 feet above the sea south of the Columbia River. Above them are upper mountain slopes and a considerable number of peaks against which the plain breaks abruptly. The peaks form true monadnocks among which Saddle Mountain displays typical features and relations.[2]

While there is great variability in rock hardness from point to point it is notable that in general the rocks are so soft as to permit rapid erosion wherever the forest is removed. Under natural conditions erosion is prevented by an extremely dense vegetal covering which not only breaks the force of the heavy rains but also binds the soil and delays run-off in other familiar ways.

The Coast Ranges of southwestern Oregon almost meet the western spurs of the Cascades. The Willamette Valley narrows toward its head, and beyond it and to the south are other streams of still more restricted valley development. At Roseburg (43° 10′), the depression between the ranges narrows to but fifteen miles. The foothills of the Cascades form a prominent though not a precipitous mountain border. The streams descend from the long, sloping western flank of the volcanic tableland of the Cascades and emerge from their rugged canyons to enter the more open valley stretches of the Umpqua, or Rogue, or Klamath rivers. Among these valleys the Umpqua alone lies north of the Klamath Mountains. It maintains an open character for but a short distance, however, then strikes boldly into and across the Coast Ranges, where its valley becomes a canyon. The most remarkable feature of the canyon is its winding course, which appears to represent the meanderings of its stream in an earlier topographic cycle when it flowed upon the surface of a peneplain now represented by the even and accordant crest lines of the Coast Ranges. The courses of the master streams, as the Nehalem in northwestern Oregon, resemble the Umpqua in the manner in which they cut across the mountains. They gained their courses on the coastal peneplain and since its uplift to form the Coast Ranges they have persisted in their courses. The smaller streams all show a sympathetic relation to the structure; their valleys in general follow the outcrop of the softer rocks.

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[1] J. S. Diller, Coos Bay Folio U. S. Geol. Surv. No. 73, 1901, p. 1.

[2] J. S. Diller, A Geological Reconnaissance in Northwestern Oregon, 17th Ann. Rept. U.S Geol. Surv., pt. 1, 1895-96, pp. 449, 488.

The eastern front of the Coast Ranges of Oregon is a bold, partly dissected fault scarp, about 2000 feet high, formed of massive sandstone which stands above the lowland developed upon the shales and thin-bedded sandstones east of it. The mountain spurs running westward to the sea have a longer and gentler descent than those extending eastward to the Willamette Valley. The western spurs terminate on the coast as prominent and cliffed headlands connected by stretches of sand beach covered with a dense growth of grass and ferns.

Great terraces have been developed on the coastal margin of the Coast Ranges of Oregon just as on the western borders of the Klamath Mountains and the Coast Ranges of California. Since their development the terraces have been uplifted to heights of hundreds of feet, the highest attaining an elevation of 1500 feet. Above this elevation uniformity of level is less marked but still sufficiently marked to indicate the existence before the last uplift of an extensive plain of erosion now maturely and deeply dissected by the rejuvenated streams.[1]

OLYMPIC MOUNTAINS

The Olympic Mountains are the most conspicuous member of the northernmost section of the Coast Range System. They lie north of the Columbia River and west of Puget Sound. Like the Cascades the dominant peaks are volcanoes that rest upon a much older schistose rock. The highest peak of the Olympics, Mount Olympus, rises 8200 feet above the sea, and crowns a magnificent range in full view from the eastern side of the Sound. The higher mountains are alpine with sharp spires and serrate ridges from 6000 to 8000 feet high. The mountains have a roughly circular form and are about 40 miles across. The drainage of the region is radial, the streams being arranged much like the spokes of a wheel of which the region of high mountains is the hub; it has been suggested that this feature is due to the domed warping of a former flattish surface of erosion.[2]

The uplift of the mountains is still progressing, or at least uplift has occurred in postglacial time, as shown by the gently folded and tilted glacial clays, sands, and gravels in the vicinity of Port Angeles. The range is one but little known to-day on account of the ruggedness of the country, the fallen trees, the lichen-covered rock slopes, and the extreme density of the tangled underbrush. Because of the high degree of humidity, the great rainfall, and the equable and moderate temperature

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[1] J. S. Diller, Roseburg Folio U. S. Geol. Surv. No. 49, 1898, p. 4.

[2] Ralph Arnold, Geological Reconnaissance of the Coast of the Olympic Peninsula, Washington, Bull. Geol. Soc. Am., vol. 17, 1906, pp. 451–468.

the mountain slopes are clothed with an almost impenetrable forest up to an altitude of 7000 feet. The Olympic forest is the densest in Washington and with few exceptions the densest in the country. It consists chiefly of red fir and hemlock.

Climate, Soil, and Forests

The Coast Ranges extend through 20 degrees of latitude and lie in two distinct climatic belts, the belt of the westerly winds and the horse latitude belt. Southern California lies wholly in the latter belt, where the rainfall is scant on the lowlands and limited on the highlands or mountains, yet sufficient on the higher exposed slopes to support a forest growth. Its forests are in general of small extent, although a number of districts in the coastal ridges and the San Bernardino Mountains have good stands of timber. The Forest Service estimates the total standing live timber of merchantable size in this district, at approximately 1 % of the total for the State. At present there is in some localities a tendency toward eucalyptus culture, which may eventually have a beneficial effect upon the run-off of the region,[1] besides supplying the demand for a hardwood, one of the great defects of the Pacific forests.[2] It is, however, particularly sensitive to cold and especially will not endure frost, hence the range of its culture will be distinctly limited.

The Coast Ranges south of San Francisco lie in the belt of winter rains and are almost rainless in summer months. Nearness to the sea, however, brings climatic responses of great importance to vegetation, even in summer. The regular northwest winds of summer blow from the sea and for several months are accompanied by cool, damp fogs which sweep inland forty to fifty miles. They temper the hot summer weather, depress the rate of evaporation, and in the lands they overlie they make possible the production of certain crops without irrigation.

The larger part of the rainfall occurs on the western slopes of the westernmost ranges, decreasing on each range in eastward succession. It is nowhere sufficient to support a true forest vegetation, except immediately south of San Francisco where the Coast Ranges are covered with a heavy growth of timber and underbrush. At the heads of the valleys which drain the higher portions of the Santa Cruz Range

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[1] Van Winkle and Eaton, Quality of the Surface Waters of California, Water-Supply Paper, U. S. Geol. Surv. No. 237, 1910, p. 65.

[2] Betts and Smith, Utilization of California Eucalypts, Circular U. S. Forest Service, No. 179, 1910, p. 6.

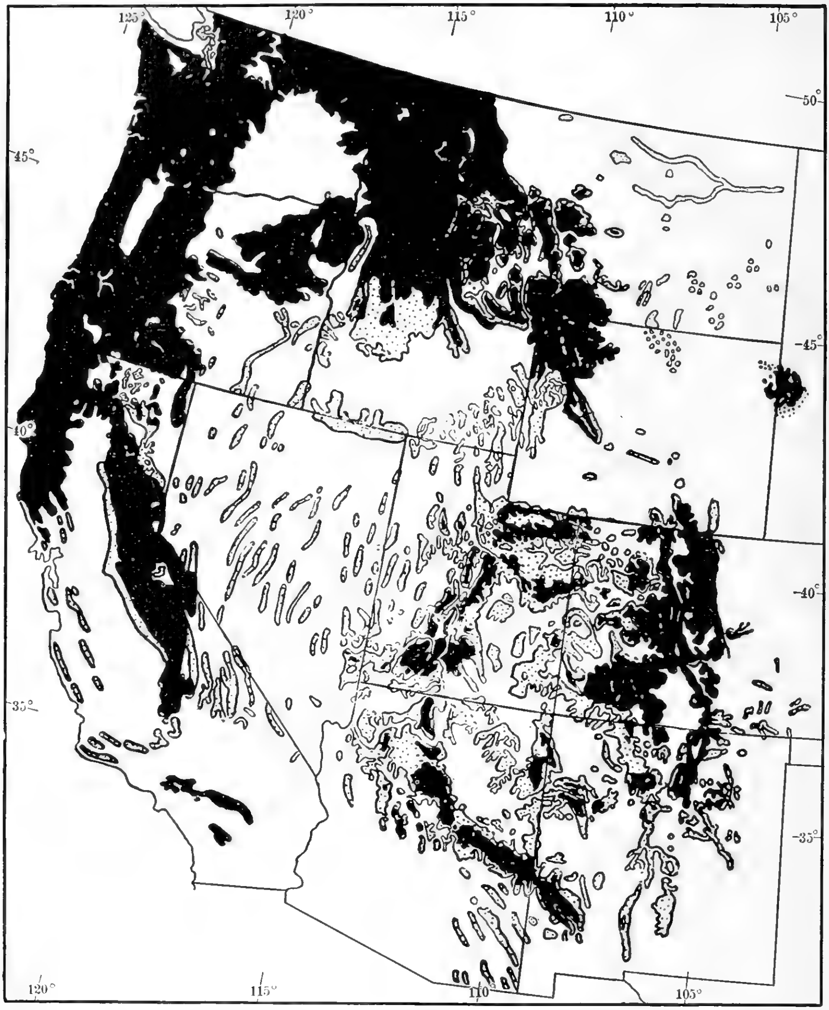

Fig. 29. — Distribution of western forests and woodlands. Solid black represents continuous forests; dotted areas represent woodland, that is, a thin scattered growth of forest vegetation. (Newell.)

the rainfall is heavy and originally supported a dense growth of redwoods.[1]

Farther south, at San Luis Obispo (lat. 35° 20′) the rainfall is 21 inches, though it has the variable quality of the true desert type of rainfall, ranging in different years from 5 to 40 inches, a feature which

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[1] Branner, Newsom, and Arnold, Santa Cruz Folio U. S. Geol. Surv. No. 163, 1909, pp. 9, 11.

greatly limits the forest growth since in dry years only the most favored situations supply trees with the necessary moisture. The higher and steeper mountain ridges are generally covered with a dense growth of low shrubs or chaparral, among which are the manzanita, scrub oak, and California lilac. The sycamore follows the watercourses and is grouped about springs, in places forming dense groves. The canyons and marshy tracts have a growth of willow and laurel. In the higher valleys white oak is abundant, while the Digger pine is common on the ranges east of those on the immediate coast.

There is great variation in the soils throughout the Coast Ranges of California and related variations are clearly traceable in many of the plant distributions. At San Luis Obispo heavy and rich soils support grasses and wild oats which replace the shrubby vegetation even on steep slopes. Live oak and laurel are found on areas where a rich soil and a good water supply are combined. Vegetation is most scanty where soils of poor quality occur, for example over areas underlain by serpentine rocks. The best growth of grasses is found on soil derived from an earthy sandstone (San Luis formation) intruded by basic rocks; these yield on decay a deep, residual soil of great fertility even on steep hillsides.[1]

North of San Francisco the rainfall increases rapidly as one enters the belt of permanent westerly winds. While the rains are more frequent and heavy during the winter season they do not fail in summer as is the case farther south. In Oregon and Washington the Coast Ranges are heavily watered and receive more precipitation per unit area than any other tract in the country. At 2000 feet the Coast Ranges of northwestern Oregon enjoy a total precipitation of 138 inches[2] and at higher elevations the precipitation is estimated at 150 inches.[3] While this enormous precipitation is not evenly distributed throughout the year the rainfall is heavy even in the relatively drier season, hence the forest growth is extremely dense and the trees of great size. Because of increasing temperature there is a marked increase in size with decreasing elevation in the well-watered portions of the mountains.

These two primary controls of forest distribution, precipitation and temperature, have important variations in altitude and latitude that are well expressed in the Coast Range System of North America as a

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[1] H. W. Fairbanks, San Luis Folio U. S. Geol. Surv. No. 101, 1904, pp. 1, 2, 14.

[2] A. J. Henry, Climatology of the United States, Bull. Q, U. S. Weather Bureau, 1906, pp. 948–949.

[3] J. C. Stevens, Water Powers of the Cascade Range, pt. 1, Southern Washington, Water-Supply Paper U. S. Geol. Surv. No. 253, 1910, p. 4.

whole. In Alaska the greater portions of the mountains are bare or covered with snow fields and glaciers; in the Coast Ranges the forest is restricted to a belt between 2500 feet and sea level. In the interior mountains of Alaska, such as the Endicott Mountains, no forests at all occur because of cold and at least physiological dryness. Farther south the cold timber line has a greater elevation and the forest belt is wider, attaining its maximum development in Washington, Oregon, and northern California. Still farther south the dryness of the lower slopes causes the forest growth to be restricted at lower elevations on account of drought, as it is restricted at higher elevations because of cold. Like the cold timber line the dry timber line lies at progressively higher elevations with decreasing latitude and increasing temperature, so that in southern California the forest growth is restricted to the upper slopes and summits in the zone of maximum rainfall.[1]

The higher mountain slopes and mountain summits of Alaska are without forests; in southern California the plains and lower valleys are without forests. The mountain summits in the latter case are sufficiently warm to support forests, but the lower slopes are too dry. The intermediate tract has neither the great cold of Alaska nor the great dryness of southern California. Its forests of fir and cedar in Oregon and Washington and of redwood in northern California are among the most magnificent in the world. Broad-leaved trees are rare however. A few specimens are found along the streams and in the lower valleys, as the maple, cottonwood, ash, and alder in Washington and the oaks in California.[2] The forest is composed chiefly of conifers, but within it there is considerable variation in the distribution of species on account of differences of soil, climate, and topography. The cedars thrive best in the moister valleys and along the watercourses, though their range includes a large extent of higher mountain slopes. The firs thrive on the drier (though in an absolute sense wet) uplands, ridges, and steep mountain slopes, but they are also tolerant of wetter situations. On the steep declivities and sharp ridges, between 4000 and 8000 feet, as well as in more favorable situations, the sugar pine is found; in the middle of its range it attains great size and remarkable symmetry of form.

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[1] J. Hann, Handbook of Climatology, 1903, pp. 305–308, presents an important summary of knowledge concerning increase and decrease of rainfall with increasing altitude and discusses the altitude of the zone of maximum rainfall. Scarcely any observations of the elevation of the zone of maximum rainfall have been made on mountains in middle latitudes, but it is probably between 3000 and 6000 feet, varying with the exposure, the temperature, etc.

[2] I. C. Russell, North America, 1904, pp. 238–239.

CHAPTER XI

CASCADE AND SIERRA NEVADA MOUNTAINS

CASCADE MOUNTAINS

Central Cascades

The Cascade Mountains form a separate physiographic province not only because of the distinct manner in which their borders lie above the surrounding country but also because of their characteristic interior features. The province is set off from the Sierra Nevada Mountains on the south, Fig. 28, by the valley of the North Fork of Feather River in northeastern California; the northern Cascades terminate quite as sharply immediately north of the international boundary line and south of the Frazer River Valley. The western and eastern borders of the Cascades descend steeply to the Sound Valley and the Columbia Plateaus respectively. The eastern border of the Cascades is particularly well marked in central Washington and in Oregon immediately south of the Columbia River, where the steepness of the slopes suggests an origin through either very sharp folding or faulting, but faults have not been actually observed, for lava flows to a large extent conceal the underlying structure.

Except for the breaks of the Columbia, Klamath, and Pitt valleys the Cascades possess marked continuity, and roads have been built across them only with great difficulty. Three railways cross the mountains to Tacoma and Seattle, but the grades are very steep and each line at the highest point requires a tunnel about a mile long.

In the earlier descriptions of the Cascade Mountains great attention was paid to the line of lofty volcanoes that are dominating elements in almost every view. Conspicuous among these elevations are Mount Rainier (14,500), Mount St. Helens (9700), Mount Baker (10,800), and Mount Adams (9500) in Washington, and Mount Hood (11,200), Mount Jefferson (10,200), and Mount Pitt (9700) in Oregon. The early explanation of the Cascades, suggested by the fact that a large amount of volcanic material occurs in the region, ascribed their forms wholly to volcanic processes, but later studies[1] show that the Cascades, at least in

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[1] I. C. Russell, A Geological Reconnaissance in Central Washington, Bull. U. S. Geol. Surv. No. 108, p. 30.

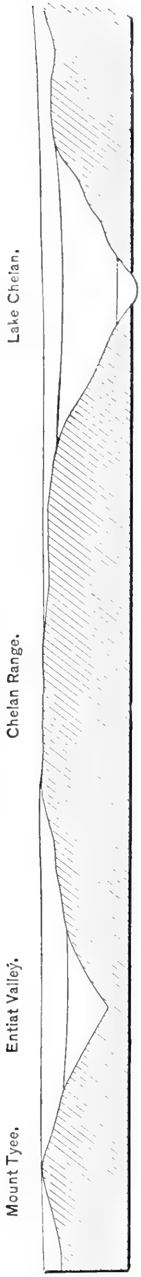

Fig. 30. — Profile across the Chelan Range (Cascades), showing the peneplaned surface uplifted and dissected. Two partial cycles are shown (1) in the lower dotted line and associated slopes, (2) in the steeper valley slopes at the lowest level. (Smith and Willis, U. S. Geol. Surv.)

Washington and north-central Oregon, have been formed not mainly by the piling up of volcanic material but by the broad uplift and deformation of lava sheets, granites, and sedimentary strata. The great volcanoes that appear to be such prominent features of the range are secondary to the main mountain forms which consist of deeply intrenched valleys and sharp ridge crests with accordant altitudes. It has also been determined that the structure of the range is highly complex and that the conception of a warped monoclinal fault block sculptured by erosion such as is properly applied to the Sierra Nevada requires considerable modification here.[1] On the basis of truncated folds and a general lack of sympathy between surface and structure over broad areas, it is concluded that the Cascades may be termed mountains of the second generation; that is to say they are mountains which have been formed by the broad uplift and deep erosion of an almost base-leveled or peneplaned surface.[2]

Perhaps the two best localities from which to observe that uniformity of summit levels which is an inheritance from the period of peneplanation are at the head of Cold Creek, Washington, or near Cascade Pass,[3] although in many localities within the province, accordance of summit levels can not be observed because of (1) the complex nature of the later deformation that affected the ancient surface, (2) the volcanic outpourings that have in many places obliterated the old relief, or (3) the presence of unreduced or residual masses. This is true especially of the more elevated portions of the range where no recognizable flat-topped remnants of the original plateau are to be found.[4]

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[1] I. C. Russell, A Preliminary Paper on the Geology of the Cascade Mountains in Northern Washington, 20th Ann. Rept. U. S. Geol. Surv., pt. 2, 1899, p. 137.

[2] Idem, p. 140.

[3] Smith and Willis, The Physiography of the Cascades in Central Washington, Prof. Paper U. S. Geol. Surv. No. 19, Plates 9 and 10, pp. 53–54.

[4] I. C. Russell, A Preliminary Paper on the Geology of the Cascade Mountains in Northern Washington, 20th Ann. Rept. U. S. Geol. Surv., pt. 2, p. 141.

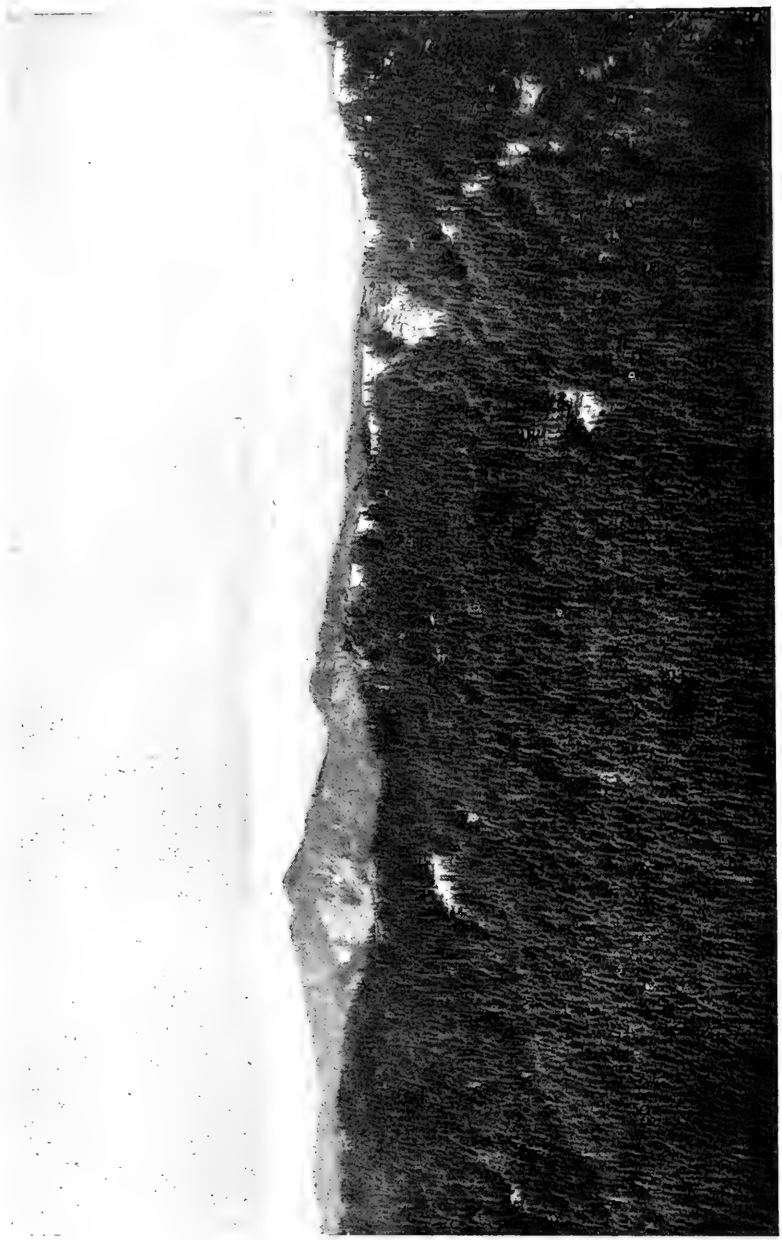

Fig. 31. — General view of the accordant ridge crests of the Cascades in lat. 45° 15′, looking south from Cone Peak. Note the steepness of the slopes and the heavy timber covering. (U. S. Geol. Surv.)

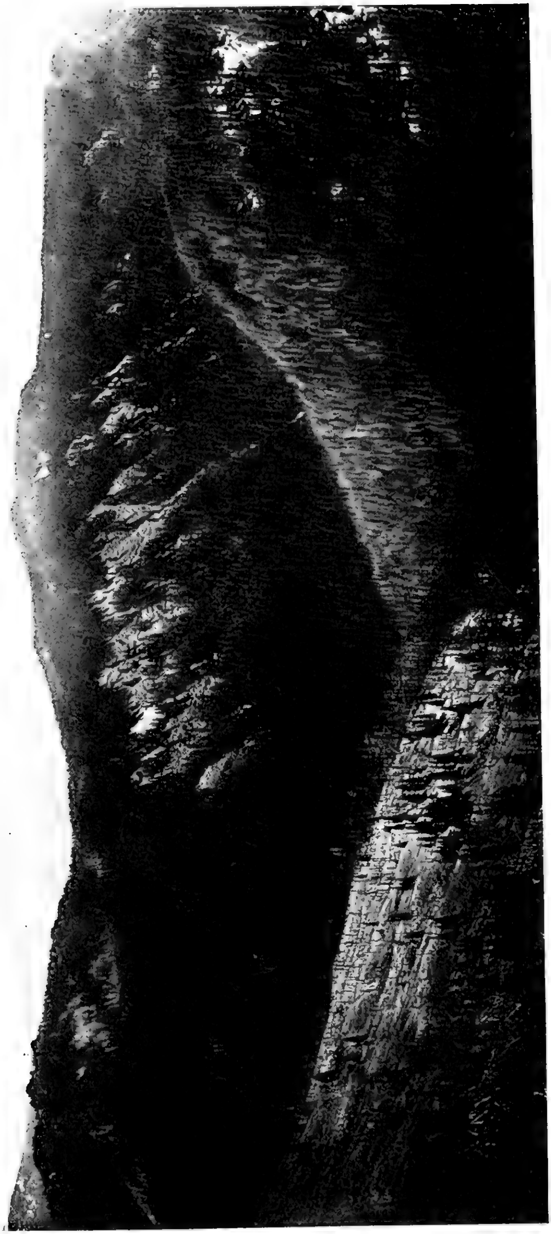

Fig. 32. — Details of Cascade topography in lat. 44° 15′, looking southeast from Cone Peak to the Three Sisters. Fig. 31 represents a more distant and general view looking south. (U. S. Geol. Surv.)

Fig. 33.—View of High Cascades from near Cascade Pass, showing uniformity of summit levels. (Smith & Willis, U. S. Geol. Surv.)

The uniformity of summit level has been found to extend over the greater part of the Cascades, but it is clearly visible only from selected viewpoints and is generally expressed in the ideal plane of the ridge crests and the hilltops rather than in the few undissected remnants of the former plateau now remaining. It occurs at elevations varying from 4000 to 8000 feet; the maximum of 8000 feet is attained north of the 47th parallel and continues to the 49th parallel. In the vicinity of Mount Rainier the plateau remnants, at about 7500 feet, form the platform on which the cone of Mount Rainier stands. Toward the south the altitude of the plateau decreases and becomes about 4000 feet in southern Oregon where the width of the province at the plateau level is from 60 to 75 miles. Between latitude 44° and 45° N. in the Mount Washington-Mount Jefferson country the accordance of summit levels among the hill and ridge crests is quite remarkable, the broad bases of the snow-capped peaks resting upon the general summit of the plateau as shown in Fig. 32. The plateau is at an elevation of 5000 feet above Mount Baker, in Washington, and thence descends westward to the Sound level in the form of a broad and somewhat regular slope.

As a whole, then, the Cascade range has a broad though greatly dissected summit about 75 miles wide, upon which is a remarkably straight north-south line of several score volcanic peaks. These lie not along the central portion of the range but near the eastern margin, so that the greater mass of the range lies west of the geographic summit and watershed. From the crowning line of peaks long, broad, flat-topped spurs, some of them having almost the magnitude of distinct ranges, descend eastward to the Columbia Plateaus and Great Basin; that part of the range west of the summit consists of long massive mountain spurs (generally with accordant altitudes on north-south lines) and intervening deep canyons. The lava flows extending outward from the line of the now extinct volcanoes have altered the drainage courses greatly by damming the streams, thus causing lakes, marshes, and new outlets. These changes have taken place so recently as to give the drainage lines many youthful features.

The eastern margin of the Cascades extends southward from the vicinity of Osoyoos lake on the 49th parallel to Ellensberg and thence down the west side of the Yakima Valley and across the Columbia into Oregon. On this side the slope has marginal flutings which extend nearly at right angles to the major uplift some distance into the lower Columbia Plateaus on the east and give the margin in places an extremely irregular outline.[1]

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[1] Smith and Willis, The Physiography of the Cascades in Central Washington, Prof. Paper U. S. Geol. Surv. No. 19, 1900, p. 25.

Long, gentle slopes along the flanks of the ridges descend to the valley floors. The dip of the rock and the inclination of the slopes of the ridges agree in direction but differ in amount, the dip of the rock commonly exceeding the inclination of the slope. Such a relation of form to structure requires the assumption of an erosion period in which was developed a topography moderately discordant with respect to structure and later deformed into the attitude in which we find it to-day.

The slopes of the older surface have a remarkably smooth development and are so regularly coördinated that the marks of recent dissection are not readily distinguishable in a view along the border. There appears to be only a gently inclined surface extending without perceptible break from the even-crested ridges to the valley floor. As a matter of fact, narrow gulches alternate with the ridges.[1]

Deformations of the ancient surface occurred in many places, and all show that the uplift of the Cascade lowland to form the Cascade plateau or mountains was not a simple broad anticlinal uplift or fault block deformation but a deformation of complex character.[2] There was at least one important halt in the uplift during which a mature topography was developed in places. One of the most important facts relating to the broad deformation of the formerly peneplaned surface now uplifted and dissected into the forms of the Cascades is the antecedent course of the Columbia River. After flowing for several hundred miles along the eastern front of the Cascades in Washington this trunk stream turns nearly at right angles and strikes boldly across the very heart of the Cascades. From a width of 2000 feet at the point where the Snake River enters it, the Columbia narrows to from 130 to 200 feet at "the Dalles," where it is bordered by high basaltic cliffs.[3] The river thus bears an antecedent relation to the range, having maintained a course outlined upon the Tertiary (Pliocene) peneplain.

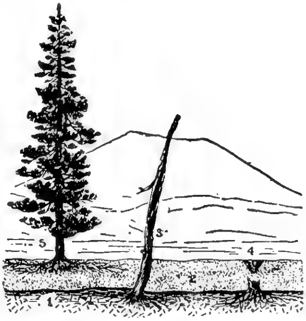

Fig. 34. — Section showing relations of former and present forest near Prospect Peak, Cal.
1. Original soil. 2. Volcanic ashes and lapilli. 3. Tree of former forest, killed by shower of volcanic ashes. 4. Pit formed by decay of old stump. 5. Tree of present forest. (Diller, U. S. Geol. Surv.)

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[1] Smith and Willis, The Physiography of the Cascades in Central Washington, Prof. Paper U. S. Geol. Surv. No. 19, 1900, p. 26.

[2] Idem.

[3] The narrow portion of the channel terminates at the foot of a line of falls and rapids called "The Cascades," whence the name of the mountains (see especially George Gibbs, Physical Geography of the North-Western Boundary of the United States, Jour. Am. Geog. Soc., vol. 3, 1870–71, pp. 144, 147, 148).

Southern Cascades

The southern end of the Cascades is the Lassen Peak volcanic ridge which extends southeast from the Pitt River to the North Fork of the Feather River. The ridge is about 25 miles wide and 50 miles long. It was built up by eruptions from more than 120 volcanic vents. A few of the craters are over a mile in diameter and were centers of enormous eruptions. All the prominent peaks of the ridge are volcanic cones. The last of the eruptions occurred very recently, a number of them taking place probably not more than 200 years ago; some of the trees killed at the time are still standing. Large portions of the original pine forest were covered with a mantle of volcanic sand or overwhelmed by lava during the more recent eruptions. In places the trees of the older forest project above the volcanic sand, their bare trunks forming a striking contrast to the new green forest developed at a higher level, Fig. 34.

The western slope of the volcanic ridge is relatively gentle and is underlain by volcanic material in the form of lava flows or agglomerate tuff. It is dry and sterile, and the larger part is strewn with rough lava fragments. The eastern slopes are in general bold.

The Lassen Peak volcanic ridge is from 5000 to 9000 feet high and about 4000 feet above the Great Valley of California on the southwest and the Great Basin on the east. Its highest point, Lassen Peak, is 10,437 feet above the sea. The ridge receives a sufficient rainfall to support an open forest of pines.

Northern Cascades

Immediately north of the 49th parallel the Cascades terminate abruptly and descend to a plateau several thousand feet lower; immediately south of the 49th parallel the Cascades have their greatest development. The distance from Mount Chopaka on the eastern to Mount Baker on the western side of the northern Cascades is about 90 miles. Thus by a pure coincidence the international boundary is also a physiographic boundary although it follows a parallel.

Like the Sierra Nevada Mountains, the Cascades terminate on the north in a triple set of subranges, the Okanogan, Hozomeen, and Skagit mountains. The Okanogan Mountains extend from Mount Chopaka to the valley of the Pasayten River. On the east the Okanogan Mountains terminate abruptly in a narrow foothill belt. Mount Chopaka here rises as a steep wall over 7000 feet high on the border of the Similkameen Valley. Between the Pasayten River and the Skagit River is the Hozomeen range; west of the Skagit River are the Skagit Mountains.

The north-south valleys of the Pasayten and Skagit thus form the dividing lines between the three subranges of the northern Cascades. We shall now briefly examine the detailed characteristics of each of these ranges.

The Okanogan Mountains consist of a great batholith of granitic rocks and are perhaps the most important igneous member of the Cascades. The Skagit and Hozomeen ranges are composed chiefly of sedimentary rock, with a large amount of conglomerate, slate, and schist, the latter having structures with a north-south trend.[1] The Okanogan Mountains have a number of high peaks such as Chopaka, Cathedral, Remmel, and Bighorn, with a nearly uniform elevation of 8000 to 8500 feet. Almost all the mountain peaks are above the 7000-foot level. The highest peaks are extremely rugged, and are bordered by deep glaciated valleys. Glaciers still persist on the north sides of a few peaks, but they are of small size. The evidences of former more extensive glaciation are particularly well shown in the deeply carved northern aspects of spurs and ridges where steep-sided cirques and gulches

Fig. 35. — Cathedral Peak, Okanogan Mountains, Washington, showing glaciated summit of the matterhorn type. Nearly vertical jointing in granite rock has assisted glacial erosion in producing rugged forms. (Smith & Calkins, U. S. Geol. Surv.)

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[1] Smith and Calkins, A Geological Reconnaissance Across the Cascade Range near the 49th Parallel, Bull. U. S. Geol. Surv. No. 235, 1904, p. 84.

abound. The southern slopes are more regular and without glacial modification. Small lakes with bordering snow banks occupy almost all the glacial amphitheaters that are tributary to the Similkameen.

Hozomeen range includes the central and main crest of the northern Cascades. Its western flank is scored by a number of remarkably narrow canyons, among which is the Skagit, whose mouth is so narrow as barely to permit the passage of the stream. The divide of the range has an elevation of 7000 to 8000 feet, and about ten miles south of the 49th parallel consists of sharp peaks with rugged outlines due to the irregular, coarse, and resistant conglomerate of which they are composed and the deep dissection of the range of which they form a part. Numerous glaciers occur and glacial cirques have been cut back into the main mass of the mountain to such an extent that the peaks are largely of the pyramidal or matterhorn type. North of the boundary the topography of this subrange becomes much less bold.

Skagit Mountains form the western subrange of the Cascades and include the wildest and most rugged country of the entire section. High peaks with precipitous sides abound and the scenery is extraordinarily picturesque. The mountain slopes are so steep that much of the country is practically inaccessible and unknown even to prospectors. Sharp, glaciated, pyramidal peaks are characteristic of the range about the headwaters of the Nooksak and Chilliwhack rivers. Some of the higher peaks are still flanked by glaciers, the feeble descendants of the large Pleistocene glaciers that are responsible for the development of amphitheaters with extremely steep walls and for the pyramidal peaks which occur throughout the range. The western portion of the Skagit Mountains consists of broader ridges, essentially flat-crested, smooth, grass-covered, and separated by broad steep-walled canyons. The western border of the northern Cascades is marked by an abrupt descent to the gravel-covered plain that extends west to the coast.[1]

The flat-topped ridges of the Skagit range west of the Mount Baker district have a somewhat uniform elevation of 5000 to 6000 feet and a gentle westerly inclination. The flat tops are interpreted as the remnants of a preëxisting topography which once occurred in the form of a fairly perfect lowland with few residuals rising above the general surface. Later uplift supplied an opportunity for vigorous dissection. Where the uplift was from 5000 to 6000 feet remnants of the old surface remain on the divides. Where the uplift was 7000 feet and more no traces of the old lowland persist, the peaks are acute pinnacles, the

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[1] Smith and Calkins, A Geological Reconnaissance Across the Cascade Range near the 49th Parallel, Bull. U. S. Geol. Surv. No. 235, 1904, pp. 13–17.

divides mere knife-edges. In the Okanogan Mountains the peaks at 8000 feet are approximately uniform in altitude and merely suggest an older topography. At the time of uplift of the northern Cascades from base level there appears to have been not a single broad upwarp; the three subranges composing the northern Cascades represent distinct upwarps separated from each other by downwarps which have determined the positions of Pasayten and Skagit valleys.[1]

The abrupt termination of the Cascade Mountains at the international boundary line has been shown to be due to a difference in degree of uplift between the Cascade country and the Interior Plateau of British Columbia since the last erosion cycle common to both mountains and plateau. The earlier structures so far as known appear to extend from one province to the other, denoting a common geologic history down to the Eocene.[2] In the latter part of the Pliocene, uplift of the base-leveled surface common to both took place, but the uplift was differential and amounted to about 4000 feet in the Interior Plateau and about 8000 feet in the Cascades. The uplift of 8000 feet was, however, not uniform throughout the Cascades; it was an uplift in the form of upwarps and downwarps, the upwarps being represented to-day by the three parallel ranges constituting the northern end of the Cascades, and

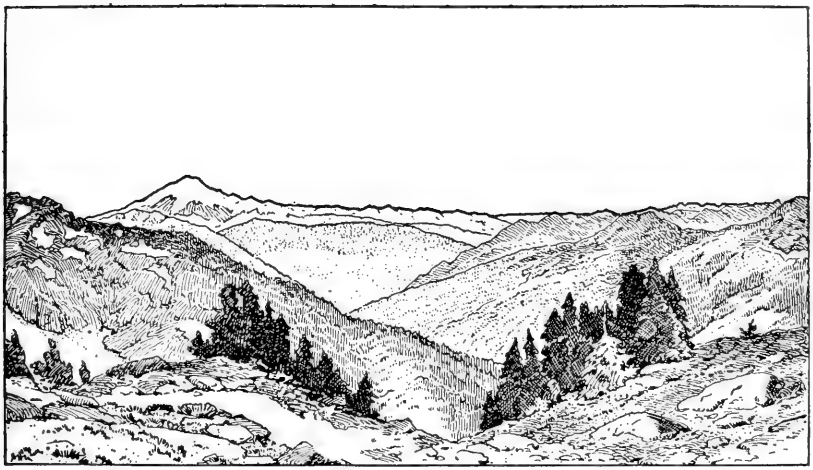

Fig. 36. — Plateau of the Cascades representing uplifted and dissected lowland surface. Western portion of Skagit Mountains, Mount Baker in left background. Looking west from Bear Mountain. (Smith and Calkins, U. S. Geol Surv.)

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[1] Smith and Calkins, A Geological Reconnaissance Across the Cascade Range near the 49th Parallel, Bull. U. S. Geol. Surv. No. 235, 1904, p. 89.

[2] G. M. Dawson, Trans. Royal Soc. Canada, sec. 4, 1890, p. 16.

the downwarps by the intervening valleys. During the upwarping certain streams persisted across the structures upraised in their paths, such as the Skagit across the Skagit Range, the Columbia across the Cascades, and the Frazer across the Interior Plateau. All these streams are therefore antecedent in portions of their courses. The differences between the Cascade ranges on the one hand and the Interior Plateau and Columbia Plateaus on the other are therefore due fundamentally to differences of elevation and degree of dissection conditioned by uplift. The eastern margin of the peneplain of the Cascades descends gradually to the plateaus of the Columbia apparently without a break; a similar but more sudden descent marks the northern end of the Cascades where they descend to the level of the Interior Plateau of British Columbia.

The rather general occurrence of the Columbia River lavas over a large part of the northern and central Cascades is accounted for by the fact that the extrusion of the lavas took place mainly at a time when the low relief of the land allowed their widespread distribution. These great basaltic inundations are to be distinguished from the much later volcanic outpourings that formed the cones now surmounting the Cascades. Mount Baker, for example, like most of the highest peaks of the Cascades, is an extinct volcano, built up of andesitic lavas of rather recent age poured out upon a topography as rough as the present; and the main drainage feature of the region, the Nooksak, was, at the time of the eruption of the lavas, practically at the present level and in the present position.[1]

All the higher peaks of the Cascades, as well as the lower country, were glaciated during the Pleistocene period, the lower limit of glaciation ranging from sea level in the Sound Valley to heights of several thousand feet, its position depending on exposure, latitude, etc. The evidences of past glaciation are of the familiar sort and consist of terminal and lateral moraines, glacially modified valleys, and aggraded stream courses at lower altitudes. Probably the most important topographic and drainage effects in the Cascades occurred in Washington in the vicinity of Lake Chelan.

> "Lake Chelan is a splendid body of water 65 miles long whose southeastern end lies open to the sky between the grass-grown hills of the outer Columbia Valley, while its northwestern end lies in shadow between precipitous mountains in the heart of the Cascade range. There are sandy shallows near its outlet, but beneath the cliffs of its upper course the water is profoundly deep." [2]

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[1] Smith and Calkins, A Geological Reconnaissance Across the Cascade Range near the 49th Parallel, Bull. U. S. Geol. Surv. No. 235, 1904, p. 35.

[2] Smith and Willis, The Physiography of the Cascades in Central Washington, Prof. Paper U. S. Geol. Surv. No. 19, 1900, p. 58.

The lake lies in the canyon of the Stehekin-Chelan River and 32 miles of its length lies within the Cascade Mountains. The depth of the lake varies from 1000 to 1400 feet, and as the water's surface is but 1079 feet above the sea, the bottom of the lake is at one place 300 feet below sea level. The water is partially retained at its present level by a dam of sand and gravel. It appears that the valley now partly filled by Lake Chelan was occupied by a great mountain glacier that deepened and widened the preglacial valley and steepened the valley walls, giving them their present precipitous character.

The glacial features of the northern Cascades are markedly asymmetric. For example, the U-shaped canyons that drain eastward to the Pasayten have northern walls of great simplicity and southern or shady walls carved into niches or hanging cirques of glacial origin. The average or prevailing aspect of the glacial cirques of the entire region is about due northeast, a feature probably due to the preglacial topography, lesser insolation on that aspect, and a certain excess of snow accumulated by drifting across the divide. The more favorable easterly aspect is well illustrated by the glacial erosion of the Hozomeen range, the glaciers flowing eastward having eaten back into the heart of the range much more than their rivals in the western valleys. So marked is this feature that many of the higher peaks have a degree of asymmetry suggesting a breaking wave.[1]

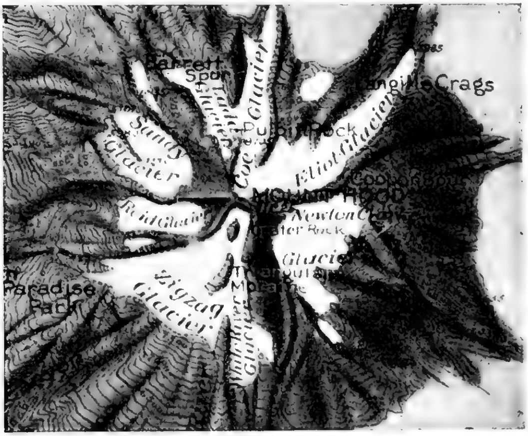

Fig. 37. — Relief map of Mount Hood, Oregon, showing the eroded condition of the volcano and the extent of its glacier systems. (U. S. Geol. Surv.)

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[1] Smith and Calkins, A Geological Reconnaissance Across the Cascade Range near the 49th Parallel, Bull. U. S. Geol. Surv. No. 235, 1904, pp. 90–91.

Glacier systems are still prominent features of the higher peaks. Mount Rainier, Mount Hood, and others are flanked by short glaciers above the 8000-foot level, Fig. 37. The snow and ice fields not only enhance the beauty of these splendid volcanoes but also serve to steady the discharge of the rivers which they feed.

Soil, Climate, and Forests

The almost endless variety of rocks which form the Cascades causes the valley soils to be formed of a great variety of mineral fragments. The valley soils do not therefore reflect the nature of the nearest rock exposures to an important degree. In the higher valleys and basins which lie parallel to the trends of the structures the soil retains to some degree the mineral characteristics of the rock (chiefly granite) from which it was derived. So far as surveys have been made the granitic rocks appear to be sandier and drier because of the mineral composition of the parent rock. They are therefore covered with a shrubby, grassy vegetation; the schist and slate rocks furnish a finer soil with a larger proportion of clay, and appear to be heavily wooded. At the higher elevations, however, the one exhibits rounded forms, the other is developed into a sharply serrate topography unfavorable to heavy tree growth. Toward the valley heads the land waste is coarse and bowldery; down valley a gradation in size is effected through transportation and deposition by water; the soils of the lower valleys are fine.

The total precipitation of the central Cascades varies from 60 to 100 inches a year. Three-fourths of it occurs in the winter season from November to May. In the higher portions of the range the snowfall is heavy, varying from 4 to 10 feet in depth. In these situations it remains throughout the winter, and, in restricted summit areas, throughout the year. On the highest peaks precipitation is almost wholly in the form of snow and well-defined glaciers, from a fraction of a mile to several miles in length, flank Mount Hood, Mount Rainier, and other peaks. The more important streams as a rule have their headwater sources in fields of perpetual ice and snow. Snowstorms in the lower and middle portions of the Cascades (Mount Hood region) are usually followed by rains and warm chinook winds which dissolve the snows and cause extremely heavy freshets in all the streams.[1]

The forests of Washington cover the state as a thick mantle from high elevations on the Cascade range westward to the Pacific. In this

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[1] H. D. Langville and others, Forest Conditions in the Cascade Range Forest Reserve, Oregon, Prof. Paper U. S. Geol. Surv. No. 9, 1903, pp. 29, 30.

great region the only mountains that reach above timber line are the Olympics in the Coast Range System and a limited number of peaks in the Cascades. The forests are the densest, heaviest, and most continuous in the United States except for the redwood area in northwestern California, and are marked by a dense and tangled undergrowth. The largest trees are from 12 to 15 feet in diameter and 250 feet in height. Red or yellow fir, in the zone of heaviest rainfall and where there is at least a moderate soil cover, constitutes the larger part of the forest, with an intermingling of spruce, hemlock, and cedar.[1]

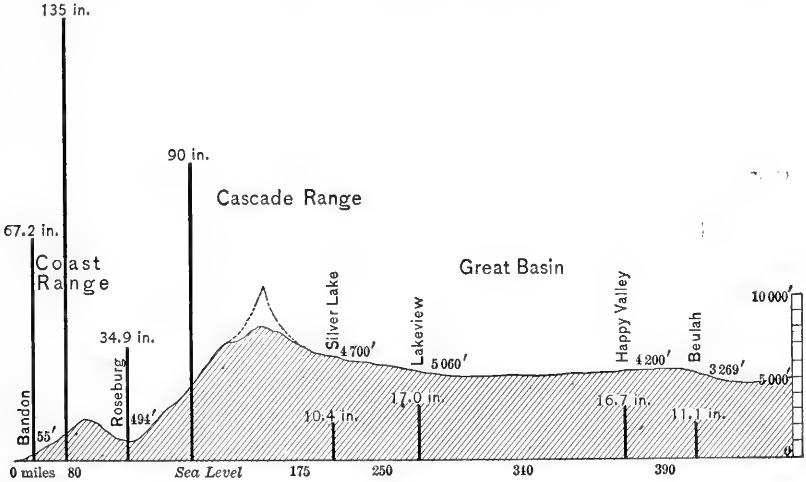

Fig. 38. — Topographic profile in relation to rainfall in the Coast Ranges and the Cascades of Oregon.

West of the Cascade range the country is occupied mainly by four species, red fir, cedar, hemlock, and spruce. The percentages of composition arranged in the same order are as follows: 64, 16, 14, and 6, with the proportions of cedar and spruce increasing toward the coast. At the highest elevations the fir disappears and hemlock and cedar come in. East of the Cascades the climate becomes rapidly drier and the timber consists almost entirely of lodgepole and yellow pine.[2]

In Oregon the timber consists of about the same species as in Washington, with the addition in the southwestern part of the state of sugar pine, noble fir, and yellow pine. The red fir constitutes by far the larger part of all the timber in the state. Cedar, hemlock, and spruce are comparatively unimportant, except along the coast. The fir occupies the entire timbered portion of the western slope of the Cascades, the

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[1] Henry Gannett, 19th Ann. Rept. U. S. Geol. Surv., 1897–98, p. 26.

[2] Idem, p. 27.

eastern slope of the Coast Ranges, and the depression between these mountains where it forms more than three-fourths of the forest. The cedar occurs mainly at mid-altitudes upon the Coast Ranges and the Cascades but forms a small proportion of the forest. Hemlock occurs notably upon the western slope of the Cascade range at mid-altitudes. East of the Cascade range in Oregon the forests are largely of yellow pine. Sugar pine extends over the entire breadth of the Cascades and from California northward to the Columbia and westward to the coast.

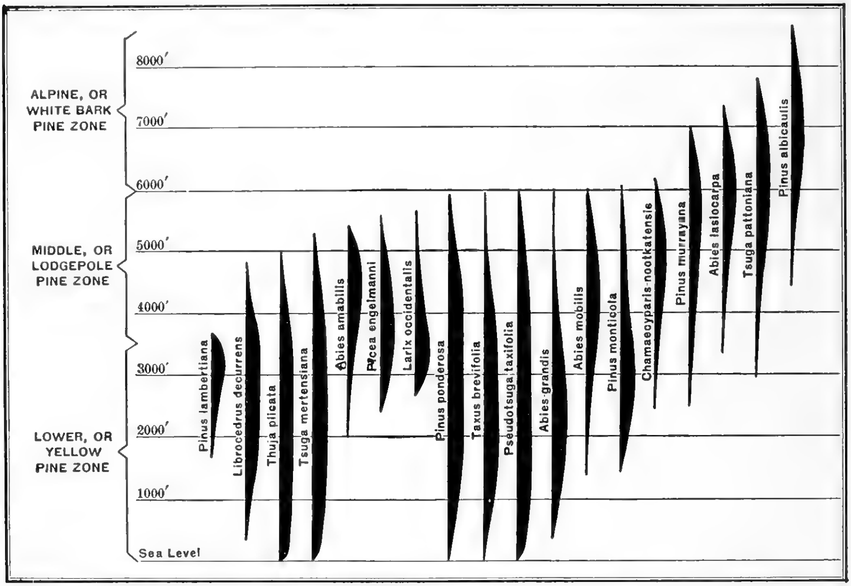

Fig. 39. — Altitudinal range and development of timber-tree species in the central portion of the Cascade Mountains. (U. S. Geol. Surv.)

On account of the exceptional height, breadth, and topographic boldness of the northern Cascades their climatic and forest characters deserve special discussion. The northern end of the Cascades is a region of short summers, comparatively free from rains. The winter snowfall, however, is extremely heavy. Besides its important relation to irrigation through its tendency to equalize stream flow, the heavy snowfall is of ecologic importance, for it determines the distribution of certain definite plant communities, influences the forms of plants as along the cold timber line where dwarfed or gnarled forms occur, and prevents excessive temperatures and too rapid transpiration during winter storms when the roots are incapable of absorbing water. In the

Okanogan Mountains the snow does not disappear until the middle of July, and several miles south of the 49th parallel deep snow remains throughout the summer and snow squalls occur even in July and August.

Similar climatic conditions occur in the eastern part of the Hozomeen range, but the western slope of this range has a much greater annual precipitation. The forests become extensive, large trees with dense underbrush cover the valley bottoms and extend well up the slopes, and grass is not plentiful except on a few ridges. Banks of snow persist throughout the year and glaciers occur on all the higher peaks. In the Skagit Mountains the summer is very short and July and August are the only months in which snow does not fall in considerable amounts. At no time in the year are the passes in the Skagit Mountains free from snow.

The climatic contrasts between the east and west slopes of the Cascades are well shown by the conditions of the old vistas cut on portions of the boundary line. In the Pasayten Valley the cuttings can be found easily, the stumps and logs are sound, and camp stools remain as they were left forty years ago. On the western slopes and in the Skagit Valley the old stumps are so decayed as to be barely recognizable, and the vista is here occupied by trees 75 feet high and 14 inches in diameter, which have grown up in the old cuttings in that short time.[1]

On the western slopes of the northern Cascades there is a heavy precipitation which supports a dense forest growth. Timber line is at 6000 feet; above this elevation trees occur only in groves or singly and most of the mountain summits are treeless. Grasses, sedges, and heather are the common growths above the forest. The best forest growth is below 4000 feet. Above that elevation the trees are apt to be shorter and more branched, and the trunks twisted or otherwise defective. Some of the basins at rather low altitudes are without forests on account of the accumulated snows which melt out too late in the spring to favor anything but a growth of grass. The red fir belt is the lowest of the three forest belts recognized here, and has associated with it the Sitka spruce, the silver fir, the hemlock, and other species. The main slopes of the mountain spurs are covered with hemlock and white fir, which constitute the second forest belt. In the third or alpine belt on the summits of the principal spurs and on the divides the growth is sparse or absent. The principal trees of the alpine zone are the mountain hemlock, alpine fir, and Engelmann spruce.[2]

The heavy rainfall of the western slopes slightly overlaps the upper part of the eastern slope of the Cascades and is accompanied by trees

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[1] Smith and Calkins, A Geological Reconnaissance across the Cascade Range near the 49th Parallel, Bull. U. S. Geol. Surv. No. 235, 1904, p. 18.

[2] H. B. Ayres, Washington Forest Reserve, 19th Ann. Rept. U. S. Geol. Surv., pt. 5, 1897–98, pp. 283–293.

characteristic of the western zone. These extend eastward over the geographical summit of the range, a feature less marked on the higher saddles, ridges, and peaks and very strongly marked in the low passes.

Sierra Nevada Mountains

The Sierra Nevada Mountains on the eastern border of California are a bold, continuous range about 75 miles in width. They have many well-defined peaks; the larger number occur in a line west of Lake Tahoe, Owen's Lake, etc., and constitute what is generally known as the High Sierra, the crest line of the Sierra Nevada Mountains over 11,000 feet in height. By reason of the dominating character of the Sierra Nevada and its high degree of effectiveness in barring the rains and snows of the westerly winds, it has an abundant water supply and is well clothed with forests of pine, fir, hemlock, etc.; in both these respects it is strikingly different from the minor north-south ranges on the east that comprise so large a portion of the Great Basin, and from the nearly treeless central valley of California on the west.

The Sierra Nevada is a notable example of a mountain range of great geologic complexity whose general physiography is of a rather simple type. In order that this may be realized a few geologic details may be given. It is probable that the Sierra Nevada rock formations range in age from Archæan or Algonquin to Recent.[1] The rocks have been profoundly affected by crustal compression accompanied by close faulting and schistosity, in many places carried to the point where the original nature of the sediments has been completely altered. These statements are sufficient to show that a complete geologic study of the mountains would include a wide range of facts related to almost every department of geologic science. Compression and folding occurred at the end of the Paleozoic, as well as a certain amount of igneous intrusion, and later the mountains were greatly eroded. At the close of the Jurassic the Sierra Nevada region was again compressed and folded as well as uplifted into the form of a prominent mountain range. Great batholithic intrusions also took place at this time. In connection with these intrusions the sedimentary rocks were largely metamorphosed and rendered schistose and platy.[2] These two facts, as we shall see in succeeding pages, are of first importance in the interpretation of the canyon forms associated with the Yosemite, Merced, Tuolumne, and other mountain streams.

In spite of the great geologic complexity of the Sierra Nevada Mountains their broader physiographic features are somewhat simple. Whatever the original relief, now lost, may have been, and however complex the structural changes that have taken place, these are on the whole of lesser importance geographically than peneplanation which brought about the existence of a topography of little relief. The highest mountains were reduced to residual mountains, the valleys were broadened out to great width, and the streams flowed in courses of slight gradient. As in so many other instances of peneplanation, the

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[1] H. W. Turner, 14th Ann. Rept. U. S. Geol. Surv., pt. 2, p. 445.

[2] J. S. Diller, Bull. U. S. Geol. Surv. No. 353, 1909, pp. 8–9.

structure of the country was practically unexpressed in its topography: high and low masses, hard and soft rocks, were as a rule brought down to a common topographic expression. Upon the floors of the ancient valleys that but slightly diversified the relief of the ancient peneplain (completed in the Miocene) auriferous gravels were deposited, and among the finer sediments are fossil leaves of the fig, oak, and other plants indicative of a low coastal country somewhat like Florida. The uplift of the peneplain was accompanied by volcanic activity. From volcanic vents near the low crests streams of lava issued and followed the water-courses, covering the auriferous valley gravels and displacing many of the streams.[1]

The Sierra Nevada Mountains, as we know them to-day, are among the major relief features of the continent, and the contrast between their former peneplaned and their present mountainous condition can be understood from the fact that block faulting on a large scale has taken place, resulting in both the bodily uplift and the tilting of a large crust block. The eastern face of the Sierra Nevada over a distance of several hundred miles is exceedingly steep and forms a fault scarp which is to be compared in steepness and continuity only with the eastern face of the Lewis Mountains in western Montana (p. 307). Among the facts supporting the hypothesis of faulting are the stream gravels on the very summits of the mountains above the steep eastern scarp where in places they are displaced through 3000 feet of vertical distance.[2]

Evidence of recent faulting has been found along the eastern base of the mountains, near Genoa, where alluvial deposits (Pleistocene) have been displaced some 40 feet; it has also been found that the Carson River on emerging from the mountains increases its grade abruptly toward the east, suggesting recent dislocation of its valley. It is concluded that the first dislocation along the eastern face of the Sierra Nevada Mountains took place at the close of the Cretaceous and that it has continued down to the present day, thus making the faulting complex. A number of more or less parallel faults have been identified within a belt 25 miles wide.[3]

Along most of the range the rocks of the Sierra Nevada scarp do not end finally, but occur in the ranges to eastward, a feature explained by a system of compound faults parallel with the eastern front of the major range. It is in the depressions between the main Sierra block and the subsidiary blocks that the chief lakes of the region occur, as Owen's Lake, Mono Lake, Tahoe Lake.[4] The Carson topographic sheet well represents

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[1] J. S. Diller, Bull. U. S. Geol. Surv. No. 353, 1909, p. 9.

[2] J. S. Diller, 14th Ann. Rept. U. S. Geol. Surv., pt. 2, p. 432; H. W. Turner, 14th Ann. Rept. U. S. Geol. Surv., pt. 2, p. 442; I. C. Russell, 8th Ann. Rept. U. S. Geol. Surv., pt. 1, p. 322.

[3] Auriferous Gravels of the Sierra Nevada, Jour. Geol., vol. 4, quoted by Spurr in Descriptive Geology of Nevada South of the 40th Parallel, and Adjacent Portions of California, Second Edition, Bull. U. S. Geol. Surv. No. 208, p. 222.

[4] See Contour Map of the United States, scale 111 miles to the inch, U. S. Geol. Surv.

this feature so common in the Great Basin region and marked out on very strong lines along the eastern border of the Sierra Nevada. The main intermont valley is broken by secondary blocks into a series of subordinate valleys. The secondary blocks are generally discontinuous longitudinally and the greater number of them are roughly parallel to the primary fault plane. The eastern slope of the Sierra Nevada Mountains thus exhibits a multiple scarp.

As an illustration of a depression due to deformation of the crust block type may be cited Owen's Valley, a V-shaped depression between the Sierra Nevada and the White Mountain blocks. This conclusion is based upon the fact that faulting and associated phenomena have been observed in many places along the eastern margin of the Sierra Nevada and also on the eastern margin of the White Mountains. Furthermore, hot springs occur in the marginal zone from the midst of Owen's Valley to Mono Lake, and a mud geyser is known at Casa Diablo, two features whose occurrence is commonly associated with faulting. The sharp truncation along the eastern border of the mountains of the inclined peneplain of the western slope of the Sierra Nevada, a feature well developed on the steep eastern face of the White Mountains in sharp contrast to the gentle western slope, points to the same conclusion. Finally, faulting and crustal movements of considerable magnitude and accompanied by earthquake shocks have taken place in Owen's Valley in historic time.[1]

In contrast to the steep eastern front of the Sierras is the gentle westward slope that descends from 9000 feet on the east to the 1000-foot level on the west at the border of the central valley of California. From any commanding view between the crest of the range and the valley of California one looks out upon a plateau whose general accordance of summit levels is striking and significant. This was once a broad plain near sea level, now uplifted to a great height.[2] Though peneplanation may be safely inferred from the discordance between the plane of the sublevel hilltops and the structure, the region is nevertheless deeply dissected by the rejuvenated streams. Canyons have been formed of such

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[1] W. T. Lee, Geology and Water Resources of Owen's Valley, California, Water-Supply Paper U. S. Geol. Surv. No. 181, 1906, p. 25.

[2] The peneplain of the western slope of the Sierra Nevada was first recognized by Gilbert (G. K. Gilbert, Science, vol. 1, 1883, pp. 194–195). Diller showed that the planation was probably accomplished during Miocene time (J. S. Diller, Tertiary Revolution in Topography of the Pacific Coast, 14th Ann. Rept. U. S. Geol. Surv., pt. 2, 1894, pp. 404–411). He also found that gravel deposited upon this peneplain had been elevated, faulted, and tilted, the degree of vertical displacement along the eastern face of the range being 3000 feet at the northern end.

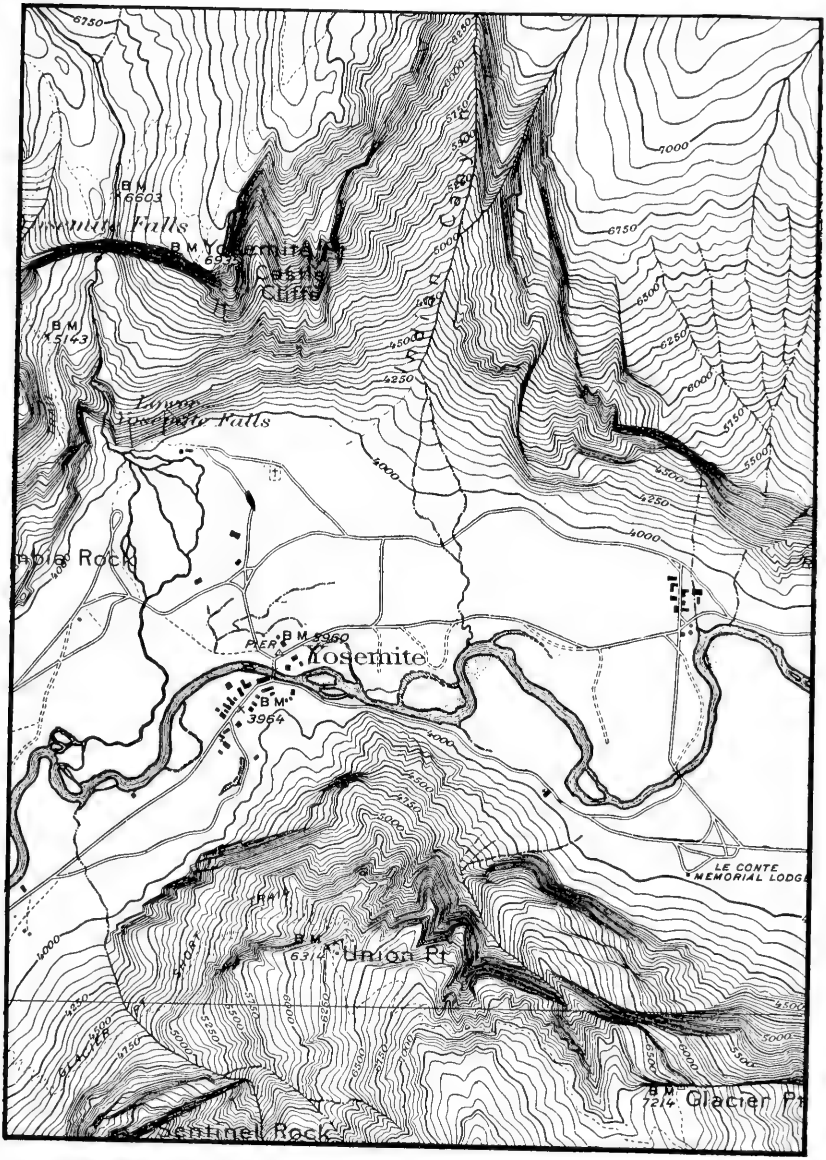

Fig. 40. — Typical portion of Yosemite Valley, showing cliffed margins, waterfalls, flat floor, and meandering stream. Partly stream eroded, partly ice eroded canyon whose details of cliff structure are due to geologic structure. (Matthes, Yosemite Valley Map, U. S. Geol. Surv.)

profound depth and steepness as to constitute the chief scenic feature of the range outside the snow-capped High Sierra.

The main streams such as the Merced, Tuolumne, Feather, and Hetch-Hetchy flow in canyons from a half mile to a mile deep. The encanyoned portions of the streams are but fractions of the total lengths of the streams, since the canyons do not appear either at the headwaters or in the foothill belt. They are limited to the intermediate levels where the alpine glaciers once occupying the largest valleys produced their most important topographic effects. All the canyons have exceedingly steep walls over which tributary streams form waterfalls of celebrated beauty. Rarely does flat land of any extent occur on the canyon floors, though this feature is well developed in the Yosemite and the Hetch-Hetchy where open grassy glades diversify the forest cover and possess a charm possessed in equal degree by few regions in the world. The canyon of the Yosemite, the most celebrated in the region, has long been regarded as due wholly to glacial erosion, but recently it has been more safely determined to be not solely a normal product of ordinary stream or ice erosion but equally a function of the structure of the country rock. The granites of the Yosemite region consist of many huge monolithic masses embedded in a matrix of more or less strongly fissured rock. There is in consequence extreme inequality of resistance to dissection and the landscape reflects very faithfully each structural character of the material from which it was carved. The dominating heights, such as Half Dome, consist invariably of resistant monoliths; the canyons and gorges are due to the erosion of zones of nonresistant fissile rocks; the courses of the rivers and lake basins in the valley floors and the scarp-like rock walls were in all cases evolved in obedience to local structural conditions. The trend and profile of each cliff are an expression of its associated structure.[1]

The Sierra Nevada block south of latitude 38° 30′ is displaced along its eastern face, chiefly along a single fault line, and the range is here much higher than to the north, and bears upon its summit a number of exceptionally high peaks, among them Mount Whitney, the highest mountain in the United States (14,800 feet).

This portion of the mountains, the High Sierra, should not be considered as a part of the ancient peneplain, since it stands several thousand feet above the general summit level of the Sierra Nevada. It is an unreduced or residual portion of the region. The main range of the Sierra is thus a belt of extremely high relief about 25 miles wide,

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[1] F. E. Matthes, The Cliff Sculpture of the Yosemite Valley, Paper before the Geol. Soc. Am., Dec., 1909, p. 4.

with numerous sharp spurs and ridges among which there are few tracts of valley land. Level tracts of limited extent, however, occur at the heads of most of the larger streams, and a few large streams have headwaters draining big valleys or lakes. This is true of the northern or lower Sierra Nevada especially. Thus the Middle Fork of the Feather River issues from a large level tract known as Sierra Valley, about 60,000 acres in extent, and Truckee River flows out of Lake Tahoe, 190 square miles in extent. Carson Valley and Little Valley west of Washoe Lake are further illustrations. The smaller streams drain small glades, ponds, or lakelets or rise directly from steep mountain flanks.[1]

In a broad view of the Sierra Nevada, five categories of form are thus distinguishable: (1) a summit zone of residual elevations, including the High Sierra and many lesser elevations, (2) a plateau zone representing an uplifted, tilted, and partly dissected peneplain, (3) a fault zone on the eastern border of the range, including steep, recently formed, and but little dissected fault scarps which are in almost startling contrast to the flat ridge tops that represent peneplain remnants, (4) a narrow, structural valley zone on the east in which the valleys represent fault depressions, (5) a broader valley zone on the west, in which the valleys are canyons of erosional origin whose architectural details alone are responses to structure.[2]

The uplift of the Sierra Nevada block rearranged the drainage of the region in many localities. In a general view of the drainage prominent features are the short and steep streams that descend the eastern scarp of the Sierra Nevada block and the generally direct courses of the streams draining the gentler western slope. It is noteworthy that the westward-flowing streams have a certain axial directness down the incline of the block, courses which appear to have been gained during or as a result of the block deformation, for their inharmonious relations to the structure indicate that they are formed upon a peneplaned surface deeply covered with land waste and at a time when hard and soft rocks did not show any important topographic differences. Several streams appear to have maintained their courses across the rising Sierra Nevada block in spite of the uplift. The forks of the Feather River persisted in their courses and cut deep canyons directly across the rising crests of some of the individual blocks of the range. The effect of the deformation

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[1] J. B. Leiberg, Forest Conditions in the Northern Sierra Nevada, California, Prof. Paper U. S. Geol. Surv. No. 8, 1902, p. 17.

[2] For a detailed description of the first four zones as developed in the Carson Lake district northeast of Lake Tahoe see J. A. Reid, The Geomorphogeny of the Sierra Nevada Northeast of Lake Tahoe, Bull. Dept. Geol., Univ. Cal. Pub., vol. 6, 1911, p. 108.

was to bring the ancient bed of the Jura River to unequal elevations above the present bed, giving the ancient bed an abnormal profile, so that the old and now lithified river gravels arch over a secondary block of the Sierra.

The northern end of the Sierra Nevada is more complex than other portions of the range. Beyond Lake Tahoe are three main crests, Clermont Hill Ridge, Grizzly Mountains, and Diamond Mountain, and each crest has a valley at its northeastern base. Each crest represents the edge of a tilted crust block whose northeastern face is a fault scarp and whose southwestern descent is a dissected remnant of a former peneplain. The western crest (Clermont) is continuous with the main crest of the range north of Lake Tahoe. The Diamond Mountain block of the northern Sierra Nevada has a long gentle slope towards the southwest, which gives that side the appearance of a plateau. Toward the northeast the mountain presents an escarpment over 200 feet high in a short steep slope to Honey Lake, Fig. 28. This escarpment is remarkably regular, with few prominent spurs and reëntrants and no important stream features which point to a recent origin through faulting. The upper courses of the westward-flowing streams are in broad shallow valleys developed upon the regional peneplain before uplift and deformation took place, but as they continue to the southwest their valleys become progressively deeper until they have true canyon profiles. All of them open into broad alluvial valleys at the foot of the mountain slope. Lights Canyon, Cooks Canyon, and the canyons of Indian and Squaw creeks are illustrations. The Grizzly Mountain crust block repeats the essential features of the Diamond Mountain block except that its crest line is less regular; a broad gap has been developed across the range and no definite traces of an inclined peneplain may be found upon the southwestern slope of the mountain.[1]

SOILS, PRECIPITATION, AND FOREST BELTS

The soils of the western forested slopes of the Sierra Nevada are chiefly residual and have been derived from the weathering of granitic rocks, diabase, amphibolites, slates, serpentine, and volcanic material. They are prevailingly of light-red to deep-red color, and generally of somewhat compact structure. The soils are sometimes separated from the underlying parent rock by a thin stratum of adobe-like material. They are frequently very shallow and marked by abundant rock outcrops, bowlders, and rough, rocky areas.

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[1] J. S. Diller, Geology of the Taylorsville Region, California, Bull. U. S. Geol. Surv. No. 353, 1909, pp. 9–12.

The slopes of the canyons are generally rocky and almost denuded of soil, but deep residual soils are found along the summits of the ridges below 4000 feet. Deep-red soils are as a rule found on the andesite, gabbro, and diabase-porphyry rocks, while the sedimentary rock is usually covered with a poor shallow soil.[1]

The foothill soils are almost entirely residual and vary in character with the nature of the underlying rock. The poorest soil, light colored and shallow, is found upon slate. A deeper and warmer soil is found upon granite, and the best soil of all — the one richest in plant food — is the so-called "red soil," derived principally from the disintegration of diabase and amphibolite.[2]

Above 5500 feet on the north and 6500 feet on the south the Sierra Nevada has been glaciated and abounds in rocky slopes, tracts of bare rock from which the soil has been swept. The present glaciers of the High Sierra are very small and occupy only the headwater amphitheaters formed by the larger ancestral glaciers. The extensive glaciers and snow fields of the past formed a large part of the existing soil; the present glaciers are above tree line, occupy but an insignificant fraction of the total surface, and have no important relation to soils or forests.

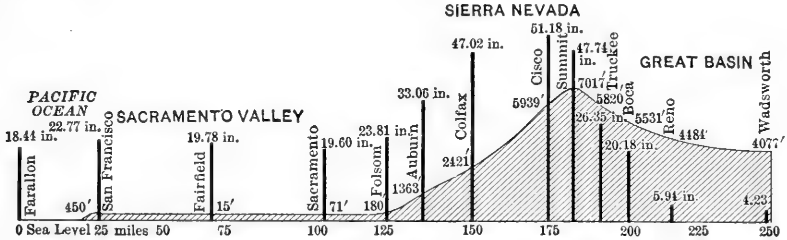

Fig. 41. — Relation of topography to rainfall, Sierra Nevada Mountains.

The annual precipitation over the Sierra Nevada, Fig. 41, ranges from 40 inches at elevations of about 3000 feet to a maximum of 70 inches at 7000 feet, with less precipitation on the eastern slopes than at corresponding elevations on the western slopes.[3] The winter snowfall at elevations above 4500 to 5000 feet is as a rule heavy, the largest banks in the deepest woods persisting until late summer. In the valleys and foothills below 1500 feet snow seldom occurs and lasts for only a few hours.

On the western slope of the Sierra Nevada three well-defined zones of vegetation may be distinguished: (1) the well-watered, heavily for-

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[1] W. Lindgren, Colfax Folio U. S. Geol. Surv. No. 66, 1900, p. 10.

[2] W. Lindgren, Sacramento Folio U. S. Geol. Surv. No. 5, 1894, p. 3.

[3] W. Lindgren, Pyramid Peak Folio U. S. Geol. Surv. No. 31, 1896, p. 1.

ested zone between 3000 and 6000 feet, known as the "timber belt," (2) the drier transition belt of thin forest below 3000 feet, and (3) the nearly treeless rolling grassy hills which occur between the floor of the Great Valley and the slope of the Sierra up to 1500 feet.

The timber belt contains magnificent forests among which the conifers predominate both in size and number. They include the yellow pine, the sugar pine, and the famous "big trees." The last-named grow in quiet hollows protected from the winter storms by the bordering ridges and surrounding forests of pines. All the larger conifers likewise flourish best in sheltered areas, though they are also found in diminished numbers on the ridges. Undergrowth is usually lacking except near springs or small streams, and this condition together with the open stand of the trees gives the forests a pleasant, park-like character. Within the timber belt are also found the spruce, fir, tamarack pine, and silver fir, the last-named generally clinging to the ridges and higher slopes, while the tamarack associated with willows and poplars is found in the low, marshy places. In the upper glaciated portion of the timber belt the rock has been swept bare of soil and the trees grow under hard conditions, their roots penetrating soil that fills cracks and joints in the granite.

The higher elevations from 6000 to 9000 feet have been denuded of their soil by glacial action and are characterized by various species of firs, spruce, and tamarack; the silver fir, for example, grows chiefly above 8000 feet. All the timber of the higher belt is sparse and of poorer quality than that found on the lower elevations. The highest slopes are rocky and inaccessible and without vegetation.

The ranges of a number of characteristic species of the northern Sierra is shown in Fig. 42. The Patton hemlock has a restricted and uneven distribution following a granite axis on the summit of the range over which its distribution corresponds with the belt of heaviest precipitation. Its continuity is broken by deep, low valleys. The Shasta fir is another essentially mountain species. It appears to require a precipitation of at least 50 inches and hence does not occur below elevations of 4800 feet. Since it is restricted to limited areas because of its temperature and moisture requirements, it is not distributed in a continuous belt but like the Patton hemlock is broken by deep valleys and canyons. The sugar pine has a wider and more continuous distribution. It is absent below 2000 feet in the western foothills and occurs on the eastern and upper margin of the belt in detached fragmentary bodies and east of the mountains almost not at all. The yellow pine has the widest range of any of the Sierra species. Its lower limit of distribution is about 1500 feet, its upper from 6500 to 7000 feet. The high precipitation and low temperature of the summit of the Sierra prevent the yellow pine from occupying the higher ridges, just as dryness prevents it from occupying the Sacramento Valley.

Some of the high ridges covered with andesitic breccia are very dry and support either no trees or shrubs or those types normally found at a lower altitude under drier conditions.[1]

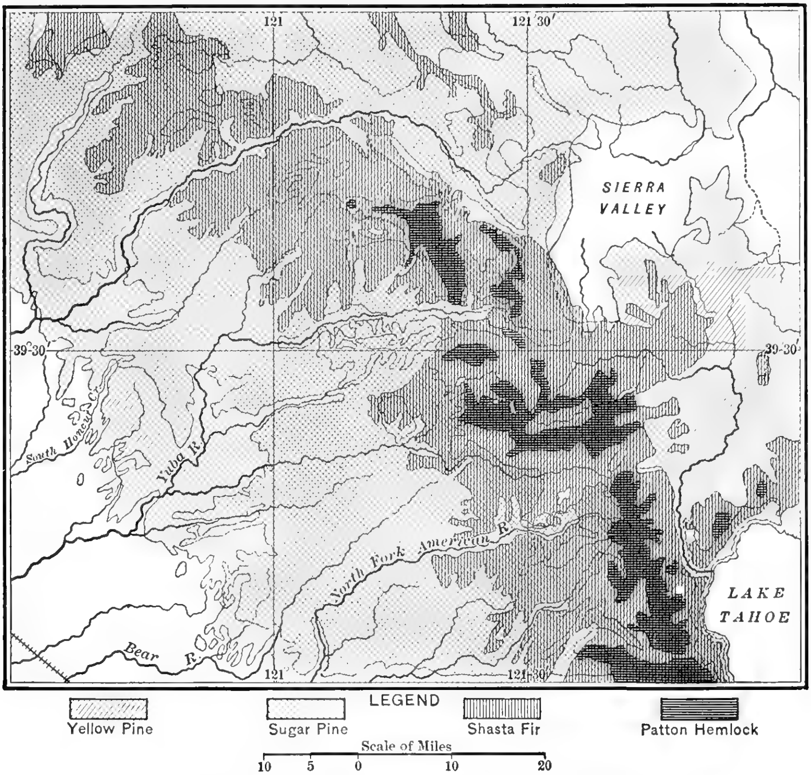

Fig. 42. — Ranges of four characteristic species in the northern Sierra Nevada. (Compiled from U. S. Geol. Surv. maps.)

The trees of the thinner forests below 3000 feet grow in thin groves or are scattered over grassy slopes. Yellow pine occurs on the higher ridges as an outlying fringe of the great forests of the timber belt, while oaks are particularly abundant on dry areas underlain by the older volcanic breccias and tuffs. Many hills are thickly covered with an evergreen shrub (greasewood), and in the lower part of the belt the Digger pine

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[1] Turner and Ransome, Big Trees Folio U. S. Geol. Surv. No. 51, 1898, p. 3.

comes in, besides stunted oaks, and a number of shrubs. The lowermost zone of vegetation in the foothill belt also contains the Digger pine and stunted oaks, and shrubs characteristic of greater dryness, such as the manzanita.[1]

Although the forests of the Sierra Nevada are more restricted in vertical range toward the south owing to increasing aridity in this direction, they persist as far as the 36th parallel, where the elevation of the mountains begins to decrease. With lower elevation the rainfall diminishes to the point where a stunted vegetation appears, and at the extreme south a true desert flora is developed. By contrast, the Coast Ranges exhibit a desert vegetation as far north as the Bay of Monterey (lat. 37°), and nowhere bear extensive forests south of San Francisco. The lesser elevation of the Coast Ranges accounts for a large part of this deficiency, though a part also must be attributed to their position on the margin of the belt of westerly winds. They receive their rainfall chiefly during the winter season, when the westerly wind belt with its cyclonic storms has migrated southward over them. But the latter deficiency is shared by the Sierra Nevada. We may therefore say that were the altitudes of the two ranges reversed the Coast Ranges would be densely wooded at least as far south as the Bay of Monterey while the Sierra Nevada would be practically without forests.

It seems clear from the topographic character of the Sierra Nevada as well as the Cascades that large portions of the existing forests grow under conditions that must for a long time to come, perhaps forever, prevent the utilization of their products. Especially is this true of detached areas of forest on high mountains and steep slopes separated from the main body of the forest by deep and almost unscalable canyons and gorges, and far from centers of population upon which the lumberman must depend for a labor supply as well as for the consumption of the forest products. The steep, cliff-like walls of the larger valleys themselves offer difficulties of the highest order. Ordinary lumbering methods are useless, extraordinary methods are so expensive as to make the development of the more difficult forest areas highly improbable. The potential value of the forests in the more difficult tracts is therefore very limited in relation to the lumber supply, but their practical value is almost unlimited in relation to stream flow. The retardation of the run-off on steep slopes is a matter of the greatest concern where both the rainfall and the snowfall are heavy and the topography extraordinarily rugged, and this is everywhere to some extent and in some places to a large extent effected by the forest cover.

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[1] F. L. Ransome, Mother Lode District Folio U. S. Geol. Surv. No. 63, 1900, p. 1.

CHAPTER XII

PACIFIC COAST VALLEYS

General Geography

One of the larger features of the continent of North America is the discontinuous line of valleys known as the Pacific coast downfold, a structural and topographic depression between the Coast Ranges on the west and the Sierra Nevada and Cascade mountains on the east. Its most striking expression is in the valleys of the San Joaquin and the Sacramento in central California and in the Willamette Valley in northwestern Oregon, where the Coast Ranges descend with marked abruptness to the level of the alluvium-filled valley floors. The width of the downfold is about 100 miles from crest to crest of the bordering ranges and from 50 to 75 miles from mountain front to mountain front; the total length is about 2500 miles. The northern and southern ends of the downfold are submerged, forming Puget Sound and the Gulf of California respectively; the higher unsubmerged sections extend through northern California, Oregon, and Washington and are separated by two mountain groups. The divisions are as follows: (1) a southern division extends from Gulf of California to Los Angeles, (2) a central division constitutes the Great Valley of California, and (3) a northern division comprises the Willamette Valley in Oregon, the Cowlitz Valley in Washington, and the broad depression at the head of Puget Sound. The mountains separating the southernmost depression from the Great Valley of California are the San Gabriel, San Rafael, San Bernardino, and others; those separating the Great Valley of California from the Willamette Valley are the Klamath, a group rather than a range of mountains, consisting of a number of secondary ranges among which are the Siskiyou, Rogue River, and others.

The Pacific coast downfold has been a feature of the western coast since the Cretaceous period, and during several geologic periods was so deeply depressed as to lie beneath sea level and receive a considerable body of sediments. The later phases of alluviation are due to the action of the tributary streams which descend in steep courses from the flanks of the high mountains near by and contribute a vast body of detrital material to the upbuilding of the valley floors.

Willamette, Cowlitz, and Puget Sound Valleys

The northernmost section of the Pacific coast downfold consists chiefly of the Willamette and Puget Sound valleys. The alluvial portion of the Willamette Valley heads near Eugene, Oregon, and extends north to the Columbia. North of that river the depression is continued by the Cowlitz Valley and lesser valleys tributary to the southern end of Puget Sound. The depression is important climatically, since on the north it lets in the sea in the form of a great mediterranean that extends 150 miles inland; and in the Willamette Valley on the south it results in a much greater seasonal range of temperature than occurs in the coastal section near by from which it is separated by the Coast Ranges. Everywhere in the northern depression the rainfall is markedly less than on the windward (western) slopes of the bordering Coast Ranges and Cascades.

In Washington the greater part of the depression is composed of alluvium and glacial or fluvio-glacial deposits. These consist of till, sand, and gravel, and were formed during and at the close of the glacial period when piedmont and valley glaciers descended from the bordering mountains and discharged into the waters of Puget Sound. The surficial deposits overlie and partly obscure an older topography, a well-developed valley system coördinated with the present system of converging sounds and bays so suggestive of the drowning which occurred here. The postglacial changes are due chiefly to the extension of the deltas at the mouths of the streams. These advance into the bays, reclaim their heads, and thus greatly modify both valley and shore.[1] The irregularities of the shore line of Puget Sound are not attributable to depression alone. The glaciation of the sound deepened and widened the depressions that were the lines of glacial movement, but the deepening was so much more important than the widening that the channels are deep and narrow. The low water-parting between the Cowlitz Valley and the valleys tributary to Puget Sound is due to the deposition of alluvium and glacial deposits upon a previously nearly level-floored intermontane depression.[2]

The Willamette Valley south of the Columbia River is to the Cowlitz north of the Columbia what the San Joaquin is to the Sacramento. It is intensively farmed, relatively, and is almost unforested in contrast to the densely forested, because better-watered, hills and mountains on

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[1] Willis and Smith, Tacoma Folio U. S. Geol. Surv. No. 54, 1899, p. 2.

[2] I. C. Russell, North America, 1904, p. 160.

either side. Its deposits are likewise of glacial and fluvial origin, deposits of the latter kind predominating.[1] The valley is 150 miles long and at present constitutes the most important single tract of arable land in the state.

Great Valley of California

CLIMATIC FEATURES

In the study of the Great Valley of California, and indeed of the physiography of the California district as a whole, one must keep in mind the great range in latitude between its northern and southern ends. The state is 800 miles long, and if it were transposed to the Atlantic seaboard with its southern end placed on Charleston, South Carolina, its northern end would lie approximately on New Haven, Connecticut. The southern end of California is a region of deserts, desert mountains, salt lakes, a sparse and specialized vegetation, and other features associated with pronounced aridity. The northern end of California lies on the whole in the belt of adequate rains; on the windward slopes of the mountains in the northwest corner of the state there is a mean annual rainfall of 81 inches,[2] and dense forests of redwood clothe the mountain slopes.

These great differences in precipitation are due to two conditions: (1) the state is of unusual size and has a wide range of latitude; (2) it lies partly within two climatic belts, the belt of westerly winds, and the horse latitudes. The mean annual rainfall varies from 1 inch to 81 inches. In the extreme southern part of California there live many people who have never seen snow in any form. At Summit, near Donner, in northern California, an annual snowfall of 697 inches, or nearly 60 feet, has been reported. Farming is conducted in an ordinary manner in large sections of northern California, though some irrigation is practiced; irrigation is the indispensable condition of the agriculture and the horticulture of southern California. Little wonder is it that under these circumstances Californians should speak of northern California and southern California as two very unlike regions. The degree of unlikeness is so extreme, the different interests so divergent in many respects, that the idea is quite widely entertained that California should be separated into two states for the better safeguarding of local interests.

In addition to the climatic differences between northern and southern California are east-west differences of climate dependent upon strong

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[1] For the character of the drainage and the topography of the upper Willamette Valley see the Eugene quadrangle, U. S. Geol. Surv.

[2] A. J. Henry, Climatology of the United States, Bull. Q, U. S. Weather Bureau, 1906, pp. 9–72.

contrasts in the different north-south belts of relief. These are summarized by Hilgard[1] as follows:

(1) Bay and coast region characteristics: Small range of temperature, the extremes being only 53° apart. Means of summer and winter are only 6° apart. There is no intense heat and frosts are very rare. Fogs from the sea are quite common on summer afternoons. Rainfall averages 27.3 inches, about 25 inches of which falls between December and May.

(2) Great Valley characteristics: Average winter temperatures lower than those of the coast, though minimum is about the same. Frosts are rare. Summer heat is very intense, often above 100°. The nights are warm but dry, and are therefore less oppressive. Extreme range of temperature 76°, mean range 23.6°. Rainfall averages about 21.5 inches, of which 19.8 inches fall between December and May.

(3) Sierra slope characteristics: Cool summers with frequent thunderstorms. The winters are often severe, with much rain and snow. Mean summer temperatures, 57.5°, with a mean range of 14° between that and the winter temperature of 43.5°. Rainfall averages 57.24 inches, fairly well distributed throughout the season.

GENERAL GEOGRAPHIC AND GEOLOGIC FEATURES

The Great Valley of California, the largest unit of the great Pacific coast downfold, lies between the two main chains of that state, the Sierra Nevada on the east and the Coast Ranges on the west. It is about 400 miles long, has an average width of about 50 miles, and contains about 20,000 square miles. It consists chiefly of two long and relatively narrow piedmont alluvial plains with a monotonously level surface and a marked parallelism with all the main physiographic features of the state lying north of the 35th parallel.

The drier southern end of the Great Valley is a region of large wheat ranches, but in later years fruit raising has begun to supplant this industry. Grazing is also a principal resource. The better-watered northern end of the valley produces lumber, dairy products, fruits, and vegetables; and the greater rainfall of the Sacramento Valley and bordering ranges so well maintains the level of the Sacramento River that a navigable depth of seven feet from Sacramento to the river's mouth is maintained at slight expense.[2]

The history of the Great Valley dates from the great orogenic disturbance at the close of the Miocene which gave birth to the Coast Ranges as a connected mountain chain. Later still (at the close of the Pliocene) the Sierra Nevada block was further uplifted and the Coast Ranges increased in height, an increase which has continued down to the present time.[3] During the post-Pliocene elevation of the crest of the Sierra and of the Coast Ranges and also in the Pleistocene period the Great Valley was gradually and finally cut off from the sea, closed in by mountains, and changed to a definite well-bounded area of sediments, upon which stream

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[1] E. W. Hilgard, quoted by Van Winkle and Eaton, Quality of the Surface Waters of California, Water-Supply Paper U. S. Geol. Surv. No. 237, 1910, pp. 10–11.

[2] Document No. 1123, 60th Congress, 1909.

[3] F. L. Ransome, The Great Valley of California, Bull. Dept. Geol., Univ. Cal., vol. 1, 1896, p. 387.

deposits began to form. The whole Great Valley is now completely walled in by mountains except where the Sacramento and San Joaquin unite to flow through the straits of Carquinez into San Francisco Bay.

The Great Valley is divided into three parts: (1) the Sacramento Valley, drained by the Sacramento River; (2) the San Joaquin Valley, drained by the San Joaquin River; and (3) the Tulare Valley, which might be considered a subdivision of the San Joaquin Valley, for it is sometimes tributary to it.

SACRAMENTO AND SAN JOAQUIN VALLEYS

The Sacramento Valley is a broad and nearly flat alluvial plain. It gradually diminishes in breadth northward and terminates near Red Bluff at an altitude about 300 feet above the sea. At this point the valley is composed of low alluvial fans which have developed to the point of confluence. On the western side of the valley the mountain slopes rise abruptly from the plain; on the east the slopes of the Sierra Nevada rise in a more regular and even manner. All the streams from the Sierra Nevada that enter the Great Valley carry large amounts of rock waste and those that drain the largest basins carry exceptionally large amounts. Their gradients are greatly decreased as they emerge from their deep mountain canyons, and a part, sometimes a large part, of their water is absorbed or evaporated. Thus the carrying power of the streams diminishes rapidly, and eventually a part of the load of land waste is dropped in the form of alluvial fans some of which are 40 to 50 miles in radius. The alluvial fans are composed of coarse waste near the mountain foot, — rough, bowldery material, very pervious, and therefore very dry. Farther from the mountains the material becomes finer; on the lower valley flats it is chiefly fine silt.

Across the broad plain of gravel and sand which forms the northern end of the Sacramento Valley the river and its tributaries have cut valleys from one-fourth mile to four miles in width and to depths sometimes reaching 100 feet. The floors of the valleys are generally flat and may be called the valley flats and flood plains of the adjacent streams. They are covered with fine alluvial soil which when well watered is excellent for agricultural purposes.[1]

The tributaries of the Sacramento before reaching the main stream turn aside and discharge in stagnant sloughs which expand and overflow large areas during the wet season. Broad belts of swamp land and lake therefore occur on both sides of the Sacramento River and are usually covered by a dense growth of tule (*Scirpus lacustris*). The plains and the lowest rolling foothills are on the whole without arboreal

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[1] J. S. Diller, Redding Folio, U. S. Geol. Surv. No. 138, 1906, p. 1.

vegetation save for scattered oak trees which give a park-like character to the landscape. The river is usually lined by tule swamps and the banks support a dense vegetation of brush and willows.[1] Farther south the Sacramento River and its principal tributary, the Feather River, flow in channels well above the general level of the flood plain. The case of the Yuba River is of peculiar interest. Mining operations in its valley have caused the delivery to the stream of an exceptional amount of alluvium, so that the town of Marysville, which was formerly well above the river, is now considerably below it at high water.

The streams draining the western slopes of the Sierra Nevada constitute the larger part of the drainage of the Sacramento Valley and have a relatively constant flow reaching the Sacramento through definite channels; the smaller streams draining the eastern slopes of the Coast Ranges seldom reach the Sacramento River at the surface but are lost in the intricacies of the sloughs which meander through the bordering tule lands. This difference in the amount of water and therefore of alluvium contributed to the Sacramento and the San Joaquin valleys on the east and west sides has resulted in a marked asymmetry of valley form, both rivers lying on the western sides of the plain. The San Joaquin, especially, flows close to the base of the Coast Ranges, having been pushed farther and farther west by the building up of low confluent alluvial fans at the mouths of the Sierra streams. In a similar way Lake Tulare lies near the western edge of the valley on account of the encroachment of the extensive fan of the Kaweah River combined with the deltas of the Kings River and other streams.

On the north the alluvial portion of the Sacramento Valley is bordered by a well-marked plain of erosion (Pliocene) which passes under the lavas of the Lassen Peak district and in some places changes gradually and in others abruptly into the mountain slopes of the Klamath region. It is considered to be a continuation of the peneplain recognized within that region. The width of the base-leveled plain at the northern end of the valley varies from one to fourteen miles, and was once part of an extensive erosion plain which formerly included middle and northern

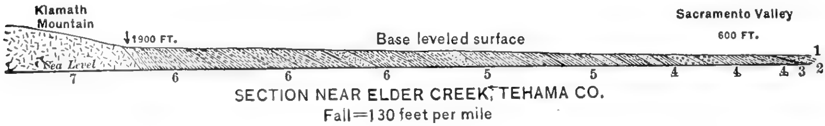

Fig. 43. — Base-leveled plain on the northern border of the Great Valley of California. (Diller, U. S. Geol. Surv.)

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[1] Lindgren and Turner, Marysville Folio U. S. Geol. Surv. No. 17, 1895, p. 1.

California, southern Oregon, and possibly an even greater area. The plain cuts across Cretaceous and Tertiary strata along the eastern border of the northern part of the Sacramento Valley. These strata pass by gentle dips westward beneath the valley and rise again to the surface along the western border, thus outlining the northern part of the valley as a broad shallow geosyncline filled with deposits of late geologic age.[1]

TULARE VALLEY AND LAKE

Tulare Valley, near the southern end of the Great Valley of California, contains Tulare Lake, which has no regular surface drainage to the sea. The waters of the lake are separated from the San Joaquin system by a gentle swell of alluvium, so that in seasons of unusual rainfall a surface connection is established between the lake and the river.

The combination of drainage conditions about Lake Tulare reminds one very strikingly of those in the Salton Sink region. The basin of Lake Tulare is due chiefly to the building up of alluvial fans across the San Joaquin Valley north of it, especially between Kings River on the east and Los Gatos and other creeks in the northern part of the Coalinga district, the latter having formed exceptionally large alluvial fans for Coast Range streams. Lake Tulare is therefore a broad shallow water body developed upon an almost level floor of alluvium and represents an expanse of water above an obstructing dam formed by alluvial fans. It derives its water supply from several streams that descend from the Sierra Nevada and spread numerous distributaries over the valley floor. Practically no surface water reaches the lake from the mountains on the west side in spite of their closer proximity. On all sides the lake is bordered by broad tule-covered swamps, hence its name.

Lake Tulare has no regular surface outlet; the water level is controlled by seepage and evaporation. It is therefore subject to great fluctuations and in periods of high water the whole central portion of the valley becomes flooded and marshy. In earlier years the lake was one of the largest bodies of fresh water in California; in later years it has been gradually declining in size owing largely to decreased rainfall, to the use of the water of its tributary streams for irrigation, and to the reclamation by dikes of the land formerly covered by it. In 1880 it overspread an area about 27 miles long and 20 miles wide; in 1889 it was 20 miles long and 15 miles broad. Still more recently successive dikes have been constructed, the lake has almost dried up, and most of the former lake bottom has been cultivated. In 1907 the precipitation

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[1] A. C. Lawson, Bull. Dept. Geol., Univ. Cal., vol. 1, 1896, p. 271.

was unusually large and the whole central portion of the valley was again inundated, the lake extending almost to its old shore line of 1880 near the base of the Kettleman Hills bordering the Coast Ranges.

During late Quaternary time Tulare was much greater than at present, as shown by an old beach a hundred feet above it. The beach is in the form of a ridge of sand about 20 feet wide, 6 to 8 feet high, and somewhat eroded and covered with vegetation. A line of depression across the middle of the main valley connects Tulare Lake by a low marshy tract with two smaller lakes, Kearn and Buena Vista, 50 miles to the south, which owe their position near the base of the Coast Ranges to the westward growth of the large delta of the Kearn River.[1]

Valley of Southern California

LOCATION AND CLIMATIC FEATURES

The valley of southern California is a lowland area limited on the north by the San Gabriel range and separated from the Mohave and Colorado deserts on the east by the San Bernardino and San Jacinto mountains. On the west the plain extends to the Pacific; on the south its limits are irregular and indefinite, a broad transitional belt occurring between it and the heights of the Sierra Madre of Mexico. It is not a part of the great Pacific downfold but a separate lowland unit. The valley of southern California is more populous, more intensely cultivated, and has more concentrated wealth than any similar area in the Southwest. These unique features depend upon its climate, its fertile soil, and its valuable products. Its southerly position gives it a moderately high mean annual temperature of about 62°. The open exposure of its surrounding mountains to the Pacific results in a marked rainfall and hence they supply more water for irrigation than is commonly supplied to the alluvial plains of the West. The streams that descend form the seaward slopes of these mountains and water the alluvial plain between them and the sea are, as such streams go, of great size and permanence of flow. The soils are generally well disintegrated arid land soils with a high percentage of soluble plant food.

TOPOGRAPHY AND DRAINAGE

The valley of southern California, Fig. 44, is divided by the Santa Ana Mountains and the Puenta Hills into two parts: (1) a coastal portion, the coastal plain, and (2) an interior portion, the interior valley. The coastal plain of southern California is about 50 miles long and 15 to 20 miles wide. Its relief is in general low and the regional slope is seaward

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[1] Arnold and Anderson, Geology and Oil Resources of the Coalinga District, California, Bull. U. S. Geol. Surv. No. 398, 1910, pp. 39–382.

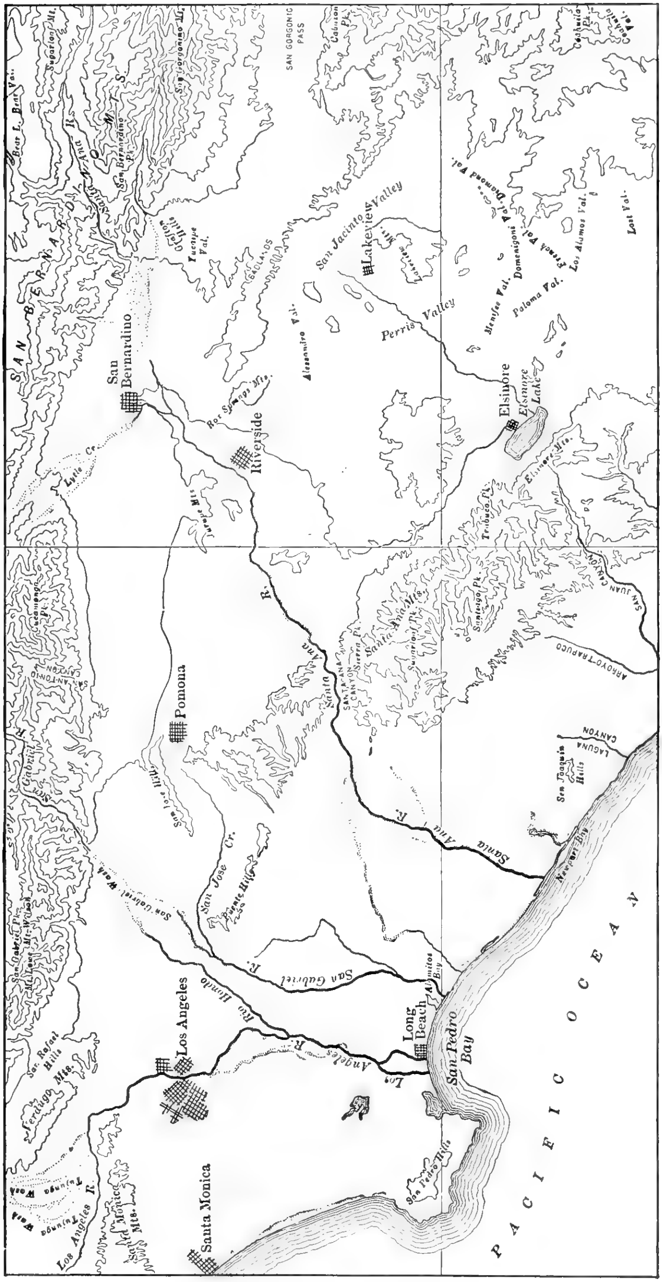

Fig. 44. — Bench lands, coastal plains, and mountains of southern California.

from an elevation of 200 to 300 feet along the inner margin to the salt marshes and sand dunes of the coast. The chief interruptions of its level surface are San Pedro Hill and a low ridge that extends southeastward from the vicinity of Palms. The inner edge of the coastal plain forms a fringe of bench land which contours the higher mountains back of it and forms bluffs except where the mountains approach the coast. It is somewhat dissected by the canyons of the small streams that cross it. These gullied benches are conspicuous back of Santa Monica and along the southern base of the Santa Monica Mountains, where they are composed of stream-deposited sands, gravels, and clays, in contrast to the marine deposits which make up a large part of the coastal plain.[1] The coastal plain of southern California is regarded as a former broad embayment of the Pacific in which débris brought down by the mountain streams accumulated; it was finally exposed by uplift and slightly modified by erosion.[2]

Fig. 45. — Inner edge of the coastal plain of southern California near Whittier. (Mendenhall, U. S. Geol. Surv.)

FORESTS AND WATER SUPPLY

In southern California, where water supply is a dominating economic necessity, a very intimate relation has been found to exist between the amount of forest cover in the mountains and the water supply

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[1] W. C. Mendenhall, Development of Underground Water in the Western Coastal Plain Region of Southern California, Water-Supply Paper U. S. Geol. Surv. No. 138, 1905, pp. 9–11.

[2] Idem, p. 11.

Fig. 46. — West Riverside district, California, representing typical relations of mountains and bordering alluvial plains, valley of southern California. (Mendenhall, U. S. Geol. Surv.)

Fig. 47. — West Riverside district, California. This view is panoramic with the one above. The mountain notch on the right is the notch on the left in Fig. 46.

of the bordering plains. The matter is of great importance to horticultural interests in southern California because of the nearly rainless summer, the precipitation occurring almost wholly in the winter months from November to April. Practically all of the rain that falls upon the flat porous valley lands is immediately absorbed by the soil or evaporated into the air. On the mountain slopes a large proportion is absorbed by the soil and humus where vegetation has not been destroyed by fire and the unprotected soil swept off. It is the water absorbed by the soil and forest litter of the mountain slopes that is the source of the important summer flow of the mountain streams. It has been found that the denser the vegetal growth and the thicker the soil on the mountain slopes, the more effectively are the winter rains stored and the more uniform is the summer flow. The effect of the forest in decreasing surface flow during the rainy season is enormous, the average of four different basins showing an absorption of 95% on the forest-covered areas and only 60% on the nonforested areas, where the rainfall is much less. A comparison of three other areas gave the following result:

> "The three forested catchment areas, which, during December, experienced a run-off of but 5% of the heavy precipitation for that month and which during January, February, and March of the following year had a run-off of approximately 37% of the total precipitation, experienced a well-sustained stream flow three months after the close of the rainy season. The nonforested catchment areas, which during December experienced a run-off of 40% of the rainfall and which during the three following months had a run-off of 95% of the precipitation, experienced a run-off in April (per square mile) of less than one-third of that from the forested catchment areas, and in June the flow from the nonforested area had ceased altogether."[1]

The disastrous results that follow deforestation are of great concern in this thinly forested region, for the private lands are being rapidly deforested by large lumber camps, whose operations cause ever-increasing danger from forest fires, floods, and summer droughts.[2]

SOILS OF THE PACIFIC COAST VALLEYS

The soils of the Pacific coast valleys range from residual and colluvial soils of the mountain foothills to deep and extensive river flood-plain and delta sediments and ancient and modern marine and lacustrine shore deposits. The wide range in value of these soils and their adapta-

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[1] J. W. Toumey, The Relation of Forests to Stream Flow, Yearbook, Dept. of Agri., 1903, pp. 286–287.

[2] Van Winkle and Eaton, Quality of the Surface Waters of California, Water-Supply Paper U. S. Geol. Surv. No. 237, 1910, p. 17.

tion to crops is dependent largely upon the possibilities of irrigation and upon local climatic conditions of rainfall and temperature.

The soils of the alluvial fan deposits, colluvial and alluvial wash from foothills and higher adjacent soil bodies, and occasional small areas of residual material are derived mainly from sandstones, shaly sandstones, and shales (Cretaceous and Tertiary), and occur upon rolling marginal hills, sloping, elevated, and dissected mesa or bench lands, and in some places on the margins of lower nearly level valley plains.

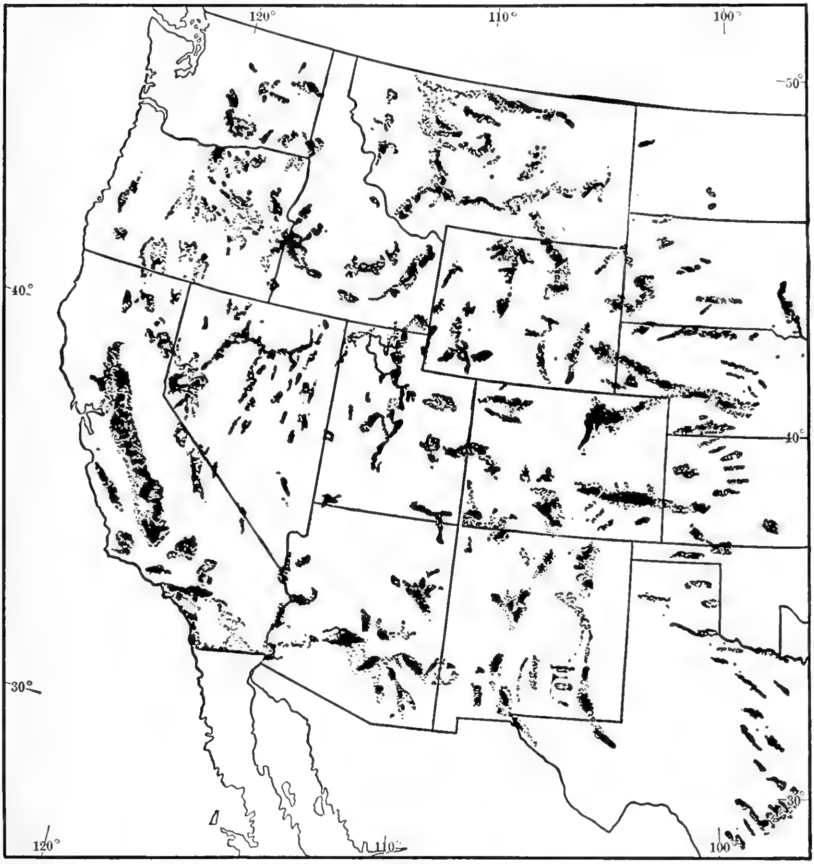

Fig. 48. — Irrigation map of the West. Irrigated areas solid black, irrigable areas dotted. (Newell, Irrigation in the U. S.)

The soils composed of recent alluvial materials derived from a great variety of rocks and deposited as river and delta plains generally occupy a lower topographic position, are of more recent origin, are subject to more frequent overflow than other soils of the region, and often support a growth of swamp vegetation, brush and willow thickets, and timber in the river bottoms and lower valley plains. The surface is generally level, slightly sloping or sometimes uneven, and is frequently marked by sloughs or the interlacing channels of streams many of which carry water only in times of flood and disappear in sandy washes. The heavier members are frequently marked by adobe structure and the soils are generally free from gravel or bowlders.

The lower-lying areas are frequently poorly drained, subject to the influence of seepage water from irrigation, and contain alkali. They are generally underlain by subsoils of fine ashy texture, light color, and compact, close structure, usually separated from the overlying soil by an alkali carbonate hardpan of white or light-gray color. The hardpan softens slowly upon the application of irrigation water, but is normally impenetrable to the roots of growing plants.

An important group of soils is composed of alluvial deposits formed by shifting streams and mountain torrents and occurring as broad, low, alluvial cones occupying gently sloping plains or slightly rolling valley slopes, generally treeless and lying above present stream flood plains. The soils of this series are derived from a variety of rocks, but generally from those of granitic and volcanic character, or from sandstones carrying large amounts of granitic material. They are generally treeless and support only a desert vegetation except where they are irrigated. They are frequently cut by arroyos, and are usually gravelly and often strewn with bowlders. These soil bodies vary from small areas of irregular outline to broad, extensive, uniform sheets. They are generally dark-colored, open-textured, well drained, and free from alkali.

The Great Valley contains no true forest growths, only lines of poplars and sycamores along the rivers. The lower foothills on the borders of the valley and up to elevations of 1000 feet are dotted with Douglas oak and live oak and occasional patches of a thorny shrub (*Ceanothus cuneatus*). During the dry summer season the main expanse of the valley presents a rather monotonous and cheerless view since it is practically treeless and covered with a dry gravelly soil or a parched growth of sparse grasses that spring up in the wet season. Along the stream courses in the axis of the valley trees are sometimes found, though willow and alder shrubs are more common growths.[1]

The soils of the valley of southern California are similar in origin, topographic position, and texture to those of the Great Valley. The

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[1] Turner and Ransome, Sonora Folio U. S. Geol. Surv. No. 41, 1897, p. 3.

most important departure from the general character is made on the coastal plain. Its outer margin has soils of distinctive character derived from marine sediments. Except along stream courses and at the heads of some of the alluvial fans arboreal vegetation is entirely wanting.

In the Tacoma region at the northern end of the series of coast valleys the bottom-land soils of the valley floors are stream-laid and vary in texture from gravel to fine silt. Silt is most common, gravel and sand have a more restricted development and are generally found near the mouths of the canyons and at the heads of the alluvial fans of tributary streams.

The soils of the uplands are disposed on steep sharp ridges and washed to such a degree as to be unfit for tillage, except in limited areas on rounded hills. Locally the soil is open in texture and very sterile, as in the case of the Steilacoom plains south of Tacoma. Although these plains receive about 44 inches of rain per year, the water drains away so rapidly in the loose, stony ground that they are an arid tract in the midst of a humid region.[1]

The primeval growth of the valley soils was fir and hemlock with cedar and maple predominating in the wet lands along the hollows and tributary gullies.

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[1] Willis and Smith, Tacoma Folio U. S. Geol. Surv. No. 54, 1899, p. 7.

CHAPTER XIII

COLUMBIA PLATEAUS AND BLUE MOUNTAINS

COLUMBIA PLATEAUS

Extent and Origin

The Columbia physiographic province includes a large variety of physical features whose basis of unity lies in their common association with those widespread sheets of balsaltic lava that form the larger part of the region. It is important therefore to have at the outset a clear conception of the geologic origin and nature, areal extent, and physiographic features of the Columbia River and Snake River lavas.

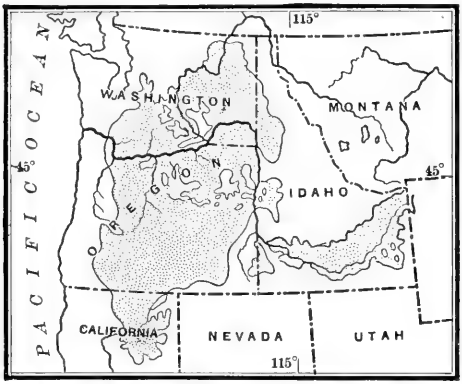

Fig. 49. — Lava fields of the Northwest. (Data from Geologic Map of North America, by Willis, U. S. Geol. Surv.)

In sharp contrast to the mountainous borders of the province are the flat or apparently flat basalt plains which cover an area of over 250,000 square miles and form probably the most extensive single field of sensibly flat basalt in the world. Their development involved the transference of about 100,000 cubic miles of dense rock from the earth's interior to the surface. For many years all these basaltic flows were believed to have originated from fissures concealed by the lava that issued from them. This was the view of Sir Archibald Geikie, for example, when in 1882 he described the Snake River basalt plains.[1] But the studies of Russell have shown conclusively that no direct evidence has been found in support of this explanation in the greater part of the Snake River lavas, while the region abounds in evidence pointing to the local accumulation of material from a large number of vents of several varieties. In many localities low mounds may be seen rising by gentle

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[1] Sir Archibald Geikie, Geological Sketches at Home and Abroad, 1882, pp. 237–242

gradients above the general level of the country. Their summits are flat, and from them may be traced lava flows which extend outward in all directions until they merge into the flat expanses of the plain. Here and there on the borders of the region flows may be traced down tributary valleys at whose mouths they expand to form part of the general surface.[1]

To produce so flat and so extensive a plain, lava must have great fluidity and must originate from separate vents thickly strewn over a given region. Both these conditions are fulfilled here. Vents are numerous and their flows have been traced into each other to such an extent that the region may be described as consisting of a large number of low gradient plains merging inperceptibly into each other. Some of the constituent minerals of the basalt (augite, etc.) fuse at such low temperatures that a high degree of fluidity had been attained by the lava. It ran readily over the gentle slopes and spread far and wide before it was congealed. Were the flows less fluid they would have gathered closer about the volcanic vents and would now show far steeper gradients, as in the Cascades.

While the Snake River lava was thus formed by volcanic extravasation of highly fluid material from many different vents, the basalt of a large portion of eastern Oregon and Washington is equally well known to have originated from a vast number of fissures. On the eastern border of the Cascades there is a great system of feeding dikes in the sandstone beneath the basalt; similar relations have been observed in the Blue Mountains, where the once overlying basalt has been removed by erosion.[2]

In central Idaho on the eastern edge of the basalt plain east of Lewiston no ash cones or tuff volcanoes are found nor are any dikes of basalt observed in the foothills of the Clearwater Mountains adjacent to the basalt. The eruption of the fluid rock must have taken place in this locality without explosive action and from fissures.[3] In the Eagle Greek range, Oregon, a local center of eruption has been discovered near Cornucopia, where at elevations of 7000 to 8000 feet there occurs a perfect network of basalt dikes intersecting the schists and granites immediately above the lava plateau.[4]

The lavas comprising the Snake River and Columbia River plains are of two general sorts, basalt and rhyolite. The basalt, as we have already seen, was spread over the surface in great flows and in a highly

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[1] I. C. Russell, Geology and Water Resources of the Snake River Plains of Idaho, Bull. U. S. Geol. Surv. No. 199, p. 66.

[2] F. C. Calkins, Geology and Water Resources of a Portion of East-Central Washington, Water-Supply Paper U. S. Geol. Surv. No. 118, 1905, p. 19.

[3] W. Lindgren, A Geological Reconnaissance Across the Bitterroot Range and Clearwater Mountains in Montana and Idaho, Prof. Paper U. S. Geol. Surv. No. 27, 1904.

[4] W. Lindgren, The Gold Belt of the Blue Mountains of Oregon, 22nd Ann. Rept. U. S. Geol. Surv., pt. 3, 1902, pp. 740–745.

fluid condition. The rhyolite, on the other hand, was extruded in part in the form of sheets or flows and part as ejectamenta — volcanic dust, gravel, lapilli, and other angular fragments. These two kinds of eruptions occurred at different periods; the greatest inundations of basaltic lava in eastern Oregon took place before the rhyolitic eruption. After the rhyolite had been extruded there came a renewal of the basaltic eruptions, which continued from time to time almost to the present day but on a far less extensive scale. The latest basaltic eruptions of the Snake River plains are so fresh as to appear to have been formed within historic times, probably not more than several hundred years ago; the earliest eruptions date back to the Tertiary (Miocene). The total number of flows varies from place to place. but in a number of cases at least 100 are known to have occurred.

There is considerable difference in the age of the Columbia and the Snake River lavas. The Columbia River lava is deeply decayed and over large areas has been changed to a soft clay-like soil having a depth of sixty feet or more, while the Snake River lavas are still fresh and even the exposed portions of older sheets show but slight changes.[1]

The volcanic outpourings of the region were not limited to the Columbia and the Snake River valleys; they extend into the Cascades, which are in large part formed of volcanic material; the southern Cascades are almost exclusively volcanic. The greater part of the eastern border of these mountains is completely buried beneath recent flows. The basaltic flows also extend northward into Canada, where they form a considerable portion of the Interior Plateau of British Columbia. Lava flows of the same kind and approximately the same age are found in many other localities in the Pacific Cordillera, as in the Great Basin and the Colorado Plateaus, where they form highly important elements of the relief.

BURIED TOPOGRAPHY BENEATH THE BASALT

To understand the present distribution of the lava of the Columbia Plateaus and the detailed character of the surface one must know that before the lava was extruded the region had considerable relief; canyons and gorges had been cut, and the whole surface was in a state of vigorous dissection. The country rock consisted of old volcanic and sedimentary formations, mainly granite, rhyolite, quartzite, and limestone.[2]

The effect of the basaltic inundations was to fill the valleys and, to a large extent, to bury the older topography. In some cases hills and mountains of older material project through the basalt as islands project above the surface of the sea, for example, Big, Middle, and

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[1] I. C. Russell, Geology and Water Resources of the Snake River Plains of Idaho, Bull. U. S. Geol. Surv. No. 199, 1902, p. 61.

[2] Idem, p. 15.

East Butte, Idaho.[1] In other cases the old divides extend for long distances into the lava fields as capes and promontories against which the basalt came to rest.

An excellent locality for the study of the relations of the present to the buried topography is northeast of the Blue Mountains, Oregon, where the Snake River has cut a gorge across a great structural arch in the basalt and has exposed successive flows with their interstratified

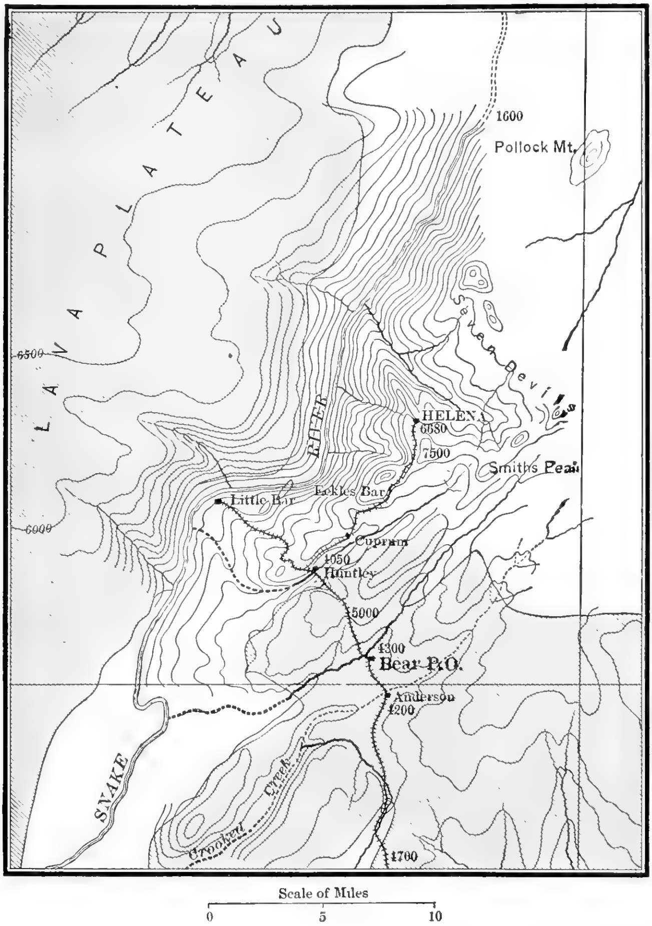

Fig. 50. — Canyon of the Snake River at the Seven Devils. Sketch contours, interval approximately 500 feet. The cross-lined areas represent basalt-covered surface; the blank areas represent older slates, schists, etc. (After Lindgren, U. S. Geol. Surv.)

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[1] I. C. Russell, Geology and Water Resources of the Snake River Plains of Idaho, Bull. U. S. Geol. Surv. No. 199, 1902, p. 62.

beds of dust and lake deposits. Near the Seven Devils, Fig. 50, the gorge is 4000 to 6000 feet deep, and is one of the most remarkable erosion features in the United States. It extends northward for 125 miles as far as Asotin, a few miles above Lewiston, and is comparable in grandeur and depth to the canyon of the Colorado. Above Asotin the canyon of the Snake River becomes deeper and furnishes many striking illustrations of columnar basalt which rises tier on tier more than 3000 feet. Near Buffalo Rock may be seen to best advantage the relations of the old and now buried topography to the basalt cover. The metamorphic rocks which formed the surface of the country before the basalt inundated it rise at least 2000 feet into the horizontally bedded flows. The river has thus cut its gorge across a buried mountain and has exposed the rocks composing it for a stretch of about a mile. The undisturbed horizontal layers of basalt abut sharply against the steep waste-free slopes of the old mountain which descend to the lowest level of the Snake River and have ancient valleys coördinated with them deeper than the present deep canyon of the Snake.[1] The crest line of the buried mountain is rugged and serrate; the gorges between the higher crests and spurs are filled with horizontal sheets of lava, showing that the flood of basalt flowed about the highest peaks and for a time left them as islands in a molten sea of rock, then overtopped their summits and completely buried them.[2] The topographies of the canyon wall above and below the contact of these two rock types are very dissimilar. The buried surface developed upon the older rocks is exceedingly irregular and steep, the spurs ending in precipices that are sometimes almost a thousand feet sheer. On the other hand the dull-brown and relatively flat-lying basalt is weathered into cliff and talus and a more regular type of topographic architecture.

Drainage Effects of the Basalt Floods

SNAKE RIVER VALLEY

The repeated and extensive outpourings of lava resulted in widespread hydrographic changes. The ancestral Snake River was dammed by lava flows to such an extent that a large lake, so-called Lake Payette, was formed, upon whose floor sediments were laid down. The lake appears to have been invaded time and again by contempo-

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[1] I. C. Russell, A Reconnaissance in Southeastern Washington, Water-Supply Paper U. S. Geol. Surv. No. 4, 1897, p. 31.

[2] Idem, p. 35.

raneous lava flows, and it is with these flows and with the widespread sheets of volcanic sand and dust that the sediments are associated. The lake beds filled the valley to a great depth, and are divided into an older (Miocene) and a younger (Pleistocene) division which carry mammalian remains and fresh-water mollusks.[1]

The waters of Payette Lake entirely surrounded the Owyhee range of Idaho, as is shown on the west side of this range where the nearly horizontal soft sandstones and shales of lacustral origin rest against eruptives (Miocene) and display a well-defined shore line from 5400 to 5500 feet above sea level. This shore line is also identified along the Boise River but at 1000 feet higher elevation, and indicates by its variable elevation at many points in the Snake River Valley that notable deformation has taken place since deposition of the lake beds.

In addition to the main Miocene lake there were formed many small lake basins caused by lava dams at the valley mouths, as in Long Valley in the northern part of Boise County.[2]

The present valley of Snake River extends across Idaho in a semicircular course about 80 miles wide. Its course is underlain by lake beds and intercalated flows of basalt that slope gently from the bordering mountains to the axis of the valley. Into these beds the river has cut a sharp canyon 400 to 1000 feet deep, thus exposing the structure. The average elevation of the Snake River plains of Idaho is from

Fig. 51. — South shore of Malheur Lake, Oregon. Salacornia growing in alkali. (Russell, U. S. Geol. Surv.)

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[1] W. Lindgren, The Gold and Silver Veins of Silver City, De Lamar, and Other Mining Districts, Idaho, 20th Ann. Rept. U. S. Geol. Surv., pt. 3, 1898–99, p. 80.

[2] Idem, pp. 95–96.

3975 feet at Shawnee to 2125 feet at Weiser. Alluvial and to some extent irrigated bottom lands occur at a number of places along the river, and they also exist along the lower courses of the Boise and Payette tributaries.[1]

HARNEY-MALHEUR SYSTEM

In Oregon the course of the Malheur River has been profoundly modified so as to bring about a loss of fully one-third of its former drainage basin. A lava flow dammed its channel in the vicinity of Mule River and caused the formation of the basin of Harney and Malheur lakes, Fig. 52. The surface of the lava is only about 10 or 15 feet above the normal level of Malheur Lake, and so delicately are the topographic and climatic conditions balanced that a very slight increase in rainfall would result in the discharge of Malheur River down the line of its old valley. The occurrence has additional interest in that the ponding of the water above the lava dam causes the entire region now draining into Harney and Malheur lakes, about 4500 square miles in area, to be removed from the Pacific slope drainage and added to the drainage of the Great Basin.

A further modification of the Harney-Malheur drainage has been brought about by the formation of hills of wind-drifted sand which invaded what was once a single basin, making the two basins now occupied by Malheur and Harney lakes. The hills are in part grass-covered, with steep-sided basins among them, and furnish a barrier between the two lakes which is only crossed by the water of Malheur Lake during high-water stages.

Deformations of the Basalt Cover

Although the basalt plains of the Columbia region were formed in a nearly horizontal position and although these plains appear to be approximately horizontal to-day, there are in reality many important departures from horizontality. The Snake River plains are now in the form of a broad trough or downfold reaching from Lost River and Sawtooth Mountains on the north to Goose Creek and Bear River Mountains on the south. Many minor irregularities of structure have been noted. In southwestern Idaho the lavas and intercalated lake

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[1] W. Lindgren, The Gold and Silver Veins of Silver City, De Lamar, and other Mining Districts in Idaho, 20th Ann. Rept. U. S. Geol. Surv., pt. 3, 1898–99, p. 77. See this author's geologic map, Plate 8, p. 76, for the distribution of the various types of rocks found in a little-known section of central Idaho south of the National Forest that lies east of Mount Idaho and northeast of the Snake River Valley.

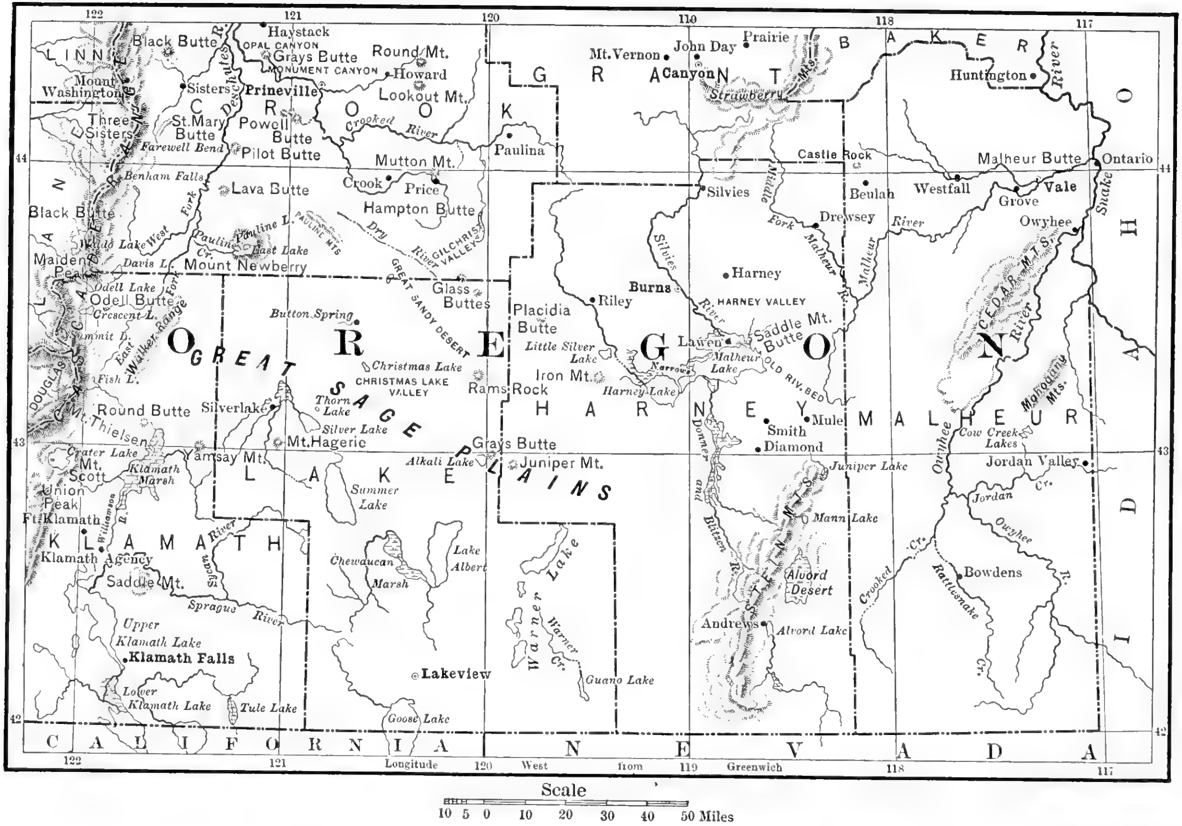

Fig. 52. — Sketch map of Southeastern Oregon, showing drainage features. (Modified from Russell, U. S. Geol. Surv.)

and river sediments have been gently flexed and, near the bases of the bordering mountains, broken and faulted.[1] These structural irregularities are of considerable economic importance, for it is upon the trough-like arrangement of the beds that the artesian condition of the deeper waters depends. The economic development of the region has been accomplished to a notable extent by the use of artesian waters for domestic purposes and for supplying stock as well as for a small amount of irrigation.

The existing relation of drainage to relief implies antecedent conditions on the part of the streams. The lava, originally disposed in an essentially horizontal position, has been deformed from this position but the deformation has not proceeded so rapidly as to rearrange the drainage courses Stream courses laid out upon the nearly flat lava sheets in response to the initial slopes have persisted in their courses, and where there have been great uplifts athwart the streams we now find great canyons. The explanation is similar to the one applied to the present course of the Columbia across the Cascades except that in the Cascades it was a base-leveled and to some extent a lava-covered surface and not exclusively a sheet of lava that was uplifted across the path of the river. Had the lava been in its present attitude when the Snake River first gained its course the river would now run in an opposite direction for some distance south of the great canyon.

Coulees of the Columbia Plateaus

Among the striking physiographic features of the Columbia River region are the coulees that occur in Washington from Patterson to Connell east of the Cascades. Many of them are scores of miles in length and of notable width and depth. They are dry or contain only small streams in spite of their great size. They have all the topographic qualities of river valleys in addition to tributary systems of branching valleys with stream-carved bluffs. Some of them represent an earlier period of more abundant rainfall during which wide, flat-bottomed, and cliff-walled canyons were formed. Others are related to the bodily diversion of the streams from their preglacial courses and the post-glacial abandonment of the temporary courses.

The largest and most rambling of the coulees is Grand Coulee. It is not only of greater interest scenically but its geologic history has been unusually interesting. This great canyon was cut by the Columbia River at a time when the profound gorge Columbia was temporarily

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[1] I. C. Russell, Geology and Water Resources of the Snake River Plains of Idaho, Bull. U. S. Geol. Surv. No. 199, 1902, p. 16.

dammed by a great glacier that came down the Okanogan Valley, filling it to a depth of several thousand feet. Upon reaching the Columbia River Valley the glacier expanded and spread out over the plateau for about 35 miles. The displaced Columbia flowed along the eastern face of the glacier for two miles below Coulee City, where the bottom of the canyon drops abruptly and where the Columbia River once poured over a mighty cataract 400 feet high. The gorge below the cataract extends southward for 15 miles.

The lakes of the plain of the Columbia are situated in the coulees. They occupy basins that represent the former irregularities of channel bottom, or that have been formed by the irregular distribution of wind-blown material. They are elongate in form and often disposed in chains. This is the character of Moses Lake, the largest body of water in the district. The lakes in the northern part of the Grand Coulee occasionally flow to the south at seasons of high water and are therefore comparatively fresh and palatable. On the other hand the waters of the southern lakes become successively more alkaline, and Soap Lake, the most southern, is extremely alkaline. On stormy days it is beaten into great masses of white foam on the exposed shore. The substances in solution consist essentially of carbonates, sulphates, and bicarbonates of soda.

Stream Terraces

Later episodes in the history of the Columbia Plateaus are inferred from the gravel deposits associated with the streams in the form of terraces. They indicate that after the erosion of the deep, rock canyons there followed a period during which the streams aggraded their valleys to depths of many feet, — in the case of the Columbia at least several hundred feet. Later still, a second period of down-cutting was inaugurated in which the streams degraded their channel bottoms, in some cases to bedrock. There were temporary halts in the down-cutting which are now expressed by the lower terraces.[1] In many cases the streams have again begun the aggradation of their valley floors.[2]

The canyon walls of the Columbia River, for example, are marked by a succession of terraces in part carved out of bedrock and in part composed of stream-laid gravels. The largest of these terraces is known as the "Great Terrace of the Columbia" and is distinguished from its neighbors by its great extent and perfection of development. The terraces above the Great Terrace were built by streams along the sides of

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[1] F. C. Calkins, Water-Supply Paper U. S. Geol. Surv. No. 118, 1905, p. 43.

[2] Idem, p. 45.

the Okanogan glacier during the period of its decline. These terraces are less regular than the lower ones and are characterized by more numerous deep pits or kettle holes, while the material composing the terraces suggests glacial débris slightly modified by water. On the other hand the Great Terrace is of postglacial age and is due to the fact that the canyon of the Columbia was once filled with fluviatile deposits from 300 to 500 feet above the bedrock floor and to the level of the Great Terrace. The terraces below the Great Terrace simply mark halts in the process of dissection in postglacial time of the original gravel filling.[1]

Gravel plains of large extent were also developed along the international boundary line in the form of low delta deposits and terraces, the variety of minor features being due to the interaction of ice and stream work.

CLIMATE, SOIL, AND VEGETATION

CLIMATE

The Columbia Plateaus everywhere receive a deficient rainfall, since the province is practically surrounded by mountains of notable height and continuity. On the west are the Cascades, which so thoroughly intercept the rain-bearing westerly winds as to leave even the higher eastern slopes of these mountains rather dry and the lower slopes very dry. The lower and flatter country to eastward is also very dry and in general receives from 8 to 25 inches of rainfall; the lesser amount falls on the Great Sage Plains of central Oregon and the lower Snake River Valley, the greater amount being restricted to the higher relief features such as the Blue Mountains of northeastern Oregon and other ranges of lesser height. Sufficient rain falls upon these mountains to support a forest growth, but the amount in even the most favored situations is nowhere large, and none of the forests is dense. The Blue Mountains shut in the plain of the Columbia on the south in eastern Washington, just as the Owyhee, Goose Creek, and Bear River ranges shut in the Snake River Valley on the south. On the north the plain of the Columbia is sheltered from cold winter winds by the Okanogan and Columbia ranges, on the east by the Cœur d'Alene; the valley of the Snake is similarly sheltered in these directions by the great mountain mass of the Clearwater and Salmon River mountains of central Idaho and the Bitterroot Mountains on the Idaho-Montana line. In both cases, however, the bordering ranges exact their toll of rainfall and leave the plains relatively dry. In eastern Washington the rainfall increases

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[1] Smith and Calkins, A Geological Reconnaissance Across the Cascade Range near the 49th Parallel, Bull. U. S. Geol. Surv. No. 235, 1904, pp. 38–41.

somewhat because of increasing elevation, though this increase should not be confounded with increases on the mountainous elevations farther east. It is sufficient over a restricted tract to make possible farming without irrigation.

The partly enclosed character of the Columbia region causes its mean annual temperature to be much higher than one would expect from its latitude and altitude. Very low winter temperatures prevail, however, in the mountain tracts, especially in the mountainous area of central Idaho, with the result that the snowy precipitation is heavy and the snow melts slowly and remains late the following spring. The effect is to give the streams draining across the bordering valleys and plains access to a natural storage of precipitation of the greatest value in maintaining a proper flow. Since forest trees normally require only about 100 days a year free from snow, the slow melting in late spring of the heavy snowfall of winter greatly increases the value of the total yearly precipitation available to the forests of the region without interfering with their growth. In the Columbia region grazing must always constitute the most important industry from the standpoint of the extent of territory involved. Irrigation by means of mountain streams may, however, become the most important industry as regards the value of the products.

SOILS

The desert quality of the climate of the region is emphasized by the presence of an extensive layer of pumiceous gravel, sand, and dust. It covers tracks aggregating several thousand square miles in extent. It is particularly abundant east of the Cascades, and also extends westward over portions of the mountains and down their slopes for twenty miles or more. Both the Great Sandy Desert (see Fig. 52) and the country west of it display this feature. In many places the layer of volcanic dust is fully 50 feet thick and a maximum thickness of 70 feet has been recorded.[1] It is extremely porous, permits the quick descent of the ground water, and invariably accentuates the dryness of the climate east of the Cascades.

On the great plain of the Columbia in eastern Washington and in many other localities the soils have been described as residual, as having been formed in place by the decay of the basalt. Calkins shows conclusively,[2] however, that in many portions of Washington the soils

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[1] I. C. Russell, Geology and Water Resources of Central Oregon, Bull. U. S. Geol. Surv. No. 252, 1905, p. 16.

[2] F. C. Calkins, Geology and Water Resources of a Portion of East-Central Washington, Water-Supply Paper U. S. Geol. Surv. No. 118, 1905, p. 45.

have been formed by wind action. The conclusion is based upon the facts that there is an absence of lamination in the soil, that it is extremely fine in texture, that there is a remarkably sharp definition between the soil and basalt, and that comparative chemical analyses indicate soils not of the character naturally to be expected from the decomposition of basalt in this climatic province. The principal source of the material appears to be the soft sedimentary beds (Ellenberg formation) in the southwestern portion of the Columbia plains.

The soils are fine loams, very light, open, and friable, with a light, tawny, brown color. The thickness of the soils varies according to location from 25 to 50 feet, the greatest thickness being on the brows of slopes where there is the most favorable opportunity for the accumulation of wind-blown material.

The character of the so-called "dust soils" of Oregon and Washington is typically represented by the following analysis. They are light, dry soils raised into clouds under natural conditions at the slightest wind and probably originated entirely through wind action akin to that which resulted in the formation of loess.[1]

CHEMICAL ANALYSES OF DUST SOILS[2]

Constituents	I	II	III
	Atathnam Prairie, Yakima County, Washington	Rattlesnake Creek, Kittitas County, Washington	Plateau on Willow Creek, Morrow County, Oregon
	%	%	%
Insoluble matter	71.67 } 76.78	78.33 } 80.53	79.21 } 81.51
Soluble silica	5.11	2.20	2.30
Potash (K_2O)	1.07	0.70	0.89
Soda (Na_2O)	0.35	0.24	0.05
Lime (CaO)	2.00	2.08	1.37
Magnesia (MgO)	1.34	1.47	1.08
Brown oxide of manganese (Mn_3O_4)	0.04	0.07	0.06
Peroxide of iron (Fe_2O_3)	6.88	6.13	5.63
Alumina (Al_2O_3)	7.91	6.12	6.02
Phosphoric acid (P_2O_5)	0.13	0.18	0.18
Sulphuric acid (SO_3)	0.02	0.02	0.03
Water and organic matter	2.82	2.35	2.55
Total	99.33%	99.90%	99.35%
Humus	4.10	....	0.44
Hygroscopic moisture	4.98	3.20	4.92

The most extensive and uniform soil types of the Columbia Plateaus consist of residual materials overlying extensive basaltic lava plains. In

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[1] G. P. Merrill, Rocks, Rock-weathering and Soils, 1896, p. 345.

[2] Bull. U. S. Weather Bureau, No. 3, 1892.

some cases the soils have been derived from granitic rocks or from ancient lacustrine sediments or extensive lake beds now more or less modified by erosion or æolian agencies. The margins of the lacustrine or residual deposits are covered by sloping plains and fans of colluvial wash from the adjacent mountain borders, while in the vicinity of the larger streams, which have carved and terraced the lacustrine beds and residual soils, are recent alluvial stream sediments derived from reworked materials of the lake beds or from the weathered products of the mountains. Soils of this type constitute a large portion of the great grain-producing lands of the Northwest. Everywhere the soils are treeless or sparsely timbered, except in the vicinity of streams.

The higher lying areas are often rough and hilly, marked by rock outcrop, bowlders, or morainic débris, and deeply cut by stream channels. Their soils "are generally of dark color, and are underlain by sticky subsoils of light-gray or yellow color. The soils and subsoils are generally gravelly, the gravel varying from fine angular chips to large, well-rounded or angular blocks and cobbles. The soils are dry farmed to grains or, when not occupying too high a position, are irrigated and devoted to grains, alfalfa, clover, and fruits."[1]

Recent flood-plain deposits are underlain by beds of gravel and cobbles, usually from a few inches to a few feet thick, sometimes partially cemented by lime. They are often marked by shallow beds or channels of meandering streams, and are frequently timbered or covered with willow or brush thickets in the vicinity of streams. They usually occur as small irregular to extensive areas, often subject to overflow. The flood-plain soils are generally rich in organic matter and of a mucky consistency, except in the lighter, higher lying members, and sometimes contain alkali.[2] The basalt of the Columbia plain weathers easily and has been decomposed to form a rich residual soil which mantles the surface and gives its slopes characteristic soft, rounded, flowing outlines.[3]

The greatest difficulty in the utilization of the water of the Snake and the Columbia arises from the fact that large stretches of these rivers occur at great depths below the general level of the country. The Columbia flows in a canyon with fairly abrupt walls sunk from 100 to 1000 feet below the broad stretches east of it in Washington. Furthermore, its gradient is much lower than that of much of the land along

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[1] Soil Survey Field Book, U. S. Bur. of Soils, 1906.

[2] Idem.

[3] I. C. Russell, A Reconnaissance in Southeastern Washington, Water-Supply Paper U. S. Geol. Surv. No. 4, 1897.

it and the application of its water to the soil is therefore exceedingly difficult. The most important streams, from the standpoint of irrigation, are those which drain the eastern flanks of the Cascades, as the Yakima, Kittitas, and others.[1]

VEGETATION

Throughout southern Idaho and over the greater portion of Oregon east of the Cascade Mountains the sage-bush is the characteristic plant. It is nowhere absent save on the barren mud plains left by the drying up of the ephemeral lakes, or upon the summits of the mountains. While not so plentiful as the sage-bush the bunch grass is dispersed almost as widely. The fresh-water ponds of the coulee bottoms are bordered by tule, while the meadows in the same situations are covered with wild grasses. The small streams are fringed with a scattered growth of willow, birch, and wild cherry.[2] With increase in elevation the juniper makes its appearance, and beyond the lower limit of the juniper are thickets and groves of mountain mahogany. At still higher elevations, yet within the range of the mountain mahogany, the pine appears and reaches up to an elevation of 8000 to 10,000 feet. However in only two areas in the whole southeastern quarter of Oregon do forests of any considerable extent occur. Castle Rock in Malheur County, Oregon, is on the border of an extensive forest of pines, as well as juniper, mountain mahogany, and many other trees, and a splendid forest exists on the mountains northwest of Harney and Burns in which the Silvies River has its sources.

Above 7500 feet the peaks of the Seven Devils and of the Eagle Creek range in Oregon are flecked with snowdrifts and scored by rock slides and a forest cover is wanting. A forest zone consisting of black pine above and yellow pine below extends from 4000 feet to 7500 feet. Below 4000 feet the canyon walls of the Snake are again almost bare.[3] The bottom of the canyon is at an elevation of about 1600 feet; snow rarely falls in it, and the rainfall is almost equally scant, so that only desert types of vegetation grow upon it.

The occurrence of forests in the region depends upon many factors, chief of which is the moisture supply. The whole tract is extremely dry and one must always ascend to a considerable elevation to find a forest growth. The lower edge of the forest growth is called the "dry

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[1] F. C. Calkins, Water-Supply Paper U. S. Geol. Surv. No. 118, 1905, p. 18.

[2] Idem, p. 22.

[3] W. Lindgren, The Gold and Silver Veins of Silver City, De Lamar, and Other Mining Districts in Idaho, 20th Ann. Rept. U. S. Geol. Surv., 1898–1899, pt. 3, 1899, p. 92.

timber line." On ascending the forest-clothed mountains one reaches also an upper limit of tree growth, the "cold timber line," beyond which only shrubs, stunted trees, and alpine flowers exist. If the aridity is intense the dry timber line will be high and the forest belt correspondingly narrow; if the aridity is not extreme the forest belt will be wide. In many cases the aridity elevates the dry timber line until it coincides with the cold timber line and no forest exists in such cases even though the mountains have a great elevation. It is for this reason the prominent Stein Mountains of southeastern Oregon have no forests. It may readily be seen that mountains which project above the dry timber line but which do not reach the cold timber line have forest-clothed summits, while those whose summits reach to elevations below the dry timber line or above the cold timber line are bare.[1] On the Cascade Mountains in central Oregon the cold timber line has an elevation of about 8000 feet, while the dry timber line, marked by the cessation of the yellow pine, may be taken at approximately 4000 feet.

In the use of the vegetation the scarcity of surface water upon areas underlain by volcanic ash is apparent in two main ways. Water is not available for fighting forest fires even though there is sufficient ground water to support a forest growth; and over large areas there is an excellent growth of grass untouched by sheep or cattle because of the absence of drinking water in the form of springs or running streams. The ash cover is a rapid absorbent and rain water that falls upon it almost immediately becomes ground water. A heavy restriction is thus laid upon the use of the land and its products, though at least one beneficial result follows — the larger streams of the region are kept in more even flow.

BLUE MOUNTAINS

The Blue Mountains of northeastern Oregon have received far less attention than they deserve from physiographers and geologists as well as from foresters. They lie in a very interesting position midway between the mountain complex of central Idaho and the Cascades, and are a projecting spur of the great crust-block composed of the Lost River, Bitterroot, Clearwater, and Salmon River mountains. While they extend well across the basin and plateau region between the Rocky Mountain system and the Pacific Mountains, they do not connect directly with the Sierra Nevada and the Cascades. From the standpoint of rainfall and forests the Blue Mountains (8500 feet) are the

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[1] I. C. Russell, Notes on the Geology of Southwestern Idaho and Southeastern Oregon, Bull. U. S. Geol. Surv. No. 217, 1903, p. 11.

most important relief feature in the entire region between the Cascades and the Rockies since they cause a local rainfall (15 to 25 inches) that waters the fertile valley flats and a belt of peripheral country of considerable extent.

Topographically the Blue Mountains consist of all that group of complex ranges that constitute the country between the Deschutes Valley on the west, the Malheur and Harney deserts on the south, and the Snake and Columbia rivers to the east and north. Within the mountain knot thus outlined are a number of ranges with such specific qualities that they have received separate designations. Conspicuous among these are the Eagle Creek Mountains, the Elkhorn Range, the Greenhorn Ridge, the Strawberry Range, and others. The mountain group thus defined stands out prominently above the surrounding plain, which lies from 4000 to 6000 feet above sea level. The highest peaks of the Blue Mountains rise to heights over 9000 feet above the sea and many exceed 8000 feet.

The geologic features necessary to an understanding of the physiography of these mountains may be briefly stated. The sedimentary rocks of which they are chiefly composed have been not only extensively and rather generally folded but also quite thoroughly intruded by granodiorite, diorite, gabbro, and peridotites. The intrusions were accompanied by uplift, — the net result of folding, intrusion, and uplift being the formation (Jurassic and early Cretaceous) of a mountain knot of impressive height. Upon this complex mass erosion produced profound effects, stripping off a great mass of material and laying bare the heart of the mountains. While they were thus deeply dissected they were never reduced to an old-age condition; erosion was carried only so far as to make them very rugged; so that were one to take away the lava flows about the Blue Mountains they would stand out as imposing heights. Lava flows (Miocene) derived from numberless fissures on the flanks of the mountains were then spread far and wide over the surrounding country, burying the older topography, subduing the relief, and separating the Blue Mountains from the Rockies, causing them to stand out as islands in a basaltic sea. The first flows were rhyolites and andesites, the later flows were basalts in increasing volume.

The effects of the great lava flows were not confined to topographic and drainage changes in the valleys of the Columbia and the Snake, but were exhibited as well in the marginal tracts of the Blue Mountains. The effects are all the more striking because of the former well-developed character of the drainage. The present river courses and the sediment-filled upper basins that are the products of volcanic flows are among the most difficult physiographic problems of the region. The lower parts of the watercourses became filled with basalt, damming the headwaters and creating lakes that were afterwards drained to a large extent by the downcutting at their outlets, thus producing physiographic effects of puzzling complexity.[1]

The precipitation of the Blue Mountains is heavy enough to produce a forest of yellow pine which shades off to mountain mahogany, juniper, and other types, in lower and therefore drier situations. The greater part of the tree cover consists of an open woodland growth since even the best watered areas receive a limited rainfall and snowfall. Small summit areas on the higher mountains, such as the Strawberry Range, Fig. 52, and the Powder River Range north of it, are without a tree cover since their elevations exceed that of the cold timber line, about 8000 feet. The alluvium-filled mountain basins, noted above, and the forest cover combine to keep the streams in more even flow than would otherwise be the case, thus making possible an important amount of agriculture in the lower irrigated valleys. The result is a fringe of population about the flanks of the mountains with finger-like extensions down the major depressions.

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[1] W. Lindgren, The Gold Belt of the Blue Mountains, 22d Ann. Rept. U. S. Geol. Surv., pt. 2, pp. 574, 575, 594, 597, et al.

CHAPTER XIV

GREAT BASIN

Arid Region Characteristics; Hydrographic Features

In spite of the prevailingly arid character of the western half of the United States its streams are in large part through-flowing, a feature due chiefly to the loftiness and position with respect to rain-bearing winds of the mountain groups and ranges in which their sources lie. The Columbia and the Colorado, for example, although they lose a part of their water by evaporation and absorption, yet maintain a considerable volume up to the point of discharge; and in other similar cases the large headwater contributions maintain a perennial flow. Therefore, in respect of drainage a relatively small portion of the arid West has the characteristics usually associated with pronounced aridity — interior basins, large streams which disappear on piedmont slopes, and salt lakes such as those that characterize the deserts of Asia, or the Sahara desert in Africa.

Two large physiographic provinces of the United States are exceptions to this general rule — the Great Basin and the basin of the Lower Colorado. Of the two the Great Basin has the more remarkable development of those drainage features that are an index of extreme aridity. The drainage of the entire Great Basin is of the interior-basin variety, no part of the water that falls within it reaching the ocean by surface drainage. Everywhere the streams descend from the better-watered mountain ranges to waste-floored forelands, where a large part of their water — sometimes the whole — is lost by evaporation and absorption. Such excess of water as locally fails to be absorbed by the porous sands and gravels of the piedmont regions is gathered upon the floors of depressions between mountain ranges in the form of salt lakes or lakes that are strongly alkaline.

Salt Lakes of the Great Basin

Chief among the salt lakes of the Great Basin are Great Salt Lake, Lake Humboldt, Carson Lake, and the group of saline lakes that occupy the Sage Plains of central Oregon, Fig. 52. Some of the lakes of the Great

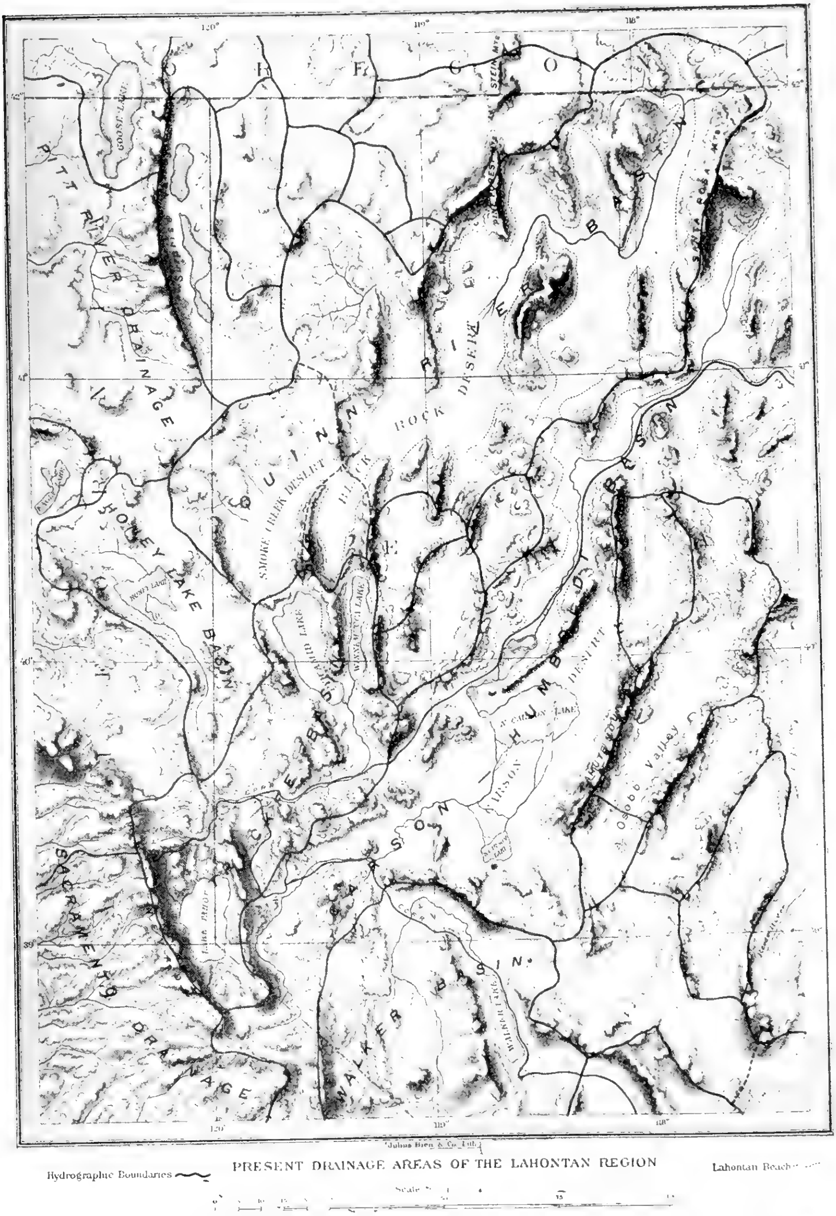

Fig. 53. — Illustrates the small size and independent character of the drainage systems of the Great Basin region. (Russell, U. S. Geol. Surv.)

Basin are composed of very dense brine of common salt, sodium sulphate, and other substances. It has been estimated that Great Salt Lake alone contains 400,000,000 tons of common salt.[1] Not all the lakes tributary to or in the Great Basin are of this character however. Some of them consist of pure wholesome water, such as Utah Lake, Bear Lake, and Lake Tahoe on the western edge of the Great Basin and near the forested heights of the Sierra Nevada. Wherever a constant outlet is assured, the lakes consist of sweet water, but an interrupted outflow is always indicated by an increase of salinity, and the absence of an outflow results in the concentration of chemical salt to such an extent as to result in dense brines.

Another important feature of many lakes of the Great Basin is their ephemeral character. In a large number of instances lakes exist on the basin floors only during periods of high water in the feeding rivers; in dry seasons such lakes evaporate and expose broad flat expanses of mud which soon become dry and sun-cracked and present on the whole a monotonous and forbidding appearance. These are called *playas* and are desert features as characteristic as sand dunes or lost rivers.

The rapid manner in which some playas are transformed into shallow lakes is almost incredible to one unacquainted with rainfall conditions in desert regions. A single storm will sometimes form a shallow lake whose waters are spread far and wide over a basin floor. The disappearance of such a lake may be almost as rapid as its formation, for the mud cracks, at least for a time, allow easy passage of the water to lower levels, and with the high temperature and clear skies characteristic of arid regions, surface evaporation is rapid, and often within a few days, sometimes even in a few hours, after the rain has ceased, the smaller lakes have disappeared.

It is easily seen that the sudden appearance and disappearance of lakes in the Great Basin region are to a large extent functioned by the flatness of the basin floors on which the waters rest. Sudden and great differences in topographic level are not characteristic of regions whose surface forms are products of alluviation. The graded and gentle waste slopes of piedmont forelands and aggrading basin floors are surfaces of such slight relief that waters which come to rest upon them may be spread over great areas and yet nowhere be of great depth. Great Salt Lake is an illustration in point. Its average depth is from 15 to 18 feet; its maximum depth is less than 50 feet. Its area in 1850 was 1750 square miles, but by 1869 its volume had increased to 2170

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[1] I. C. Russell, North America, 1904, p. 142.

square miles.[1] From 1900 to 1904 it was feared it would disappear entirely and its bed become a salt desert. Since that time the level has risen to such an extent that large engineering works, like the Lucin cut-off of the Southern Pacific and the roadbed of the Western Pacific are endangered and may have to be abandoned. These changes are mainly in response to changes of rainfall, 1910 having been abnormally wet.[2] The changes that have taken place in the past half century are to be regarded as changes that may be repeated at any time in the future.

The rate of supply of water to the lake is constantly undergoing changes in sympathetic response to changes in precipitation in the drainage basin. Likewise, the rate of evaporation at the lake surface is subject to considerable fluctuation. A third variable factor is the rate at which water is diverted from tributary streams for irrigation purposes. All of the natural changes are subject to periodic fluctuations. Climatologic studies have shown that rather definite changes are characteristic of the climatic elements in all portions of the earth. These changes are cyclic in character and occur in periods of 11 and 35 years and undoubtedly in even longer periods of a hundred, several hundred, and even many thousands of years. The effects of the cyclic return of wetter conditions have been noted in the case of many lakes of humid regions and in their discharging streams; but the maximum effects of such climatic changes are felt in regions in which the drainage is of the interior-basin variety. The water of an interior basin must rise in response to wetter conditions until evaporation from the expanded surface just equals the rate of supply. The amount of expansion would represent, roughly, the increase of rainfall. If the changes from wet to dry and from dry to wet are not only cyclic but also progressive in one direction, as appears to have been the case at least during and since the glacial period, the repeated rise and fall of the lake surface by large amounts would be recorded in the form of shore features of familiar kinds. Thus there are small changes of lake level that affect all lakes in all climates; also changes of greater amplitude and of far greater physiographic importance, that may be designated as geologic. Such changes are best recorded in the basins of desert regions, for these are, on the whole, without outlet, and the surplus waters are confined and must faithfully record upon their margins the manner in which the changes occur.

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[1] G. K. Gilbert, Lake Bonneville, Mon. U. S. Geol. Surv, vol. 1, 1890.

[2] Ebauch and Macfarlane, Comparative Analyses of Water from the Great Salt Lake, Science, n. s., vol. 32, 1910, p. 568.

Since the Great Basin is the only large physiographic province in the United States in which interior-basin drainage predominates, it follows that the clearest drainage records of climatic change are to be found there. During the glacial period a wetter climate prevailed in extra-glacial regions such as the Great Basin, and each lake in this province expanded until the rate of evaporation or evaporation and discharge just equaled the supply. The two largest of these lakes were in Utah and Nevada. The ancient lake that once existed in Utah has been called Lake Bonneville; its counterpart in Nevada is known as Lake Lahontan. Lake Bonneville has all but disappeared, its descendant being Great Salt Lake; and the discontinuous water bodies called Lake Lahontan have shrunk to such an extent that the lowest parts of the various basins are to-day occupied by a few salt- and brackish-water lakes such as Carson Lake, Humboldt Lake, etc. During its maximum development Lake Lahontan contained salt water, as its shrunken remnants do to-day, though it was undoubtedly less salt than they; on the other hand, Lake Bonneville was fresh or only slightly alkaline when it stood at its highest level, for it rose so high as to discharge for a time over the col on the divide between its basin and the Snake River Valley.

About the borders of the basin of Great Salt Lake may be seen shore features associated with the ancient lake levels and still in an almost perfect state of preservation. Upon the surrounding slopes and up to elevations of 1000 feet above the surface of Great Salt Lake are well-defined deltas, bars, beaches, spits, capes, cliffed promontories, and bottom deposits, all formed by or associated with the ancient lakes whose waters once stood at these high levels.[1]

Some of the most interesting and important lake features of the Great Basin are associated with the lakes of southern Oregon. For example, the water bodies in Lake County, southern Oregon, are all shallow. None exceeds 25 feet in depth. The size of these shallow water bodies depends on the seasonal rainfall, and changes in size are characteristic features in the absence of an outlet to the sea which might permit the maintenance of a more or less constant level, the level of the point of discharge. Important changes in the outline of some of these lakes have taken place since the settlement of the country.

In the early days of Lake View the town was on the edge of Goose Lake, but it is now six miles from it. In 1869 the lake overflowed for a short time southward into Pitt River. In 1881 it also overflowed for two hours during a severe gale from the north.[2] The fluctuation in

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[1] G. K. Gilbert, Lake Bonneville, Mon. U. S. Geol. Surv., vol. 1, 1890; I. C. Russell, Geological History of Lake Lahonton, Mon. U. S. Geol. Surv., vol. 11, 1885.

[2] I. C. Russell, 4th Ann. Rept. U. S. Geol. Surv., 1884, pp. 456–457.

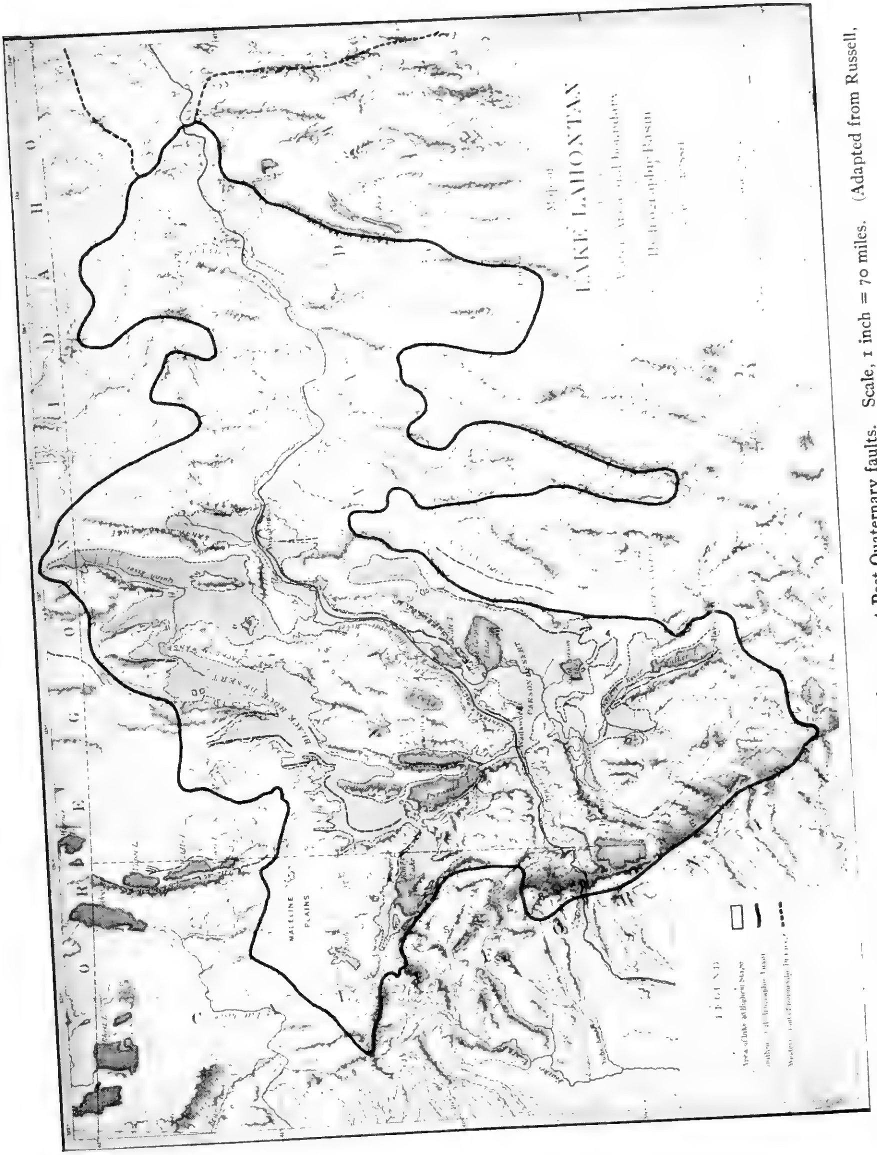

Fig. 54. — The dotted lines of intermediate strength represent Post-Quaternary faults. Scale, 1 inch = 70 miles. (Adapted from Russell, Mon. U. S. Geol. Surv., vol. 11, Plates 4 and 44.)

the level of Goose Lake is also marked by the fact that in the early emigrant days the trail crossed Goose Lake Valley at a point where now the floor of the valley is under several feet of water.[1] The fluctuations in lake level have brought about a certain amount of litigation in relation to lands in the valley of Warner Lake, the decision turning upon the question whether some 4000 or 5000 acres now dry was swamp land or part of the bed of the lake at the time of the passage of the Swamp Land Act of 1860. After the exceptionally dry season of 1887–88, Silver Lake dried up, its bed was cultivated by farmers and one season's crops were gathered before the lake again occupied its old floor.[2]

The degree of alkalinity of the lakes of southern Oregon may be appreciated by comparison with the average alkaline content of the fresh-water lakes of North America as given by Russell,[3] who notes that the amount of alkaline material in the fresh-water lakes of this continent is between 15 and 18 parts in 100,000. The water of Summer Lake, Oregon, on the other hand, has 500 or more parts of salt (sulphate of soda, carbonate of soda, and bicarbonate of soda) in 100,000.[4] The practical bearing of these facts may be appreciated when it is known that the limit of alkalinity for domestic or irrigation purposes is about 400 parts to 100,000, although this limit depends largely on the character of the salt in each particular instance. The water of Lake Abert, southern Oregon, has a content of 3.9% of salt, showing that the water is more strongly impregnated than ocean water, which contains about 3.5% of mineral salt.[5]

Rivers of the Great Basin; Precipitation

The chief rivers of the Great Basin receive their principal supply of water not from rainfall in their middle or lower courses but from melting snows in the mountains, as on the eastern and western borders of the basin. The stream discharge of the region is characteristic, the maximum occurring in the late spring or early summer, with a decrease of flow during the summer and a minimum during the winter months. The streams receive little or no additions after leaving the mountains, and diminish in size and often cease to flow at the surface.[6] The streams which discharge eastward from the Sierra Nevada, such as the Carson and the Truckee, have an immense run-off during the late spring, although the snows accumulate to a great depth in their thickly forested head-

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[1] G. A. Waring, Geology and Water Resources of a Portion of South-Central Oregon, Water-Supply Paper U. S. Geol. Surv. No. 220, 1908, p. 12.

[2] Idem, p. 12.

[3] I. C. Russell, Lakes of North America, 1897, p. 55.

[4] G. A. Waring, Geology and Water Resources of a Portion of South-Central Oregon, Water-Supply Paper U. S. Geol. Surv. No. 220, 1908, p. 14.

[5] Idem, p. 13.

[6] La Rue and Henshaw, Surface Water Supply of the United States, 1907–08, pt. 10, The Great Basin, Water-Supply Paper U. S. Geol. Surv. No. 250, 1910, p. 28.

water regions and a considerable quantity is stored in natural lakes which supply water gradually to the streams into which they discharge.[1]

The streams that descend from the basin ranges are variable as to length and discharge, the latter feature depending ultimately upon the great variations in the height of the mountains (Fig. 55) with which the rainfall and snowfall are inevitably associated. Most of them disappear in the loose material of piedmont slopes, some of them discharge into lakes, all of them are subject to considerable variation in volume. These variations are immediately related to the forest and soil cover of the mountains in which the sources lie and to the rapid melting of the winter snows provided the mountains are of sufficient height to receive their precipitation in this form during the winter months. Only a few of the highest ranges were ever glaciated, hence few lakes occur in the regions of snowy precipitation, and natural storage of mountain waters is markedly absent. Those streams that are supplied by melting snows have great changes in volume from season to season, especially if the supply from springs is exceptionally deficient.[2] Thus the Humboldt River derives its supply from the melting of snows in headwater regions, and the run-off during the spring and summer months is very heavy; but as soon as the snow is gone the rivers are left practically without a source of supply and their channels gradually become dry.

Few better illustrations can be found of a stream not subject to excessive changes of volume and yet without forests or extensive meadows than Bear River, which drains the northern slope of the Uinta Mountains and discharges its waters into Great Salt Lake. The basin contains no marshes and but few small lakes near the head of the river, but the greater part of the precipitation is in the form of snow and the chief sources of supply are from melting snow and from numerous small springs. The latter form so steady a supply that after the annual high-water period during May and June the stream although diminished in volume does not cease to flow.[3]

SPECIAL TOPOGRAPHIC FEATURES

Having no outlet to the sea, the streams of the Great Basin sink into the alluvium of the basin slopes and floors or evaporate from the surfaces of salinas and salt lakes. The surface evaporation of the drainage waters also halts the waste which the drainage water carries and it

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[1] La Rue and Henshaw, Surface Water Supply of the United States, 1907–08, pt. 10, The Great Basin, Water-Supply Paper U. S. Geol. Surv. No. 250, 1910, p. 100.

[2] Idem, p. 56.

[3] La Rue and Henshaw, Surface Water Supply of the United States, pt. 10, 1907–08, The Great Basin, Water-Supply Paper U. S. Geol. Surv. No. 250, 1910, p. 29.

therefore accumulates upon the land and tends to aggrade it. The disposition of the waste brought down by desert streams to lower levels is thus of special interest. Each basin floor becomes a local base level if there is no outlet to a lower basin. In the case of normal topographic development the surface of the land, though it may be built up temporarily, tends ultimately to be worn down to base level, which is almost sea level. In the development of the topography of a desert tract with interior-basin drainage, like the Great Basin, the elevations are worn down but the depressions are built up. The plane of reference, the common plane to which these forces will ultimately bring both depressions and elevations, is then not sea level but some higher level of indeterminate position. When this level has been attained further degradation of the surface will be chiefly through the exportation of dust by the wind to extra-desert regions. The drainage systems, at first independent and local, will become more and more interdependent and general, as one basin after another becomes filled or captured and enters into tributary relations with some lower neighboring depression. When the heights have been reduced and the basins all filled to a common level the rainfall is lessened by the decrease of relief and the streams will become enfeebled and disorganized or over large tracts cease to flow altogether.

The Great Basin streams are still in the early stages of basin filling. The region was deformed so recently (Miocene) that the topographic forms produced by the last deformation are still of mountainous proportions and the basins are only partly filled with land waste. Whether an ultimate level will be reached will depend (1) on the stability of the present climate: at one time (Pleistocene) a Great Basin lake (Bonneville) overflowed to the sea because of a wetter climate, and the same occurrence may be repeated. (2) It will also depend on crustal stability: some crustal movements have occurred in late geologic and even in historic time; if they are repeated and extensive they may offset the tendency toward leveling on the part of the streams.

BASIN RANGES

The most important topographic elements of the Great Basin are the roughly parallel mountain ranges that cross it from south to north and that diversify its surface to a greater degree in Nevada than elsewhere. The mountains are long and narrow and frequently have sharp crests with steep slopes on one side and relatively gentle slopes on the other. The mountain ranges of the Great Basin are explained by block faulting. In general each range may be considered as the upturned edge of a

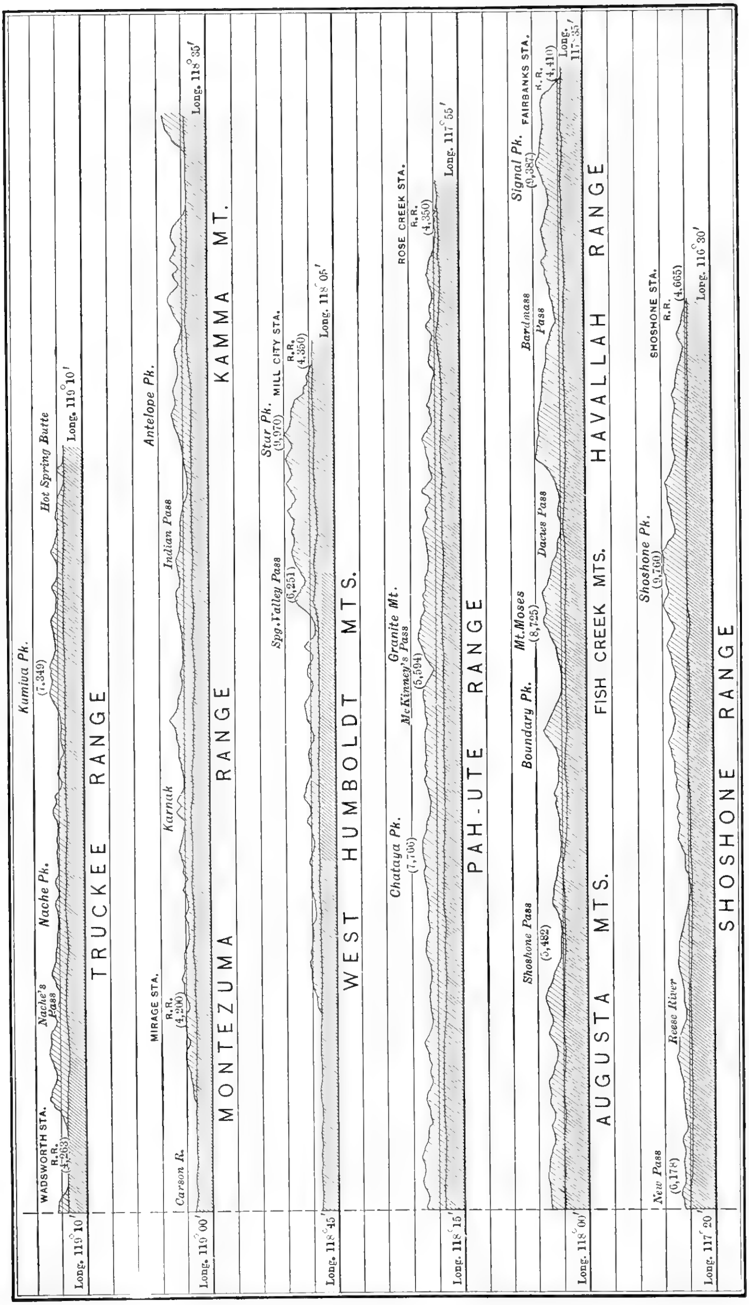

Fig. 55. — Longitudinal profiles of a number of the Basin Ranges. Lighter shading represents elevation of ranges above surrounding country. Horizontal scale, 25 miles to the inch; vertical scale, 37,500 feet to the inch. (King Surveys.)

block of the earth's crust, the faulted edge of the block forming a steep scarp, the tilted back of the block forming a long and relatively gentle declivity that merges imperceptibly into the bordering plain.

In some instances the rocks of the basin ranges appear to have been so complexly faulted that the relief has a peculiarly irregular quality with an absence of parallel ridges and valleys such as characterize the greater number of the basin ranges. The result has been described as a fault mosaic. The complexity of the main fault systems in the Bullfrog district, Nev., is indicated in plan in Fig. 56; the vertical displacements are shown in Fig. 57. Extensive mining development in Nevada in recent years has led to a much more detailed study of actual faults than has heretofore been possible and has removed from the realm of theory to that of well-determined fact the question of the existence of faults that affect the topography.[1]

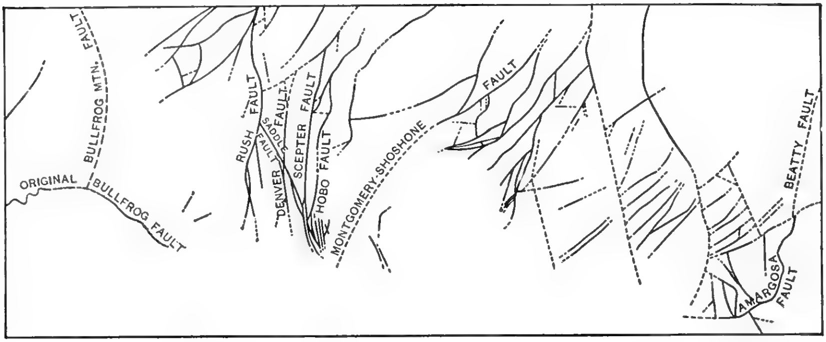

Fig. 56. — Plan of the principal faults in the Bullfrog district, Nevada. (Emmons, U. S. Geol. Surv.)

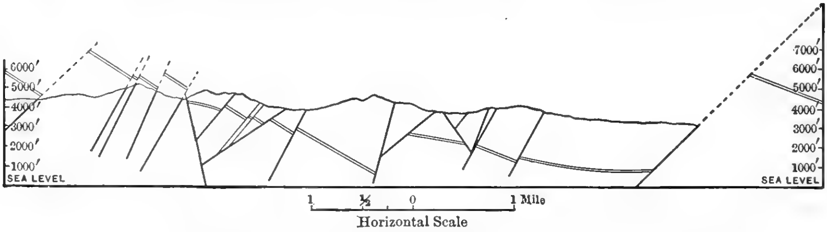

Fig. 57. — Diagram illustrating fault-block displacements in the Bullfrog district, Nevada. (Emmons, U. S. Geol. Surv.)

GEOLOGIC DATA

The structure and geologic history of the Basin Ranges are so directly related to the physiographic features of the Great Basin that we

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[1] In this connection see the paper by W. H. Emmons, A Reconnaissance of Some Mining Camps in Central Nevada, Bull. U. S. Geol. Surv. No. 408, 1910, pp. 76–81 et al.

may well consider for a moment the later geologic events of the region in so far as they serve as a guide to the interpretation of the topographic forms.

The internal structures of the Basin Ranges indicate an early period of mountain making in which were formed anticlines and synclines whose surface expression was probably not markedly unlike that of the Appalachian Mountains of to-day. These beginnings of physiographic history took place in the Jurassic period and resulted from the extensive folding to which the region was subjected at that time and from its gradual uplift above the sea. It is inferred from the internal structures of the ranges that these early deformations produced mountains of great size and height.[1]

The second period of folding (post-Jurassic) took place almost entirely on north-south lines or on lines very closely approximating this direction. East-west lines of folding are extremely rare, and the ranges resulting from such folding were neither long nor important. It should be carefully noted that the axes of folding trend somewhat more east of north than the ridge lines of the present ranges. The formation of these early mountain ranges was followed by a long period of erosion and the development of a topography of very low relief.

The next important geologic event was the beginning of crustal warping and the production of fresh-water lakes in considerable numbers and of large size. During the period of crustal warping explosive eruptions took place from a number of volcanic centers, and rhyolitic outpourings covered large tracts of land. Great faults were then developed and a period of active differential elevation inaugurated. It was the differential movement of large crust blocks which produced the present mountain ranges and broad intermontane basins. Adjacent blocks rose or sank as units, though they did not move as absolutely rigid units, for there is evidence of internal deformations of both folding and warping on a limited scale. The result of the differential movements of crust blocks was the formation of the Great Basin as an interior basin, the formation of mountain ranges by block faulting, and the development of intermontane valleys or great structural troughs whose broad characters do not rest upon stream erosion but upon faulting and stream aggradation. Since the period of principal faulting dissection has progressed to the point where alluvial fans and cones of great size have been formed.

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[1] G. D. Lauderback, Basin Range Structure of the Humboldt Region, Bull. Geol. Soc. Am., vol. 15, 1904, p. 336.

VARIATION IN TOPOGRAPHIC DEVELOPMENT

The Basin Ranges were not all formed at the same time nor of the same material; they therefore possess distinctly variable topographic qualities. In the northwestern corner of the basin (southeastern Oregon) the ridges appear to be of very recent origin, and their forms have been but slightly changed from the original outlines of the tilted blocks. Their youthful condition is indicated by the remarkably straight and regular character of their frontal scarps and crest lines and by the small amount of dissection which they have suffered. Another indication of youth is the frequent occurrence of landslides upon their steep faces where gradation has not yet produced a surface over which land waste is transported in an orderly manner.

A conspicuous instance is found in the Satas ridge in southern Washington, where the face of the uplifted block is so steep that huge landslides have occurred, one of which affected the cliff face over a distance of half a mile and at a height of about 2500 feet above the adjacent plain. It has a very irregular surface and its margin is circled by a line of hills 200 feet high where the material of the plain was pushed up ahead of the slide.[1]

The ranges occupying the central portion of the Great Basin are of earlier origin. Like the ridges of Oregon they appear to have been formed by the uplifting and tilting of long narrow blocks, but the blocks are larger in Nevada than in Oregon, and the displacements are of greater value. Also the dissection of the block mountains of Nevada has progressed much further, so that they may be described as maturely dissected. Each range has one relatively short steep slope and one long gentle slope, but the outlines of the original block are scarcely discernible and the crest lines of the ranges are minutely irregular.

In southeastern California and southwestern Arizona many of the fault-block mountains are in a still older stage of development and indicate the condition which the young block mountains of Oregon and the maturely dissected block mountains of Nevada will ultimately reach. They have often been described as presenting the appearance of buried mountains, for they are surrounded on all sides by long gentle slopes of gravelly waste sometimes overlying a smooth rocky floor as a veneer. The original outlines of the blocks have been completely lost; only the alignment of the ranges has been maintained. The opposite slopes of each range have become nearly equal in both gradient and length. There are no pronounced spurs or deep, profound valleys. The mountains have rather gentle relief and occupy but a small portion of the total surface.

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[1] W. M. Davis, Physical Geography, 1899, p. 162.

EVIDENCES OF FAULT-BLOCK ORIGIN

One of the most interesting features concerning the fault-block mountains of the Great Basin is the physiographic evidence of faulting that is there displayed; indeed this class of evidence is of the utmost importance in an interpretation of the Basin Ranges, for the prodigious quantity of waste accumulated about the borders of the mountains and in the intermontane basins makes it impossible always to observe the structure in detail and to establish by direct observation the fact of faulting.[1]

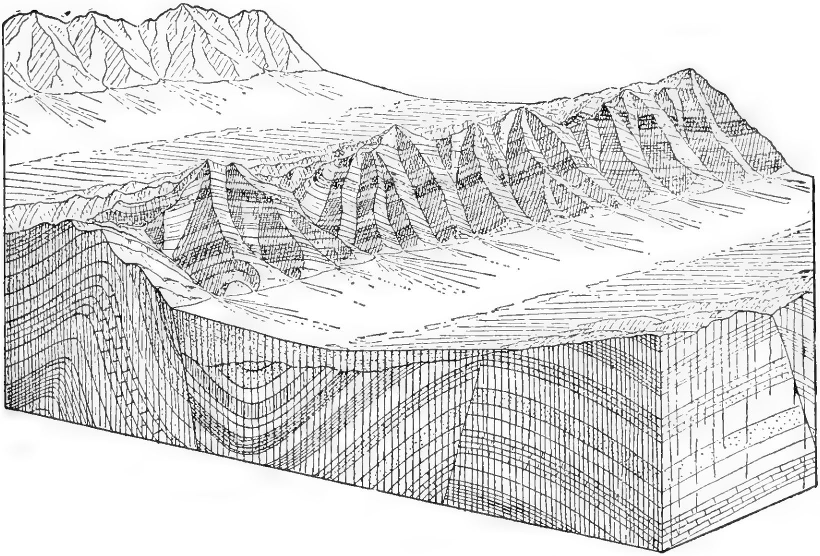

Fig. 58. — Diagram to illustrate the manner in which the strike of the beds diverges from the mountain front in the fault-block mountains of the Great Basin. (Davis, Science, 1901.)

MOUNTAIN BORDER AND INTERNAL STRUCTURE

A condition of first importance in determining the origin and physiographic aspects of the Basin Ranges is the manner in which the border

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[1] In an attempt to formulate the principles that should guide the interpretation of such forms, Davis has made an elaborate study of the theoretic problem of the explanation of fault-block mountains. The block diagrams from that paper (W. M. Davis, The Mountain Ranges of the Great Basin, Bull. Mus. Comp. Zoöl., vol. 42, Geol. Ser., vol. 6, 1906), reproduced here, very clearly present the main problems associated with the three elements necessarily involved in the problem of block faulting — the pre-fault topography, the topographic effect of the faulting, and the degree of dissection of the faulted blocks. The paper includes a comparison of the base line of residual mountains with that of fault-block mountains; a description of the canyons and ravines of block mountains; and the order of development and means of determination of spurs and terminal facets.

of each range cuts across the internal or primary structure so that the structure is very commonly oblique to the mountain front, Fig. 58. It is a safe inference that there can be in such a case no direct relation between the trend of the range and its primary structure, otherwise there should be a certain harmony between them, such as exists for example between the strike of resistant strata in the Appalachian Mountains and the trend of the Appalachian ridges.

CONTINUITY OF RANGE CREST

One of the most important indications of the origin of the Basin Ranges through block faulting of later date than the internal structure of the ranges is the fact that the body of each range is usually continuous although incised by sharply cut valleys. If the mountain ranges were residuals of a period of long-continued and undisturbed erosion such as must be postulated if the broad intermont valleys are explained by erosion, each range should be dissected into a number of short mountain ranges and isolated peaks. Stream action profound enough to excavate the broad intermont valleys would produce in the same time equally profound differential erosion in the body of the ranges. On the other hand, had the region been reduced at one time to a lowland of faint relief and the relief still further reduced by lava outpourings, the formation of great fault blocks would result in broad and flat intermont valleys as conspicuous as the ranges between which they lie, and the ranges themselves, if not too maturely dissected, would possess a marked rectilinear quality.[1]

THE OREGON RANGES EXHIBIT CRITICAL FEATURES

The indifference of mountain border to internal structure, and the continuity of the individual ranges, are both seen to best advantage in southern Oregon. In most parts of the Great Basin the typical basin-range structure produced by the faulting and tilting of long narrow crust blocks is largely obscured by erosion or by the topographic effects of complex internal folds and faults. In south-central Oregon, however, the crust blocks have been deformed so recently that erosion has but slightly modified them, and no internal deformation in the body of the blocks preceded the faulting.[2]

In the bedded lavas of Lake County, Oregon, topographic features[3] occur which seem closely related to a great upward fold or anticline

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[1] W. M. Davis, Current Notes in Physiography, Science, n. s., vol. 14, 1901.

[2] Idem.

[3] G. A. Waring, Geology and Water Resources of a Portion of South-Central Oregon, Water-Supply Paper U. S. Geol. Surv. No. 220, 1908, p. 25.

which has been extensively faulted in places. Chewancan River has cut its channel along the axis of the fold for a number of miles. In Summer Lake Valley the anticline is broken down, the western side remaining in place to form Winter River Valley, while the eastern is buried beneath lake deposits. Goose Lake Valley lies on the dropped keystone of the anticlinal arch, its eastern side being marked by a steep slope, its western side by a longer monoclinal slope.[1]

An immediate result of the earth movements by which the ridges were formed was the formation of a large number of enclosed basins whose floors are now occupied, to some extent, by lakes. There are all gradations between basins so small and poorly supplied with water that none whatever accumulates on the basin floor, and basins in which the rainfall is sufficient to maintain either temporary or permanent alkaline or saline lakes; or, as in the case of Goose Lake basin, a water supply sufficient to cause the basin occasionally to drain into the sea. Distinct shore terraces indicating the level of ancient Quaternary lakes that once existed here are to be found on the slopes of many of the basins.

EVIDENCES OF PROGRESSIVE AND RECENT FAULTING

BROKEN WASTE SLOPES

Not only have the Basin Ranges been blocked out by great faults, but faulting has continued down to the present. It is expressed among other ways in broken fans at the foot of the scarps which form the range fronts. Such broken fans have been noted repeatedly in glacial and postglacial deltas and fans along the base of the Wasatch Mountains, as in the delta of Rock Canyon Creek near Provost.[2] Low escarpments in lacustral beds and alluvial slopes in places form irregular lines along the bases of the mountains, and at times cross the valleys. They present a small cliff or steep ascent between two nearly horizontal plains.[3] The crests of the scarps are always irregular and sometimes form zigzag lines that may be followed for miles; they are fault scarps of very late origin. In many cases it is believed that they could not have existed in their present condition more than a few years. In places they are more than a hundred miles long and vary from a few feet to more than a hundred feet in height.[4] That they are recent fault scarps is shown by the fact that they commonly occur in Quaternary lake deposits and recent alluvial slopes but little modified by erosion; and in many instances they are without vegetation. Similar scarps have been observed at the eastern base of the Sierra Nevada and at the foot

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[1] G. A. Waring, Geology and Water Resources of a Portion of South-Central Oregon, Water-Supply Paper U. S. Geol. Surv. No. 220, 1908, p. 26.

[2] W. M. Davis, The Mountain Ranges of the Great Basin, Bull. Mus. Com. Zoöl., vol. 42, p. 160.

[3] I. C. Russell, Geological History of Lake Lahonton, a Quaternary Lake of Northwestern Nevada, Mon. U. S. Geol. Surv., vol. 11, p. 274.

[4] Idem, p. 375.

of the slopes of many of the Basin Ranges. In the Lahonton area recent fault scarps are a common feature in the topography of the valleys, Fig. 54. Scarps of a similar nature were first observed in the Great Basin by Gilbert and were recognized as the result of recent crustal movements.[1]

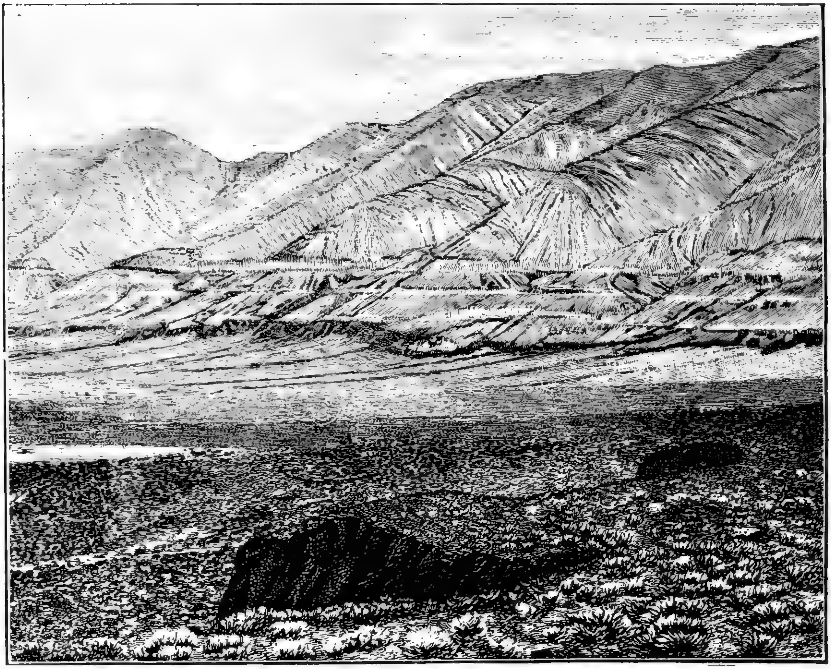

Fig. 59. — Post-Quaternary fault on the south shore of Humboldt Lake. (Russell, U. S. Geol. Surv.)

The recent faults of the Basin Ranges occur most commonly on the steeper sides of the mountains and invariably the throw is toward the valley. Occasionally they cross stream channels and cause rapids, as in the case of the American Fork, Utah, where it crosses the Wasatch fault. The distribution of recent faults is in marked sympathy with the ancient lines of displacement as determined by evidences of a topographic character such as have just been outlined. But it should be remembered that the recent faults are but a small fraction of the entire displacement.

STREAM PROFILES AND RECENT FAULTING

Among the significant elements of topographic form indicative of recent faulting are the abnormal profiles of many stream channels crossing the fronts of the fault blocks. Prolonged erosion of a stable block

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[1] Second Ann. Rept. U. S. Geol. Surv., 1880–1881, p. 192.

mountain would result in the development of stream gradients of the normal type whose descent from the headwaters of the region would be progressively more and more gentle. In the Basin Ranges, however, it has been frequently noted that the stream gradients are distinctly abnormal, and that they are notably peculiar in that a V section persists down to the mountain base where the steep-sided ravines suddenly open upon gravel fans that form parts of wide piedmont alluvial plains. Typical examples occur in the Pueblo range and in the Weber and Ogden canyons of the Spanish Wasatch. It is noteworthy that the steep-walled canyons that appear near the base of the range are in contrast with the upper portions of the valleys where flatter gradients occur. It appears that the progressive elevation of the fault-block mountains causes progressive down-cutting on the part of the draining streams. This lack of stability in the mountain mass and constant rejuvenation of the streams by repeated uplift prevent the streams from widening their valleys to the normal form.

TERMINAL FACETS OF THE MOUNTAIN SPURS

Another feature indicative of progressive faulting is the occurrence of terminal facets of peculiar and significant character and of very perfect development. In the case of the Spanish Wasatch the facets slope at an angle of 38° or 40°, are of remarkably regular occurrence and form, and are set off from each other by deep ravines that diversify the mountain front. The base line of this range is almost rectilinear, a feature in itself of the greatest importance in the interpretation of the morphology of a mountain mass whose structure possesses sufficient diversity to occasion under ordinary conditions topographic irregularities of considerable degree.

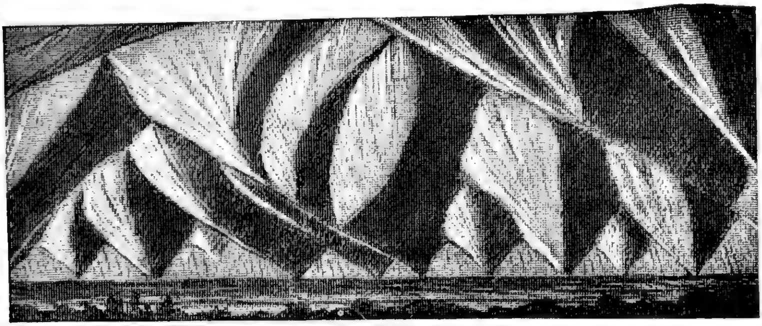

Fig. 60. — Ravines, spurs, and terminal facets of the Spanish Wasatch, looking east. Note the even base line developed on rocks of varying resistance. (Davis, Bull. Mus. Comp. Zoöl.)

SPRINGS AND FAULT LINES

Throughout the entire Great Basin there is a rather intimate association between thermal springs and lines of recent faulting; and the hottest springs almost invariably occur on the lines of displacement that have suffered most recent movement.[1] This relation of thermal springs to recent faults along the bases of the frontal scarps is almost constant and is in entire sympathy with the explanation of continued block faulting in the Great Basin region.[2]

FEATURES OF THE DEATH VALLEY REGION

If we now turn to other ranges in the Great Basin than those we have thus far noted we shall find a striking persistence of the structural and physiographic features already examined. In the Death Valley region the fault-block type of structure and topography has been clearly identified. The strata of this region suffered deformation (Eocene) in which faulting and tilting took place and parallel mountains and valleys formed that trend northwest in the general direction of the Sierra Nevada. Deformation of any type tends to produce enclosed basins and in an arid climate this tendency is usually realized in a pronounced way. In the Death Valley region faulting and tilting produced enclosed basins in which lakes were formed and lake sediments deposited to a thickness of several thousand feet. These lake sediments include great deposits of salt, gypsum, soda, and borax. Later still (Miocene) another period of deformation set in. It was characterized by faulting and tilting as in the earlier period of deformation but along lines more nearly north than before and parallel with the basin ranges. Immense mountain ranges were the result, such as the Funeral and Panamint ranges, with the Panamint, Detah, and Amaragosa valleys between them. In the enclosed basins that were thus formed lakes existed for a time, and on their floors and about their borders were deposited sediments similar to those of the earlier lake period.[3]

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[1] I. C. Russell, Mon. U. S. Geol. Surv., vol. 11, 1885, p. 276.

[2] The relation of hot springs to recent faulting is brought out clearly in a map of the United States published in 1875: Report upon Geographical and Geological Exploration and Surveys West of 100th Meridian, Wheeler Surveys, vol. 3, Geology, 1875, pp. 148–150. Sixty-seven springs occur in the western region and but 15 in the eastern. Forty-seven of the first group have a temperature as high as 100° F.; only 2 in the latter group reach this temperature. The areas are in the ratio of 13 to 3. If the country were better known the ratio would show an even greater preponderance of springs in the western region.

[3] M. R. Campbell, Basin Range Structure in the Death Valley Region of Southeastern California (Abstract), Bull. Am. Geol. Soc., vol. 14, 1903, pp. 551–552.

Soils of the Great Basin

The soils of the Great Basin are derived from a great variety of rocks, and consist of colluvial wash of the mountain slopes, thick lacustrine and shore deposits associated with ancient Lake Bonneville, and recent stream-valley sediments and river-delta deposits. When not situated above or outside the limits of irrigation, or rendered unfit for cultivation by accumulations of alkali or seepage waters, they are of great agricultural importance.

The soils of alluvial cone deposits are usually gravelly and very dry, and therefore treeless, except in the immediate vicinity of stream courses. The more elevated areas are frequently rough and hilly and marked by the presence of rock outcrop and bowlders. They are frequently cut by washes or intermittent stream channels, and are well drained, except in the lower-lying areas occupying depressions.

The soils of lacustrine sediments and material derived from stream deltas occur upon low, level plains, marking the site of recent lake bottoms. They are generally barren, deficient in drainage, and heavily impregnated with alkali salts. They are derived from eruptive, sedimentary, and altered rocks of various ages and are without gravel. They cover extensive areas, are usually dark in color, and in general have little or no agricultural importance.

The soils formed of colluvial mountain wash or of residual material mingled with alluvial deposits of intermittent or torrential streams are often gravelly, sometimes marked by rock outcrop, and frequently cut by washes and intermittent stream channels, and generally treeless. The soils are derived primarily from red sandstone, modified in places by an admixture of material derived from shales, slates, eruptive rocks etc., and are typically of vermilion or bright-red color. They occur generally as extensive areas. The lower-lying and heavier soils are often poorly drained and alkaline.

Along valley troughs and in the vicinity of river flood plains, stream sediments of recent origin or in process of formation form an important group of soils. They occupy low or slightly elevated valley plains, have a smooth, nearly level surface, and are frequently marked by the presence of stream channels or sloughs. They are derived mainly from eruptive, early sedimentary, and altered sedimentary rocks, are generally dark in color, and are underlain by light-colored sands or sandy loams or by heavy red subsoils.

Forests and Timber Lines

The high barrier of the Sierra Nevada on the windward side of the Great Basin so reduces the rainfall on the lower Basin Ranges as to make the forest growth thin and scattered or wholly absent. No large and dense forests occur in the province, Fig. 61. The existence of a forest is conditioned by the amount of rain that falls on each range. As a whole the province is not one whose forest growth is of great importance to lumbermen; but the very scarcity of forests in so arid a region makes doubly important the study of the physical conditions surrounding the isolated forests that do exist.

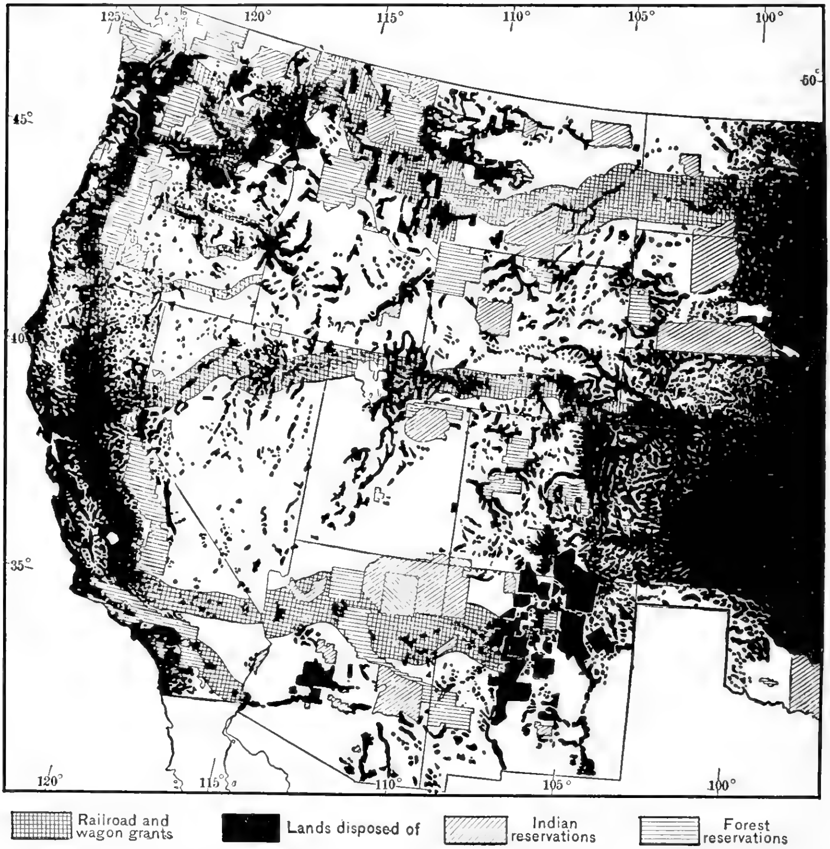

Fig. 61. — Location of vacant public land. Note the disproportionately large amount of vacant public land in the Great Basin. (Newell, Irrigation in the U. S.)

In the arid Great Basin a lower timber line and an upper timber line are clearly defined on most of the mountain ranges. The position of the upper or cold timber line is determined mainly by the annual temperature of 32° F., but has some variation depending upon differences in snowfall, soil conditions, severity of winter storms, and exposure to the sun. The vegetation above the cold timber line is commonly alpine flowers and grasses of various sorts up to the lower limit of snow.[1] The lower limit of tree growth may be called the dry timber line, although to drought is added the influence of cultivation, soil conditions, alkali, hot winds, exposure to the sun, etc. Unlike the cold timber line,

Fig. 62. — Approximate location and extent of open range in the West. (Newell, Irrigation in the U. S.)

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[1] This line is at sea level in Alaska and northern Canada, where it defines the polar limit of the subarctic forest and may be called the "continental timber line." North of it is a zone of tundra and barren grounds corresponding to the zone of alpine flowers above the cold timber line on the mountain slopes and summits of temperate latitudes.

the dry timber line may be independent of latitude and altitude, its position depending almost entirely upon the amount of rainfall. Below the dry timber line of the Great Basin are, in some cases, treeless, grassy to arid plains and valleys, while in other cases the dry tree line merges into the zone of juniper. In central Idaho the cold timber line is at 10,000 feet, the dry at 7000 feet. Its position in the Prairie Plains province in eastern Kansas and Nebraska is dependent upon the gradual increase of rainfall eastwardly from the Rockies and High Plains. The dry timber line disappears in humid regions, as in the Adirondacks and the White Mountains. The meeting of the dry and the cold timber lines on those ranges in the Great Basin that are both cold above and excessively dry below, as the White Mountains of western Nevada, Plate IV, results in the complete absence of forest growth.[1]

Fig. 63. — Typical view of desert vegetation, southern Great Basin, near Goldfield, Nev. (Ransome, U. S. Geol. Surv.)

While the upper timber line is determined usually by temperature, other factors may have a determining local influence and in nearly all cases have an important influence. Among these factors are the slopes of the surface, the degree of exposure to the sun, the depth of the snow, the

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[1] I. C. Russell, Timber Lines, (Abstract) Bull. Geol. Soc. Am., vol. 14, 1903, pp. 556–557.

severity of the winter storms, etc., though the dominant cause is the low temperature.[1]

The most abundant and most generally distributed trees from the western foothills of the Wasatch Mountains in eastern Utah to southeastern California, northern Arizona, western Colorado, and southern Wyoming are the juniper and the nut pine (*Pinus monophylla*). In central Nevada the juniper often descends into the valleys and forms open stunted forests at elevations of about 5000 feet. It is more abundant and of larger size on arid slopes at elevations of 8000 feet above the sea, where it occurs in dense and nearly pure forests.[2] The nut pine, or piñon, occurs on dry gravelly slopes and mesas throughout the same territory, often forming extensive open forests at elevations between 5000 and 7000 feet.[3]

From the commercial standpoint the most important trees in the Great Basin are the yellow pine and Douglas spruce, but their growth is limited to the higher ranges of the provinces where they form open woodland, never a true forest. A typical growth is found on the Snake Range which lies just west of the Nevada-Utah line, trends north and south, and is about 135 miles long. It contains the highest peak between the Wasatch and Sierra Nevada, Jeff Davis or Wheeler Peak, more than 12,000 feet high, besides being one of the most rugged ranges in the Great Basin.[4] The intermediate slopes, Fig. 64, are covered with a tree growth. Alpine fir, white fir, Douglas fir, and Engelmann spruce are the principal species, yellow pine being relatively scarce and limited to the lower elevations. The higher portions of the range are almost devoid of vegetation owing to the low temperature. The cold timber line lies at 10,500 or 11,000 feet. It should not be considered a definite line, however, since the forest disappears on the dry spurs at much lower elevations than in the wet canyons. The dotted line near the summit in Fig. 64 represents the upper limit of growth in the canyons. The foothill belt below the dry timber line is covered with sagebrush and bunch-grass. The valleys have a better growth of grasses, while the springs and streams are lined with shrubs and aspen and a few cottonwoods.

By far the greater number of the Basin Ranges are desert or support

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[1] For a discussion of this matter see I. C. Russell, Timber Lines, Nat. Geog. Mag., vol. 15, 1904, pp. 47–49; for a criticism see C. H. Merriam, Nat. Geog. Mag., vol. 14, 1903.

A "wet timber line" may also be identified about the borders of lakes, swamps, etc.

[2] C. S. Sargent, Manual of Trees of North America, 1905, p. 89.

[3] Idem, p. 12.

[4] J. E. Spurr, Descriptive Geology of Nevada South of the 40th Parallel, Bull. U. S. Geol. Surv. No. 208, 2d ed., 1905, p. 25.

only a scanty growth of sage-brush and juniper and a few stunted pines near the summit. They have only a very scanty supply of water and a few widely separated springs.[1] The Cedar Mountains west of Salt Lake Valley afford typical conditions.

The Montezuma Range in western Nevada also illustrates this type of range. Only a few stunted pines and junipers are found and these grow only on the upper slopes and in the more sheltered canyons. The range lies not far from the great Sierra Nevada on the west and in spite of its bold appearance provokes but little rainfall from the winds that pass the higher topographic barrier on the west. The range is one of the driest in Nevada.[2] Excellent grass is abundant, however, and has high value for grazing, but in order to supply stock precautions must be taken to prevent spring waters from running to waste.

Fig. 64. — East side of Snake Range, Nevada. Jeff Davis or Wheeler Peak from Robinson's Ranch. Yellow pine comes in on the lower edge of the timbered belt and Alpine fir, white fir, and Engelmann spruce are the principal species at higher levels. (U. S. Geol. Surv.)

Many of the Basin Ranges with intermediate elevations have important forest tracts even though a continuous forest cover is wanting.

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[1] S. F. Emmons, Desert Region, Descriptive Geology, vol. 1, 1877, p. 462 (King Surveys).

[2] Arnold Hague, Descriptive Geology, vol. 2, 1877, p. 752 (Hayden Surveys).

The Schell Creek Range, for example, has closely restricted patches of yellow pine and fir in the moister canyons and small upper basins. While these are not important in a large way, they at least supply a most important need on the part of the ranchmen, farmers, and miners engaged in developing resources near by.

The most prominent range between the Sierra Nevada and the Wasatch is the East Humboldt Range in central Nevada. It is a bold, single range about 80 miles long with many summits reaching over 10,000 feet. Because of its relatively high altitude and its greatly dissected condition it has a more alpine aspect than the other Basin Ranges and, as compared with the lower ranges about it, receives more rainfall and snowfall. In response to the heavier precipitation it supports an open tree growth. Its higher canyons and upper slopes are covered with scattered forests including several varieties of pines and firs, among which the limber pine (*Pinus flexilis*) is the prevailing species. The trees do not, however, supply much valuable timber since they are knotty and rarely over 50 feet high.[1]

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[1] Arnold Hague, East Humboldt Range, Descriptive Geology, vol. 2, 1877, p. 528 (King Surveys).

CHAPTER XV

LOWER COLORADO BASIN

On account of the scarcity of arboreal vegetation in the lower Colorado Basin and the close genetic relationship of its forms with those of the Great Basin already somewhat fully discussed we shall devote but a few paragraphs to its physiography. The province includes (1) an eastern section of low, residual mountains, piedmont slopes, and intermontane basins forming the southwestern portion of Arizona, and (2) a western section of interior basins west of the Colorado and north of the mountains of dry southern California.

The mountains of the eastern section are regarded as of the basin-range type — fault-block mountains originally like those of southeastern Oregon. They are, however, much older than the latter and are so thoroughly dissected that their original asymmetry has been lost. The broad structural valleys between the ranges have been in part floored by piedmont and basin deposits in part extended by rock planation, a result attributed to sheet-flood erosion.[1] The basin floors in the Sonora district of Mexico and Arizona, where the half-buried mountains rise above broad plains, appear at first to be wholly alluvial. More intimate examination shows that only half of their surface is covered with alluvium; the other half is in reality planed rock. Two-fifths of the entire area including both plains and mountains is smoothly-beveled rock floor, the rock being granite, schist, and other types, planed off in a belt from 3 to 5 miles wide which merges with the alluvial portion of the basin on the one hand and from which the mountains rise sharply without any intervening foothills on the other. The graded character of the floor is no doubt to be ascribed to water action, as was insisted by McGee; but the fact that the surface of the rock floor on the basin margins is kept relatively free from alluvium should probably be ascribed in large part to wind action which is universal and almost constant.

A peculiar feature of many of the basin floors of the arid region is the gravelly appearance of the surface. Gravels and small bowlders

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[1] W J McGee, Sheet-flood Erosion, Bull. Geol. Soc. Am., vol. 8, 1897, pp. 87–112.

are found scattered over the higher slopes of nearly all the intermont valley plains. The general appearance is that of a vast gravel bed. It is not uncommon to find an area several acres in extent covered with small angular stones as closely and evenly set as mosaics. The pebbles constituting the gravel are, however, but a thin surface veneer. The wind constantly blows away the fine material and is unable to remove the coarse, which accumulates as a protective cover. The pebbles are sometimes only one deep, and below them there is often a fine porous loam which may be of great fertility.[1]

It is estimated that about 85% of the entire surface of the eastern section of this province (east of the Colorado River) is plain and about 15% is mountains. Such an excess of low over high country in an arid region means that the mountain-born streams will quickly wither on the plains and that trunk streams will be either rare or wanting altogether. Where the mountains are low, the streams are insignificant in size and disappear almost at the mountain bases. Except the Gila and the Colorado, which have their sources in high and well-watered country, the Lower Colorado Basin has no through-flowing streams; the majority of its streams are of the type of "lost rivers" which disappear by absorption and evaporation before reaching the sea.

The western section of the province beyond the Colorado is exceptionally arid and hot and includes the Mohave desert. The rivers terminate on the piedmont slopes of the desert ranges or feed permanent salt lakes or the temporary lakes of salinas and playas (see Fig. 27).

Types of Lowlands

The portion of the Lower Colorado Basin that lies in Arizona contains three distinct kinds of lowlands: (1) valleys and canyon floors now containing running water such as the Colorado and Williams valleys and Santa Maria Canyon; (2) old, deeply filled, alluvial valleys such as the Sacramento and the Big Sandy; and (3) plains of erosion such as those that in many places border many of the desert ranges and are due to sheet-flood erosion. Among the intermontane plains are Cactus, Posas, and Ranegras plains, etc. They are in part old, deeply filled valleys that have a general altitude of about 2000 feet toward the plateau region on the east and gradually descend westward to about 400 feet at the Colorado River. All of them have been somewhat modi-

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[1] C. R. Keyes, Rock Floor of Intermont Plains of the Arid Regions, Bull. Geol. Soc. Am., vol. 19, 1908, pp. 63–92. See also C. F. Tolman, Erosion and Deposition in the Arizona Bolson Region, Jour. Geol., vol. 17, 1909, p. 14.

fied by crustal disturbances and basaltic extrusions from many local centers of igneous activity.[1]

One of the largest of these valleys is the Detrital-Sacramento Valley which extends north and south parallel to the Colorado River for more than 100 miles. It is interrupted here and there by lava masses, but its material consists chiefly of gravel filling of great depth. It is in a region of profound faulting and warping, and may have originated as a succession of structurally depressed areas. Whatever its origin it has been greatly modified by a stream of considerable size which has almost filled the entire bottom of the valley with an enormous amount of detrital material. This work may have been accomplished by the Colorado or by some stream now extinct, a fact which has not yet been safely determined.

SPECIAL DRAINAGE FEATURES

The lower valley of the Colorado River, that portion which crosses the Lower Colorado Basin, is remarkable for extreme irregularity of topography within short distances. It consists of a series of narrow, steep-walled gorges, and broad alluvial basins through which the river winds in an exceedingly irregular course. It is concluded[2] that at one time the Colorado River ran through the present Detrital-Sacramento Valley, that it filled this valley and adjacent depressions with a prodigious quantity of alluvial material, and when, on account of changed climatic or geologic conditions or both, the river began again to degrade its channel it occupied its old valley throughout the greater part of its course; but at certain places, as in Pyramid Canyon, Eagle Rocks (Fig. 65), and other localities farther south, its course at the moment of change from aggradation to degradation was directed across alluvium-buried mountain spurs and knobs. With the progress of down-cutting these spurs and knobs were uncovered and the course of the river across or through them is now marked by narrowness, bank declivity, hard rock, and steepened gradient, instead of the flat gradients of the alluvial bed and the wide flat-floored valleys that elsewhere characterize its course.

The Colorado River is to-day carrying immense quantities of silt which it is spreading over its rapidly aggrading flood plain. The river carries more suspended matter per unit volume than any other stream in North America — 2000 parts of sediment per 100,000 parts of water, or enough in one year to cover 164 square miles 1 foot deep with mud.

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[1] W. T. Lee, Geologic Reconnaissance of a Part of Western Arizona, Bull. U. S. Geol. Surv No. 352, 1908.

[2] Idem.

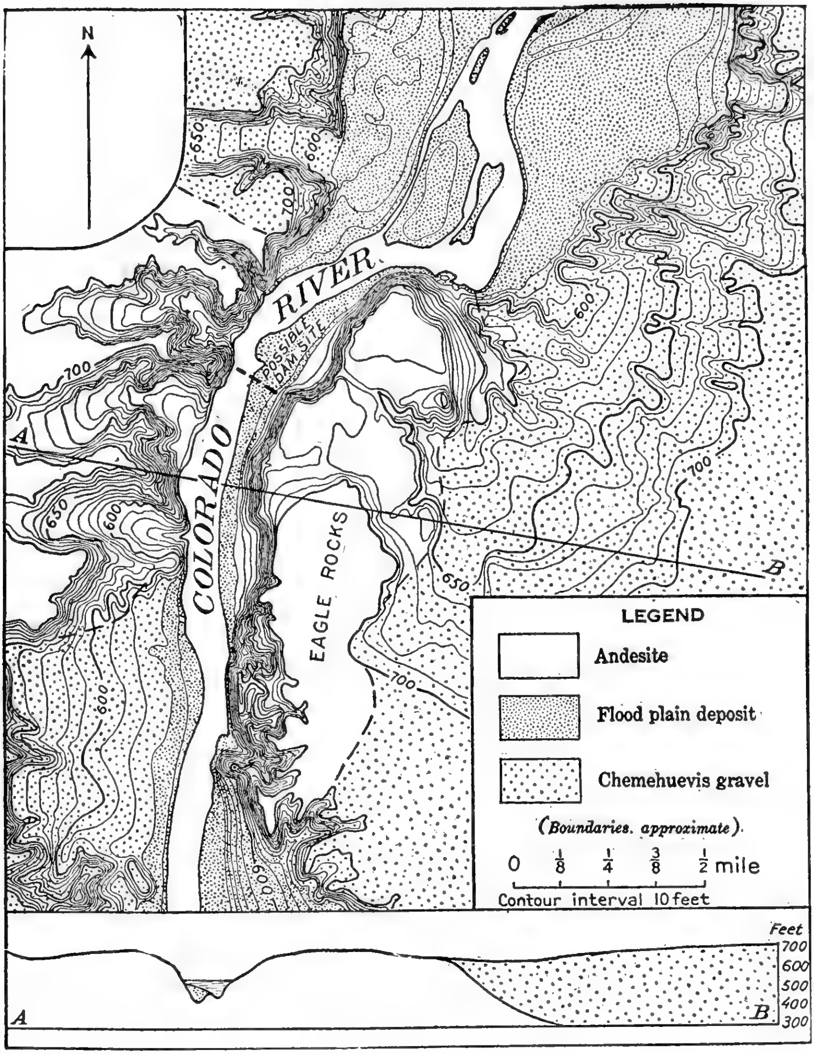

Fig. 65. — Map of part of Colorado Valley, showing old gravel-filled channel on right and rock channel on left. (Lee, U. S. Geol. Surv.)

The rapidity of filling of the Colorado River on its flood plain is indicated in many places where lateral cutting exposes the roots of trees and shrubs now buried to a greater or less degree. In many places living arrow weeds may be seen standing in five feet or more of silt. The material is well stratified and exceedingly fine. When deposited in thick beds it dries and cracks in great columns two or three feet in diameter, the cracks themselves being several inches wide and two feet or more deep.

The river frequently changes its course over the wide bottom lands which it drains, sometimes by normal lateral cutting and sometimes by more intense erosive action during a period of high water. These changes result in the formation of new channels, the abandonment of old ones, the formation of cut-off meanders, sloughs, lagoons, ox-bow lakes, and dry channel courses.

But little of the land along the Colorado is irrigated because the river and its tributaries are in general so far below the bordering lands as to render diversion extremely difficult or impracticable. At Yuma two pumping plants lift water from the river for irrigation and several other lifting plants are located below this point. The Imperial Canal diverts water from the river at a point about 10 miles below Yuma.[1]

The Colorado is subject to annual overflow from April to June and may spread out over the Salton region of the Colorado desert forming lakes. Mearns noted (1892–1894) that these lakes eventually dried up, but for a long time after the water had disappeared the region was green and vegetation throve in the rich surface deposits. Cattle were driven in and the owners endeavored to make a breach in the Colorado River bank at each annual overflow, so that the region became flooded through the channels of New and Salton rivers, causing a fresh crop of forage plants to spring into life.[2]

Salton Sink Region

That portion of the Lower Colorado Basin known as Salton Sink is of special interest because it contains one of the two tracts of land in the United States below sea level.

The Salton Sink region contains two fertile valleys, the Coachella Valley in Riverside County northwest of Salton Sink, and the Imperial Valley in Imperial County southeast of Salton Sink. Lying partly in each of these two counties is Salton Sea, the bottom of which is 273.5 feet below mean sea level.[3]

In recent geologic time Salton Sea was a part of the Gulf of California which then extended about 200 miles farther northwest than at present. At that time the mouth of the Colorado was near Yuma, 60 miles from its present location, and was gradually building a delta

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[1] Freeman and Bolster, Surface Water Supply of the United States, 1907–08, Colorado River Basin, Water-Supply Paper U. S. Geol. Surv. No. 249, pt. 9, 1910, p. 34.

[2] E. A. Mearns, Mammals of the Mexican Boundary of the United States: A descriptive catalogue of the species of mammals occurring in that region, with a general summary of the natural history and a list of trees, Bull. U. S. Nat. Mus. No. 56, pt. 1, 1907, p. 28.

[3] Freeman and Bolster, Surface Water Supply of the United States, 1907–08, pt. 9, Colorado River Basin, Water-Supply Paper U. S. Geol. Surv. No. 249, 1910, pp. 46–51.

that extended southwest toward the Cocopa Mountains. Deposition continued until the upbuilding of this delta had completely separated the head from the rest of the gulf and converted its floor into an inland sea. Delta growth continued until the inland lake became not only entirely independent of the Gulf but also actually raised to a higher level than the sea. Consequently one may see to-day faint terraces in favorable places on the margin of the depression, and on rocky points is a thin deposit of calcium carbonate and slightly cut sea cliffs about 40 feet above sea level. Even some of the alluvial cones formed on the shore line had beaches which, although easily eroded, are even now well preserved, an indication of their recent formation; and over the floor of the desert and along the sandy beaches are thousands of shells of fresh- or brackish-water mollusks.[1] The water of the lake was not perfectly fresh, for it is estimated that the evaporation from its surface nearly equaled the average annual inflow from the Colorado, and even if the flow of the river exceeded this evaporation it could not have done so by a large amount; in either case the waters of the lake would be markedly alkaline. This is also shown by the fact that wherever the lake waters broke in spray and evaporated more rapidly than usual, carbonate of lime was deposited. It is known from the extent of the delta that the river broke out of its channel many times while building it and alternately discharged into the Gulf of California and the Salton Sea. During those periods in which the river discharged into the Gulf of California, Salton Sea must have contracted and become more and more alkaline. The last natural discharge of the Colorado into Salton Sink was of very recent occurrence. It is probable that the lake which it supplied existed but little more than a thousand years ago. In recent years we have had well-known instances of changes.

During the summer of 1891 the Colorado overflowed into Salton Sink at the time of high water to such an extent as to endanger the Southern Pacific Railway line; and in the summer of 1905, after a number of winter and spring floods in the Gila River and a heavy summer flow in the Colorado, the floods were repeated on a much larger scale. The gravity of the situation was increased by the existence of diverting canals which conveyed water to the Imperial Valley from the Colorado. The canals were not provided with protective headworks, and had a gradient much greater than that of the river, so that after the flood of 1905 and in July the main canal was carrying 87% of the total flow of the river, and the water was deepening and widening the Alamo River, along which the canal extended, to a great gorge. Strong efforts by the Southern Pacific Railway Company resulted in the control of the Colorado in the early fall of 1906, but it broke out again on December 7, and was only closed finally in February, 1907. On December 31, 1908, the surface of the Salton Sea was still far above its normal level, being only

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[1] R. E. C. Stearns, Remarks on Fossil Shells from the Colorado Desert, Am. Nat., vol. 13, 1879, pp. 141–154.

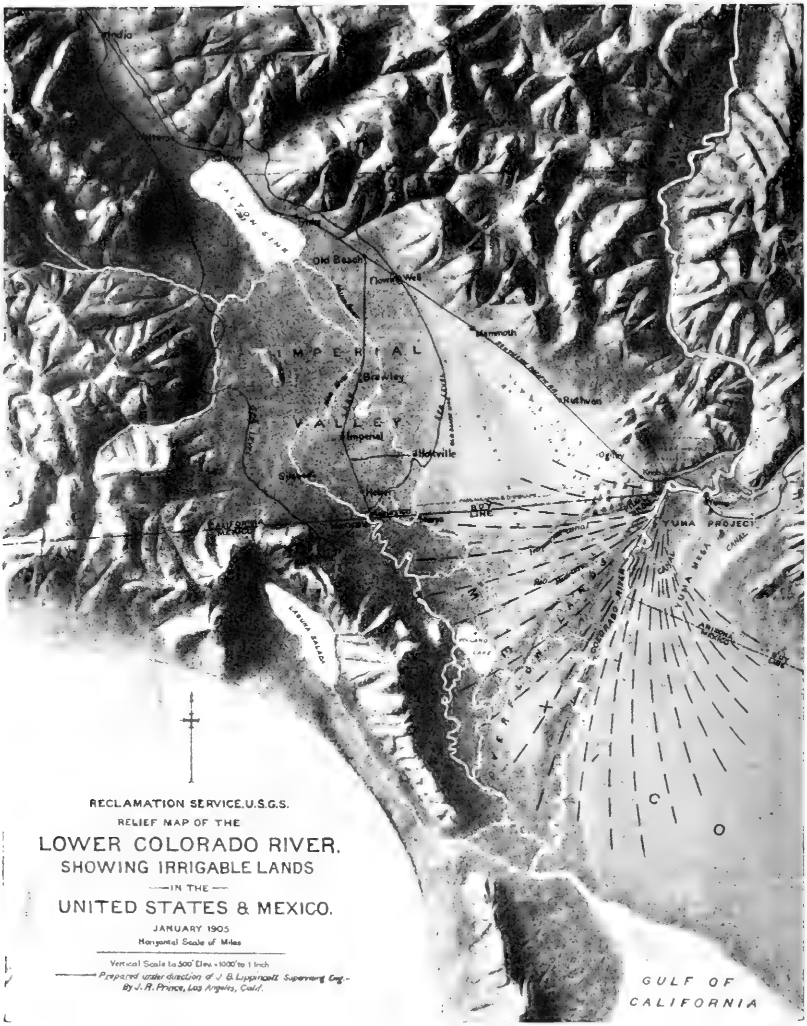

Fig. 66. — Map of the Salton Sink region, California. (U. S. Geol. Surv.)

206 feet below mean sea level. It then had a maximum depth of 67.5 feet and an areal extent of about 443 square miles. Its temporary enlargement necessitated shifting the Southern Pacific tracks over a stretch about forty miles long, a stretch that was originally constructed on the 200-foot contour below sea level. Another line has since been surveyed and graded on the 150-foot contour below sea level for possible use in the future. The Sea has also completely submerged the plant of the New Liverpool Salt Company and a few ranches near Mecca.[1]

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[1] Freeman and Bolster, Water-Supply Paper U. S. Geol. Surv. No. 249, 1910, pp. 50–51.

So completely cut off from the rest of the Gulf of California was the Salton Sink region before 1905 that the waters of the beheaded section of the ancient gulf were evaporated to the point where only a fragment of the original water body remained. Its waters were until recently exceedingly salty and the shores of the lake or sink were fringed with wide, white belts of salt-incrusted land. Only a few trifling streams descend from the higher portions of the San Bernardino and San Jacinto mountains to feed the dwindling remnant of what was once a great water body. In Fig. 66 is represented the maximum size of the ancient water body as recorded in a well-preserved strand line that contours evenly about the margin of the basin.

Climate, Soil, and Vegetation

The following data on the relief, climate, and vegetation of the southern border of the Lower Colorado Basin are compiled mainly from the excellent work of Mearns.[1] They are typical of the relations of topography, rainfall, and vegetation over a much wider area and deserve close examination by the student of forestry.

The mountains of the southeastern portion of the Lower Colorado Basin form continuous ranges rising very sharply from the plains. They are seldom well forested because of the steepness of their slopes, from which the soil is blown or washed away almost as fast as formed, leaving the bare rocks without vegetation except in crevices, benches, and hollows.

The soils of the region are mainly of colluvial, alluvial, and lacustrine origin, modified by the addition of recent stream sediments; they are without important amounts of humus owing to the aridity. They occupy mountain foot slopes, alluvial fans, débris aprons, or sloping plains of filled valleys, sloping or nearly level plains, and bottoms of stream valleys or sinks and drainage basins. Since the climate of the arid Southwest is characterized by semi-tropical desert conditions, the soils have little or no value save as they can be irrigated or as they occur in limited amounts in rock crevices, etc., and as a thin veneer on higher slopes where the rainfall makes a thin forest growth possible.[2]

There is a very thin population along the entire boundary, the only towns near it being Bisbee, Santa Cruz, Nogales, Yuma, and San Diego. Except for these towns and a score of small settlements in the principal valleys the zone of 24,000 square miles along the boundary, 20 miles on either side, contains less than 100 permanent inhabitants.

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[1] E. A. Mearns, Mammals of the Mexican Boundary of the United States: A descriptive catalogue of the species of mammals occurring in that region, with a general summary of the natural history and a list of trees, Bull. U. S. Nat. Mus. No. 56, pt. 1, 1907.

[2] Soil Survey Field Book, U. S. Bureau of Soils, 1906.

The average precipitation along the entire boundary is about 8 inches and on the Yuma and Colorado deserts it is but 2 or 3 inches. For 700 miles between the Rio Grande and the Pacific, the boundary line is crossed by only five permanent running streams although it crosses the mountain ranges nearly at right angles, a direction most favorable for encountering existing streams. There are two periods of rainfall, one in midwinter and one in midsummer, the midsummer rainy period being known as the rainy season. The summer rains generally begin about the first of July and last until the middle of September. Soon after the first rain falls the vegetation assumes a spring-like aspect, leaves burst forth, hills and valleys are covered with grass, and a bewildering profusion of wild flowers covers the surface. The plants grow with great rapidity, their seeds mature before the rains cease, and in a month or so after the rains have stopped they have the somber colors typical of fall and winter.

On the whole the Mexican boundary district of the Lower Colorado Basin is treeless; the forests are confined almost entirely to the mountain ranges and the stream courses, but those in the latter situation are few in number and of insignificant size. On some of the desert spaces arboreal cacti and yuccas form open groves. The streams are lined with Fremont cottonwood, black willow, box elder, walnut, sycamore, oak, mulberry, ash, etc. Among these the cottonwood and willow are found on every permanent stream, and are usually flanked by a broader zone of mesquite. The desert willow, hackberry, and indigo tree are found in arroyos in which there is a slight amount of moisture.

There are a few large alkali flats perfectly bare of vegetation and a number of spots in the desert are without plants, but over the great stretch of desert country between the Gila Mountains and the Colorado River there are found almost everywhere four species of plants — the creosote bush, the sage, an ephedra, and a grass. The prickly, thorny shrubs and bushes together with the cacti and yuccas are usually disposed in groups or thickets surrounded by more or less open spaces. In the sheltered situations are found more or less tender shrubs, grasses, and other herbaceous plants.

Shrubs and grasses increase in number and variety on the foothills and there is often an abundance of shrubbery in the ravines near timber line. On the whole the rocky soils are much richer in plant food than the sandy soils because they retain moisture better. The desert vegetation with the exception of a few green-bark trees and shrubs is dull and dusty and in general the plants have pulpy leaves and exude gums and resins for retarding evaporation. The leaves are usually small and many are covered with waterproof dermal structures.[1]

Under 4000 to 6000 feet the rainfall is so low and the evaporation so high that true desert conditions prevail. Upon the higher mountain slopes are limited areas where much more mesophytic conditions are found — less evaporation and greater precipitation; hence islands of vegetation occur on the mountains surrounded by great desert plains. The greater portion of the area is occupied by true desert species equipped for life under arid conditions — structures for preventing evaporation and other structures for rapid absorption, great storage, and long retention of a scanty water supply.[2] The highest portion of the province lies in south-central Arizona, where a few mountain ranges — Baboquivari, Carobabi, and Cobota ranges — break the continuity of the plains. The Gila, Mohawk, and Growler mountains are important ranges farther west. None of them has a sufficient summit extent to provoke large quantities of rainfall, hence even the highest portions are very scantily covered with tree growth.

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[1] Mearns, loc. cit., pp. 32–34.

[2] D. T. Macdougal, Across Papagueria, Bull. Am. Geog. Soc., vol. 40, pp. 724–725.

CHAPTER XVI

ARIZONA HIGHLANDS

Topography and Drainage

The Arizona Highlands cross Arizona from northwest to southeast as a broad zone of short and nearly parallel mountain ranges separated by valleys deeply filled with river and lake deposits. The width of the zone is from 70 to 150 miles and the lengths of individual mountain ranges such as Santa Catalina, Pinal, Dragoon, and Ancha rarely exceed 50 miles, while the elevations are rarely above 8000 feet. The northeastern portion of the Arizona Highlands is continuous with the ranges of the Great Basin in Nevada and Utah. On the east the common line of division of the Arizona Highlands and the Trans-Pecos Highlands is roughly the Mimbres River just west of the Rio Grande. The ranges east of this line trend north, those west of the line trend northwest. Between these two divergent lines, and on the north, is the lava-fringed southern border of the Colorado Plateaus; on the south the ranges of the two provinces have no well-defined dividing line.[1]

The mountain structures are very similar to those of the Great Basin. They are usually monoclinal, and in the Chiricahua and Pinal ranges the monoclinal structure is demonstrably due to faulting as shown by Gilbert and by Ransome.[2] The greater number of ranges consist mainly of sandstone, quartzite, and limestone (Paleozoic) that rest upon schists and granites (pre-Cambrian). Both types of rocks are partly covered by volcanic flows, Fig. 67.

As a result of the monoclinal structure of the mountain ranges and the prevailing northwest strike of the beds, the southwestern slopes are longer and somewhat less steep than the northeastern slopes, the latter consisting of a series of steep scarps and benches that give the individual ranges notably bold mountain fronts.

The larger creeks of the region have broad, sandy or gravelly beds of distinctly even gradient, and the tributaries of the main creeks exhibit similar features on a smaller scale. The regular gradients of the stream

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[1] G. K. Gilbert, The Geology of Portions of New Mexico and Arizona, U. S. Geol. Surv. West of the 100th Meridian (Wheeler Surveys), vol. 3, 1875, p. 508.

[2] F. L. Ransome, Globe Folio U. S. Geol. Surv. No. 111, 1904.

channels and the fact that the channels are dry for the greater part of the year result in their use by man for purposes of travel and transportation; they are the natural roads of the region. Throughout the Arizona Highlands a considerable part of the small annual precipitation (15 to 20 inches and less) falls in sudden rainstorms or "cloud-bursts," which are common in July or August. The stream channels are rapidly filled with turbulent waters that wash along great masses of loose detritus swept down from the hill slopes above. The cloud-bursts are incredibly violent and do a remarkably large amount of work. It is through their energetic action that the mountains are dissected and the basins filled with alluvium. For this reason the erosive work due to water action is very important in the aggregate in spite of the semi-arid character of the climate.

Soils and Vegetation

With the exception of the timbered slopes of the mountains and of the alluvial areas along the main arroyos, the surface of the region is almost without soil. The grass and shrubbery occur in such small amounts as to exercise but little retaining influence upon the land waste during short periods of heavy rainfall. Furthermore, the deficient vegetation results in the formation of very small quantities of humic acid, and the rock is therefore not affected by such acid to anything like the degree to which it is affected in humid regions. The granitic masses crumble into particles of quartz, fragments of mica, and angular fragments of crystals of rather fresh feldspar. The quartz and mica are washed down the larger streams by the sudden rains; but the larger fragments of feldspar often accumulate upon the alluvial fans and give them a very distinctive appearance.

The occurrence of arboreal vegetation in response to greater rainfall and its zonal distribution in response to temperature are here as everywhere in the Southwest interesting subjects of study. The general geographic distribution of the many types of vegetation has been worked out as follows:

Fig. 67. — Geologic section from Colorado River to Colorado Plateaus (right). The basement rock is crystalline; the Yampai Cliffs are of limestone; Truxton Plateau and other areas in black represent lava flows; the valleys are deeply filled with alluvium; the Cerbat Mountains are composed of sedimentary rocks. (Lee, U. S. Geol. Surv.)

(1) Zone of cactus, yucca, agave, scanty grass, 3000 to 3500 feet. More luxuriant vegetation in the vicinity of water.

(2) Zone of Obione and Artemisia (greasewood and sage-brush), poor grass, diminished growth of cactus, altitude 3500–4900 feet.

(3) Zone of cedar (*Juniperus monosperma*), few cactus, 4900 to 6800 feet.

(4) Zone of pine and fir, 6800 to 10,800 feet.

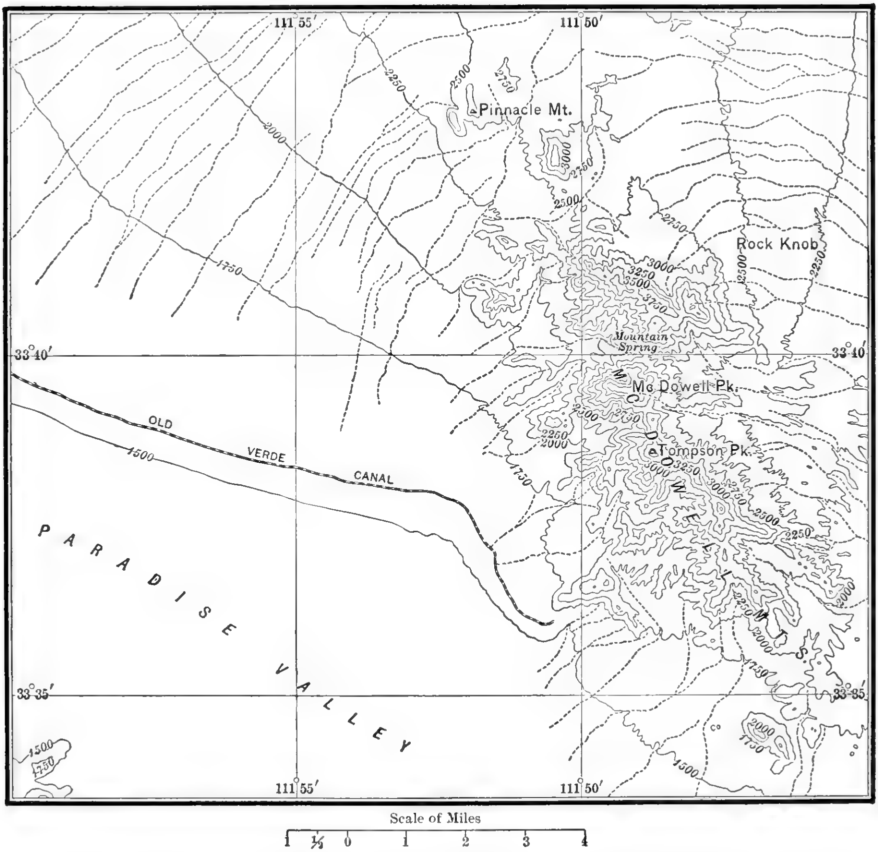

Fig. 68. — Waste-bordered mountains of the Arizona Highlands, Camelsback quadrangle, U. S. Geol. Surv. Note the lack of a permanent stream, the large number of intermittent streams as shown by the dotted lines, and the ragged character of the mountain slopes. Contour interval, 250 feet.

These zones are lower on eastern and northern than on southern and western slopes and the amount of canting increases with increasing elevation (p. 293). The quaking aspen is seen below 7500 feet, likewise the fern (*Pteris aquilina*). Above 7000 feet the white oak accompanies the pine but is never found in great quantities, principally in small patches or groves. In some instances the pines occur in splendid forests.[1]

The character of the tree growth in the extreme southern part of the Arizona Highlands has been analysed by Mearns.[2] He found (1893) the Mexican white pine (*Pinus strobiformis*) at the summits of the main peaks of the San Luis Mountains south of the boundary line (7874 feet); also on the Animas peaks in New Mexico (8783 feet); and in the San José Mountains (8337 feet), where a few trees grow close to the summit of the main peak. It is a common tree on the highest peaks of the Huachuca Mountains where it occupies a considerable area and descends as low as 6550 feet. It is an interesting fact in the distribution of this tree that it belongs to the Canadian life zone and is usually associated with the Douglas spruce, aspen, etc. The yellow pine has a vertical range (on the Mexican line) from 6200 feet in the San José Mountains of Sonora to 8500 feet in the Huachuca Mountains of Arizona. The Douglas spruce is found on the San Luis, Animas, and Huachuca Mountains, on all of which it reaches the summits and extends as low as 6000 feet, in cold wet ravines, and is not found on any other mountains of the boundary strip.[3]

On the Dog Mountains in New Mexico the regular juniper zone extends from 6000 feet up to the summits, but in most canyons it descends to the base of the mountains. There is a well-marked juniper zone at 7500 feet on the west side of the San Luis Mountains also. The desert yucca in the fifty-mile desert west of El Paso occurs in open forests spread over large areas where the largest trees grow to a height of 16 feet. The aspen or quaking asp has a vertical range on the Mexican line from 7690 feet in the San José Mountains of Sonora, Mexico, to 9472 feet in the Huachuca Mountains in Arizona. The Fremont cottonwood (*Populus fremontii*) is the most common, beautiful, and valuable shade tree in the whole Mexican boundary region. It grows naturally on almost every stream along the boundary and is found planted around the houses and along the irrigation ditches of almost every ranch. In deep narrow canyons its stem is tall and slender, but in open spaces the isolated trees have full round tops with spreading and often drooping branches. The vertical range of the cottonwood is from sea level to 6100 feet in the Huachuca Mountains near the boundary.[4]

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[1] Report upon Geographical and Geological Explorations and Surveys West of the 100th Meridian (Wheeler Surveys), Geology, vol. 3, 1875, pp. 603–604.

[2] E. A. Mearns, Mammals of the Mexican Boundary of the United States, etc., Bull. U. S. Nat. Mus. No. 56, pt. 1, 1907.

[3] Idem, pp. 38, 39, 40.

[4] Idem, pp. 43–48.

A common tree or shrub through the desert Southwest is the mesquite (*Prosopis glandulosa*). The vertical range is from sea level and even below sea level in the Colorado desert up to about 5500 feet. In the deserts of New Mexico, Arizona, and California it is a shrub which obstructs drifting sand, thus forming mounds of sand and lines of sand hills; in the most fertile places along the Colorado River and its tributaries it is a tree of considerable size. Along the Santa Cruz River in Sonora are forests of unusually large mesquite, with some individuals 2½ feet in diameter and 50 feet high.[1]

The San Luis Mountains are composed largely of calcareous rock and are steep and rough. Where a soil covering has been formed they are wooded from a well-marked dry timber line at 5250 feet to the summit at 7870 feet. Below the lower timber line the country is covered with grass and in places with patches of mesquite and chaparral. The forest trees at the lower timber line of the San Luis Mountains are mostly evergreen-oak (*Quercus emoryi*), though in the low canyons grow cypress, walnut, cherry, sycamore, and gray oak (*Quercus gresea*).[2]

The trees of the Animas Mountains (northward continuation of the San Luis Range) in New Mexico are the same as those of the San Luis, with the addition of a zone of quaking aspen. The lower timber line in the Animas mountains is at 5250 feet except where springs occur that support a belt of fine oak timber in the moist canyons far below the main timber line. In one instance a straggling line of oaks is actually continuous across the valley between the Animas and San Luis Mountains, joining the two timber lines of these mountains down two long canyons.[3]

Regional Illustrations

CLIFTON DISTRICT

In portions of the Arizona Highlands, as for example in the vicinity of Clifton, near the eastern border of the state, the topography becomes far less regular than is generally the case. Looking north of Clifton it is impossible to discern any well-defined mountain system. The whole region north of Gila Valley at this point appears as a maze of short ridges, small plateaus, and insignificant peaks.

The topographic complexity of the highlands in the Clifton district is explained by the geologic structure. A core of older rocks (granites, limestones, and sandstones) was deeply and irregularly eroded, and at

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[1] E. A. Mearns, Mammals of the Mexican Boundary of the United States, etc., Bull. U. S. Nat. Mus. No. 56, pt. 1, 1907, pp. 59–60.

[2] Idem, pp. 89–90.

[3] Idem, p. 92.

a later time (Tertiary) was partially covered by great masses of volcanic flows (rhyolites and basalts), with great variations in thickness and character. The drainage developed upon the lavas after their extrusion was consequent upon the lava flows; those portions of the region not affected by lava flows preserved their original drainage. The consequence was that extremely irregular drainage courses were made still more irregular by the differences in hardness between flat-lying basalt and deformed rock of older age.[1] The only regular features of the Clifton district are the small plateaus due to volcanic accumulations or to the regular and broad uplift of sedimentary rock; but even these plateaus are but dimly discerned and all of them are deeply dissected by canyons and furrowed by a maze of shallow and wide-spreading ravines.

The arboreal vegetation of the Clifton district is found at elevations above 6000 feet, though below this elevation the ridges generally support a certain amount of agave, yucca, and low cactus. Above the 6000-foot level stunted juniper and cedar are quite common and are used as firewood; on the higher slopes a growth of manzanita bushes and stunted oak is also found. The heaviest timber grows in the sheltered mountain basins at altitudes of 5000 to 6000 feet and consists largely of yellow pine. Along some of the river bottoms are large groves of cottonwood. Many of the dry mountain spurs are covered with piñon and juniper.[2]

BRADSHAW MOUNTAINS

The higher peaks of the Bradshaw Mountains district are composed of gneiss, granite, and schist, the granite having been intruded into the schists. Differential erosion has resulted in a high relief, due to the more resistant character of the intrusive granite. In some places quartzite combs in the granite stand prominently above the general level of the wide valleys formed upon the less resistant schist and may be traced for miles by their distinctive and bold relief.

Toward the northwest the Arizona Highlands are also marked by a large number of rather extensive lava flows which have covered over the older topography and simplified the contour of the surface. Among them is Black Mesa, 10 miles east of the Bradshaw Mountains, Bigbug Mesa, 15 miles northwest of Black Mesa, and many others of lesser extent. They are striking forms, for they lie in a region of generally rugged topography whose irregularities have been devel-

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[1] Waldemar Lindgren, Clifton Folio U. S. Geol. Surv. No. 129, 1905, p. 1.

[2] Idem, p. 2.

oped upon rocks of complicated structure and variable hardness. They are almost without soil, since they consist of durable basalt recently formed. The basalt weathers into spheroidal fragments of variable size which cover the surface and make the so-called "malpais" of the region. Between the fragments finer waste accumulates in small quantities and supports a thin growth of grass in the rainy season.

The schists of the district weather very slowly and their soils are thin, so that the outcrops of the steeply inclined or vertical strata are visible for miles. The quartz-diorite and granite weather more rapidly and are covered with a sandy soil which supports a good forest growth in the higher mountains of the region toward the north. The quartz-diorite weathers most easily of all and is noted for the characteristic basin or park-like forms developed upon its outcrops.

Fig. 69. — Bradshaw Mountains, looking northwest near Goddard. The mountains are composed of granite; the plain in foreground is underlain by basaltic agglomerate. (U. S. Geol. Surv.)

The semi-aridity of the plains and valleys of this district has resulted in the development of a characteristic arid vegetation. The common vegetation of the lower slopes consists of cactus, yucca, maguey, paloverde, "cat claw," etc. In favored localities there are stunted growths of oak and manzanita, and in the arroyos one may find larger oaks and sycamores in some quantities. On the mountains where greater rainfall is precipitated on account of the greater elevation pine and fir find a congenial habitat.

In the Bradshaw Mountains the precipitation is greater than on the surrounding plains. Heavy thunder showers occur almost daily in July and August, and during the winter months the mountains are frequently covered with snow. The heaviest timber grows in the mountain basins at 5000 and 6000 feet and is largely yellow pine and its varieties. Some of the river bottoms have by contrast thickets of willow, mesquite, and alder, and groves of cottonwood, while the mountain spurs are frequently covered with thick mats of shrubs or dense stands of pin oak, nut pine, greasewood, and juniper.[1]

SANTA CATALINA MOUNTAINS

The Santa Catalina Mountains ten or twelve miles north of Tucson are among the most impressive ranges of the province and indeed of the Southwest. Their deeply dissected, bold, picturesque slopes rise to a series of exceptionally ragged peaks. Perpendicular cliffs and sharp ridges are common, among them "The Needles," a series of long slender precipitous points which crown the summit of a sharp granite ridge that rises 3000 feet above the plain at the mountain base. The highest point in the range is Mount Lemmon, which rises to 10,000 feet, or 7000 feet above the plains. The ranges composing these mountains are subparallel, extend nearly east-west, and the whole belt is about 50 miles long and almost as wide. The southern slope is especially rugged, so that even the cacti, hardy yuccas, and Spanish daggers have a hard struggle to maintain themselves on the barren rocks. Oaks and juniper are occasionally found in some sheltered alcove, and the summits of the higher mountains and large portions of the northern slopes are covered with pine and fir.[2]

Eastern Border Features

The northeastern edge of the Arizona Highlands is formed by the Grand Wash cliffs and their continuation — the Yampai Cliffs — which rise in a precipitous manner 4000 feet or more above the plains that on the north stretch westward from their base, Fig. 67. The continuity of the westward-facing escarpment is broken by several canyons. Here in a few places the confluent alluvial fans constitute a piedmont foreland of slight development. The lower portion of the cliffs is steep but not even approximately perpendicular. It is composed of granite, while the upper portion of the slope is of limestone and decidedly precipitous.

In the northern portion of the Arizona Highlands and in the Sacra-

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[1] Jaggar and Palache, Bradshaw Mountains Folio U. S. Geol. Surv. No. 126, 1905, p. 1.

[2] J. W. Toumey, La Ventana, Appalachia, vol. 8, 1897, pp. 225–232.

mento Valley region in northwestern Arizona the mountain escarpments face the plateau and are due to faulting. Specific localities are Globe, Arizona, and the mouth of the Grand Canyon. Farther from the edge of the plateau sedimentary rocks do not occur in many cases, and it is difficult to tell whether the mountains, composed of crystalline rock, are the products of local uplift or of circumdenudation. In general the mountains parallel the bordering plateau and become smaller and more isolated the greater their distance from the plateau. As the mountains grow less conspicuous the valleys broaden to greater and greater width and finally blend into each other in such a manner as to form a plain completely surrounding isolated mountain groups. The topographic character of this portion of Arizona lies between two extremes of well-defined fault-block mountains and narrow gorge-like valleys near the Colorado Plateaus and broad alluvial plains surrounding single mountain groups at a distance from the plateau.

Truxton Plateau serves as a type of the eastern border features. It is comparatively level and extends from the Yampai cliffs on the east to the Cottonwood and Aquarius cliffs on the west. It lies about 5000 feet above the sea and consists of denuded granite whose depressions have been almost filled with eruptive rock but whose higher portions project above the lava. Truxton Plateau is described as a lava-covered peneplain which has been slightly dissected by a few streams that have cut narrow canyons.[1] The recent uplift of Truxton Plateau is indicated by the rapid deepening of the stream valleys as they approach the cliffs to the west, while their courses within the plateau are distinctly shallow.[2]

For general remarks on Soil Investigations and the Soils of New Mexico and Arizona see G. K. Gilbert, U. S. Geol. Surv. West of the 100th Meridian (Wheeler Surveys), vol. 3, 1875, pp. 594–597. For climatic conditions, idem, pp. 598 et seq. Also idem, pp. 603 et seq., for the geographical distribution of plants in this region.

RAINFALL AND RINGS OF GROWTH

The conditions of growth of the forests of yellow pine in the northern Arizona region have suggested that they might form climatic registers of great importance and that a study of the rings of growth may indicate the character of the climate during the life of the individual tree. This matter has recently been studied with some very interesting results.[3]

[1] W. T. Lee, A Geologic Reconnaissance of a Part of Western Arizona, Bull. U. S. Geol. Surv. No. 352, 1909, p. 21.

[2] For a brief discussion of the physiography of Arizona and the topography of the Globe quadrangle with some excellent cross sections see F. L. Ransome, The Geology of the Globe Copper District, Arizona, Prof. Paper U. S. Geol. Surv. No. 12, 1903.

[3] A. E. Douglass, Weather Cycles in the Growth of Big Trees, Weather Rev., June, 1909, pp. 225–237.

It has been shown that at the 7000-foot elevation at which these trees grow the seasons are very sharply defined; the mean temperature for January is 29°, that for July 65°. Consequently there is a sharply seasonal character to the tree growth. A narrow red ring is formed during the autumn and winter and a broad, soft, white ring during the summer. Under the microscope the winter cells look lean and emaciated; the summer cells are round and well fed. The winter ring is thin, hard, and pitchy; the summer ring is wide, white, and pulpy. It appears probable that the red winter rings are governed directly by the low temperature and the white summer rings by the abundance of moisture.

About twenty sections have been measured by micrometer scale and the result is thousands of readings covering a period of from two to five centuries. On theoretical grounds it would seem that these rings of growth ought to register the rainfall, for they are a measure of the food supply, which depends entirely upon moisture, especially where the supply is limited and the life struggle of the tree is against drought and not against its fellows or members of other species. The measurements show that the rainfall curves and curves of growth have a really remarkable resemblance. An analysis of the curves of growth for longer periods during the life of the tree indicates that there is a direct connection between curves of growth and curves of rainfall in 21.2 and 32.8 year periods[1] with suggestions of shorter periods, especially in the case of the 11-year period already determined by Bigelow.[2]

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[1] E. Brückner (Vienna), Klimaschwankungen seit 1700, nebst Bemerkungen über die Klimaschwankungen der Diluvialzeit, 1890. In this paper the author assembles the data for the changing level of the Caspian Sea and its tributaries to show a strikingly regular rise and fall in cycles of about 35 years. Further investigations by Brückner show that these oscillations hold for much larger areas than the Caspian region, probably for the whole world. Still later analyses of rainfall curves in numerous localities have brought out the generality of this fact and the wide application of the law of climatic oscillations.

[2] F. H. Bigelow, Studies of the Diurnal Periods in the Lower Strata of the Atmosphere, Weather Rev., July, 1905.

CHAPTER XVII

COLORADO PLATEAUS

THE physiographic province known as the Colorado Plateaus is roughly circular in shape and embraces portions of the states of Utah, Arizona, Colorado, and New Mexico. The Grand Wash Cliffs on the west, the Uinta Mountains on the north, the Colorado ranges and the Trans-Pecos Highlands on the east, and the Arizona Highlands on the south are the most conspicuous border features. The boundaries are definite on the west, north, and south, but the eastern boundary is in many places indefinite, partly because of its topographic character, partly because it is the least-known portion. The outline displayed on the general physiographic map, Plate II, follows rather closely that assigned by Dutton.[1]

Its most prominent and general characteristics are (1) the flat and but partially dissected upper surfaces of the various members of the province; (2) the distinct boundaries of the individual members as determined by (*a*) strongly developed, northward-trending fault scarps and (*b*) eastward-trending lines of cliffs developed most strikingly upon the out-cropping strata of the High Plateaus of Utah; and (3) the great canyons that ramify through almost every large section but are thoroughly developed in the central portion. The most striking physiographic features of the province are the Colorado River and its world-famous canyon. An early view of the course of the river ascribed its origin to a great fault which the river followed and modified. The detailed studies of later years show that certain portions of it are demonstrably located upon faults but that the course as a whole is independent of faulting; and the facts as at present known point to a consequent origin upon either (1) the deformed surface of a peneplain or (2) the present structural surface when it was in a different attitude.[2]

While the surfaces of the individual members of the Colorado Plateaus are smooth or gently undulating, level or slightly tilted, and so undis-

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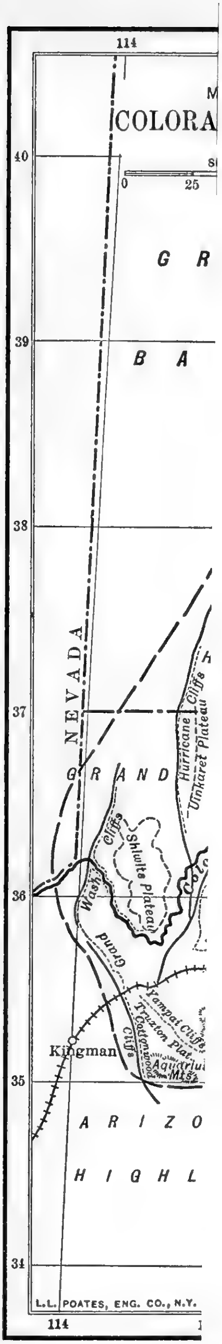
[1] C. E. Dutton, Mount Taylor and the Zuñi Plateau, 6th Ann. Rept. U. S. Geol. Surv., 1884–1885, pp. 114–117, and Plates 11 and 12.

[2] H. H. Robinson, The Tertiary Peneplain of the Plateau District and the Adjacent Country in Arizona and New Mexico, Am. Jour. Sci., vol. 24, 1907, p. 129.


114
M
COLORA
40
0
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G R
39
B A
38
NEVADA
37
Hurricane Cliffs
Uinkaret Plateau
GRAND
Cliffs
Shiwits Plateau
Wash
Grand
36
Yampai Cliffs
Truxton Plat.
Cottonwood Cliffs
Aquarius Mts.
Kingman
35
A R I Z O
H I G H L
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PLATE II

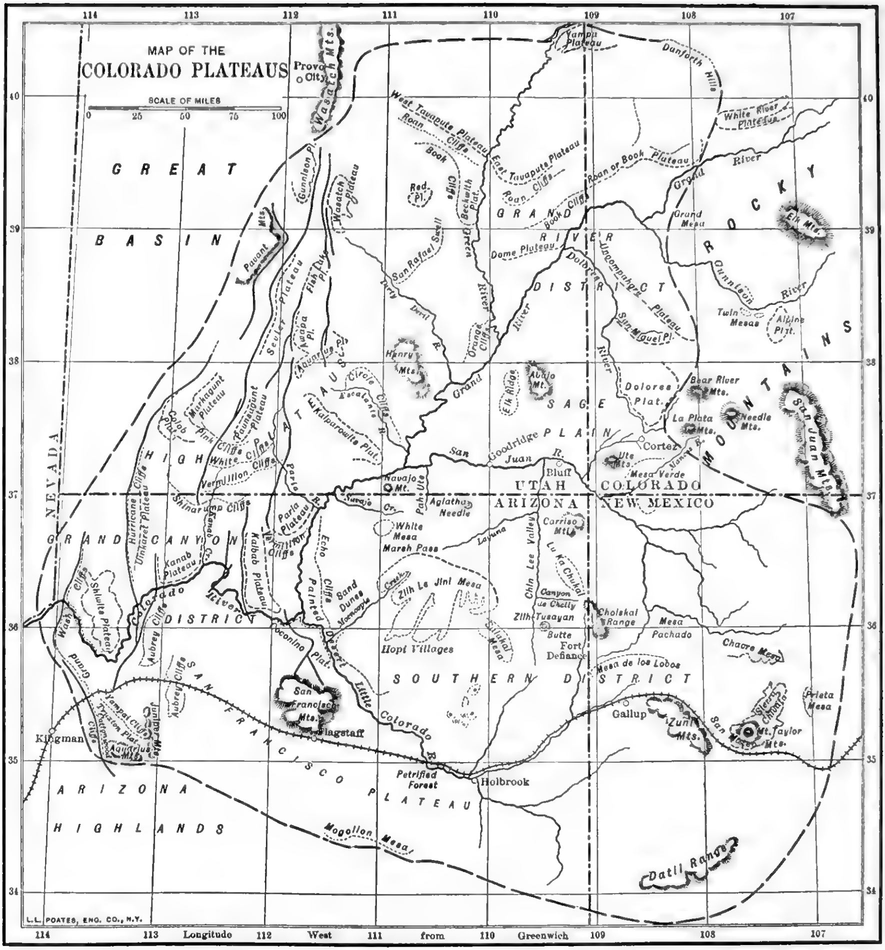

Plate II. — Colorado Plateaus.

sected as a whole that the level sky line, the broad expanse, the great extent of structural surface are among the most important elements of the relief, yet it must not be thought that the region can be described even in general phrase as level. The great depth to which the canyons have been cut and the great breadth to which they have been widened by the action of secondary erosional processes have resulted in strong relief so that the province is one of the ruggedest in the West. Unlike the mountain sections of the West its relief is not to any important degree the product of upward departures from the general level of the region but of downward departures. Instead of mountain flanks we have here prodigious canyon walls diversified by innumerable cliffs; instead of lofty ridges and peaks we have here profound chasms. Exceptions to this rule are the volcanic and laccolithic

Fig. 70. — Ute Mountains, from Cortez, Colorado. Also called El Late Mountains (Hayden Surveys). A group of laccolithic mountains breaking the evenness of the plateau surface. Looking from the same point as in Fig. 71, but in a southwest direction. (Photograph by H. Brigham, Jr.)

masses that rise above the general level to a truly mountainous height, such as Mount Taylor (southeast), the San Francisco Mountains (San Francisco Plateau), Mount Dellenbaugh (Shiwits Plateau), Mounts Trumbull and Emma (Uinkaret Plateau), and the Ute Mountains of southwestern Colorado, Fig. 70. They are not in the aggregate of great extent, but they are important not only through their relief but also through their association with those great lava sheets that although greatly eroded still cover large portions of the Colorado Plateaus.

It is important to see at the outset that the degree of dissection of the different portions of the province is not everywhere the same. The San Francisco Plateau is so little dissected that within its margins there is little hint of the great erosion forms to be found elsewhere in the region, and the flat plateau quality comes out strikingly in every general view; on the other hand the northeastern, north-central, and central portions of the province are dissected by a maze of ramifying canyons. The great breadth of the canyons in this portion of the province might be made the basis for a separate division of the plateau country — the Canyon Lands, as Powell termed the large district included in the valleys of the upper Colorado and the lower Green and Grand.[1] So thoroughly dissected is this portion that the walls of the labyrinthine canyons are the dominating elements of the relief, and movement across the country is by tortuous and extremely toilsome routes, now paralleling some small stream in the depths of a profound abyss, now crossing a plateau spur of mountainous proportions. The degree of topographic development which each district has attained will be the subject of further discussion; here it is sufficient to note that although the strata in their horizontal development are decidedly uniform over the whole area, the topographic aspects of the various sections are as decidedly variable.

A special feature of the plateau country is the manner in which erosion takes place. It is directed against the almost vertical edges of the strata much more than upon the almost flat upper surfaces. Plateau erosion is by stripping through cliff recession. Wash is almost ineffective on the flat gradients of the plateau summits; on the steep and alternating slopes and cliffs of canyons and the cliffed edges of outcropping strata everywhere it is vigorous, as is suggested by the name "Colorado," whose colored, turbid current carries the waste of its

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[1] J. W. Powell, Lands of the Arid Region of the United States, U. S. Geog. and Geol. Surv. of the Rocky Mountain Region, 1879, p. 105.

great tributary system of cliffs and slopes with their streams of land waste.[1]

With this special erosion feature in mind it will be easy to understand how extensive the canyon systems of the plateau and the associated terraces are, and yet how within the borders of each plateau there is in many cases so little dissection; each plateau is attacked practically on its margins only and so preserves almost until extinction a marked summit flatness. Conversely we should not understand because such large expanses of flat plateau exist, and each is so little dissected within its borders, that erosion of the general surface is not active, for in the province as a whole, and between the flat-topped plateaus, erosion is taking place at a most rapid rate.

The Colorado Plateaus consist of a large number of individual members separated from each other in various ways but in most cases by strongly defined lines, Plate II. The most striking line of division is the Colorado Canyon itself, which separates a northern

Fig. 71. — Panorama of Mesa Verde, southwestern Colorado; an example of mesa and scarp topography in the Colorado Plateaus. Looking southeast from Cortez. The border of the mesa is a ragged cliff formed on Cretaceous beds. Formerly these beds extended farther toward the foreground; in time they will be pushed still farther back. Sandstone caps the cliff and underlies the surface in the foreground. Between them are layers of shale. (Photograph by H. Brigham, Jr.)

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[1] For a discussion of erosion by cliff recession see J. W. Powell's various reports on the Colorado Plateaus.

from a southern series. Crossing the canyon almost at right angles are a number of northward-trending faults and associated fault scarps which block out an east-west series of plateaus. A third type of plateau boundary is exhibited in central Utah where the worn edges of outcropping, northward-dipping plateau strata constitute a line of remarkable cliffs of great physiographic interest and unusual scenic beauty. Besides these well-marked divisions are others of lesser definition. The northeastern and southeastern sections, although of great extent, have never been studied in the same detail as the rest of the plateau province, and their mutual boundaries are therefore less definitely established. They are roughly separated from the other divisions by the Green-Colorado Valley on the northwest and the Little Colorado on the southwest, and from each other by the valley of the San Juan. The various lines of division block out four large and important districts or sub-provinces, a fact that needs emphasis, for the elementary student usually regards the great plateaus north of the canyon and in the Kaibab district as the only important parts of the province. The separate districts may be called for convenience:

I High Plateaus of Utah: Awapa, Aquarius, Paria, Kaiparowits, Markágunt, Paunságunt, Tushar, Wasatch, Sevier, Fish Lake, etc.
II Grand Canyon District: Shiwits, Uinkaret, Kanab, Kaibab, San Francisco, Coconino, etc.
III Southern District: Zuñi, Natanes, Taylor, etc.
IV Grand River District: White River, Roan or Book, Uncompahgre, Dolores, etc.

HIGH PLATEAUS OF UTAH

In any general view of the plateau country, as shown in Plate II, two distinctly different scarp systems may be seen. The north-south system as just described is caused by great faults with downthrow on the west. Almost equal to the north-south system of escarpments in magnitude is the east-west system that crosses the plateau country several hundred miles north of the Grand Canyon, a system due to plateau stripping, each cliff marking the outcrop of a resistant stratum. The individual scarps of the latter system break the northward continuity of the Colorado Plateaus in a most decided manner and block out the country into a series of north-south plateaus, among which are the Colob, Markágunt, and others, the whole series known as the High Plateaus of Utah.[1] They are all characterized by great ruggedness of

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[1] C. E. Dutton, The Tertiary History of the Grand Canyon District and Geology of the High Plateaus of Utah, Mon. U. S. Geol. Surv., vol. 2, 1882.

outline, pronounced declivity, and a rude parallelism, although they are most irregular in detail. Named in order from south to north the principal ones are the Shinarump Cliffs, Vermilion Cliffs, White Cliffs, and Pink Cliffs, while many lesser cliffs block out plateaus of smaller extent.

The cliffs and intervening plateaus constitute a group of great terraces from 30 to 40 miles in extent north and south and 100 miles east and west. Among the great cliffs perhaps the most remarkable in form are the White Cliffs, while among the most remarkable in color are the Vermilion Cliffs. The latter are from 1000 to 2000 feet high, more than 100 miles long, and consist of evenly stratified layers of sandstone and shale with gypsiferous partings. In color they are brick red, which at twilight takes a strong vermilion hue; in form they are very ornate and architectural, with many vertical ledges rising tier above tier with intervening talus slopes through which the fretted edges of the cliffs project.[1] Though the profile is complex it never loses its typical character and is always extremely picturesque because of the numberless alcoves and alternating promontories where streams cut into the edges of the plateaus which these cliffs terminate.

The escarpments of the northern plateau country are all of a different type from those to the south. They consist of the outcropping edges of resistant northward-dipping strata that act as cliff makers and are being slowly stripped off the plateau surface by wind and water erosion. The former greater extent of the strata is inferred from the remnants left out upon the surface of the plateau south of the main cliffs in the form of isolated buttes and mesas. The map abounds in illustrations, of which perhaps the most conspicuous are the mesas that occur south of the Virgin River and west of Canyon Spring.

In general the drainage of the region in which the east-west line of great cliffs occurs is from the north southward, and it is therefore in this direction that the main canyons run in contrast to the east-west course of the Grand Canyon farther south. There are three principal streams in this district: the Virgin flows west to the Great Basin and finally to the Colorado; Kanab Creek flows southward through a deep narrow gorge to enter the Colorado midway of the Kanab Plateau; and Paria River enters the Colorado at the head of the Marble Canyon. The beds of the plateau streams retain pools of water in the depressions provided they are flooded with material that is not too coarse. These pools are called "water pockets," "lakes," "pools," or "tanks." They are scattered and few in number though always important features of the

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[1] C. E. Dutton, Tertiary History of the Grand Canyon District, Mon. U. S. Geol. Surv. vol. 2, 1882, pp. 17, 52, 53.

whole region. They are much more numerous in the higher plateaus of Utah than in the lower country. They are an important source of supply for travelers, settlers, and stockmen, and are the resort of bands of wild horses that roam the uninhabited desert tracts.

The High Plateaus consist of three principal members, a western, a central, and an eastern, Fig. 72. The western member is composed of the Pávant, Tushar, and Markágunt plateaus, named in order from north to south; the central member is composed of the Sevier and Paunságunt plateaus, named in the same order; and the eastern member consists of the Wasatch, Fish Lake, Awapa, and Aquarius plateaus.

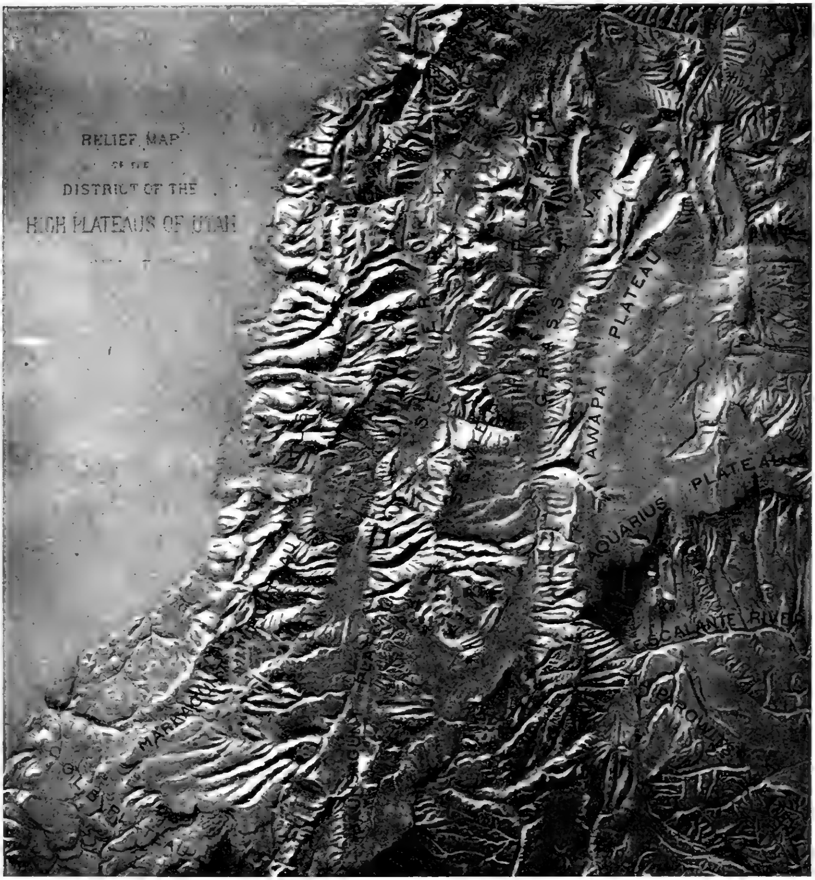

Fig. 72. — Principal relief features of the High Plateaus of Utah. For Colb, lower left-hand corner, read Colob. Scale, 30 miles to the inch. (Dutton, U. S. Geol. Surv.)

We shall describe only a few of the great plateaus of this northern region, selecting those which from our standpoint appear most important as types in the series.

AQUARIUS PLATEAU

The Aquarius, the grandest of all the High Plateaus, is about 35 miles long, of variable width, and 11,600 feet high. Its summit is clad with dense spruce forests sprinkled with grassy parks and exceptionally beautiful lakes.[1] These are not small pools but broad sheets of water from 1 to 2 miles long. Their existence is due to differential erosion by local glaciers that originated in the higher portions of the plateau; 8500 to 9000 feet was the lower elevation of the glaciers of the region and it is at this level that the terminal moraines are usually found. The high elevation of the Aquarius Plateau, 10,500 to 11,600 feet, favored the exceptional development of glacial forms in the Pleistocene, just as to-day it favors a greater rainfall and better forest cover than occur on the neighboring lower plateaus.

The upper surface of the Aquarius is developed upon a 1000- to 2000-foot layer of basalt, which gives rise to marginal cliffs of exceptional height and steepness, as on the northwestern flank. Again, on the eastern border, a great wall from 5500 to 6000 feet high overlooks the lower country and owes its boldness largely to the hard lava cap at the summit.[2]

AWAPA PLATEAU

The Awapa Plateau is 35 miles long and about 18 miles broad; its elevation is about 9000 feet. The western border of the plateau is a wall from 1800 to 3000 feet high, but the other boundaries are less distinct. The slopes of the surface everywhere converge toward a central depression, Rabbit Valley. Although its altitude is that at which moisture and vegetation usually occur, only sage-brush and grasses grow and not a spring or a stream is found upon its entire surface. It is an endless succession of hills and valleys and shallow canyons (400 to 500 feet). It consists entirely of a great variety of volcanic material which has been poured out upon a sedimentary base or platform. Some of the grandest and most massive trachytic beds of the plateau region are found here. The irregular distribution and varied dissection of the many kinds of lavas that occur upon it are in large part the cause of the irregular relief of the surface.[3]

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[1] C. E. Dutton, Geology of the High Plateaus of Utah, U. S. Geog. and Geol. Surv. of the Rocky Mountain Region, 1880, p. 5.

[2] Idem, pp. 292–293.

[3] Idem, pp. 272–276.

PARIA PLATEAU

The Paria Plateau terminates on the south in a semicircular line of cliffs which are really a great southward prolongation of the Vermilion Cliffs and include the same strata (Triassic). It lies almost in line with the great Kaibab series of plateaus, yet topographically it is a part of the High Plateaus of Utah and like them is a great structural terrace. It is scored by a labyrinth of sharp narrow canyons which cut deeply into the platform-like surface. The course of the main drainage feature, the Paria River, is independent of the dip of the strata; the courses of the smaller streams are all dependent upon the structural dips.[1] Only the channel of the Paria, however, carries water. The rest are all dry channels which appear to have been formed during the moister glacial period and to have become functionless with the advent of the drier postglacial climate. Growing aridity has extinguished the smaller streams and increased the area drained by the living streams.[2]

KAIPAROWITS PLATEAU

Between the Henry Mountains and the Paria Plateau, Plate II, is a broad area of plateau and canyon country known as the Kaiparowits Plateau and the Escalante Canyon. The canyons of both the Escalante and its numerous tributaries are a network of deep narrow chasms hemmed in by great unscalable cliffs. The depression carved by these streams is bordered on the north and west by a line of cliffs which terminate the Aquarius and Kaiparowits plateaus respectively. The Aquarius Plateau is forest clothed because high and relatively well watered; the Kaiparowits Plateau has only a scattered tree growth of very limited development; the depression below them on the southeast is waterless and treeless — a desert country, swept bare of soil. The cliffs which border the Kaiparowits Plateau on the northeast are 60 miles long and almost 2000 feet high. Their summit constitutes a divide from which almost no streams descend to the barren country below them on the east and only a few traverse the gentler western slope.

MARKÁGUNT PLATEAU

The Markágunt Plateau, Plate II, is a broad plateau expanse south of the Tushar Plateau. It is limited on the west by the Hurricane fault scarp; the eastern base lies at the foot of the great Sevier fault on whose

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[1] C. E. Dutton, Tertiary History of the Grand Canyon District, Mon. U. S. Geol. Surv., vol. 2, 1882, p. 201.

[2] Idem, p. 202.

eastern side the Paunságunt Plateau is found. The greater part of the area is covered with eruptive rock (trachyte) resting on sedimentaries (Tertiary). The southern margin is a line of cliffs not made by faulting but by erosion of hard cliff makers in the northward-dipping series that constitutes the High Plateaus of Utah. The surface of the Markágunt consists of rolling hills and ridges and grassy slopes, the greater part covered with scattered groves of pine. Few canyons are sunk below its general level.[1]

PAUNSÁGUNT PLATEAU

The Paunságunt Plateau is the southernmost extension of the High Plateaus of Utah and fronts south, with a marginal line of cliffs like its neighbors both east and west. These are the Pink Cliffs, often resembling in a most striking way well-known architectural forms such as ruined colonnades, buttresses, and panels. Its strata are sensibly flat and are wholly of sedimentary origin, not volcanic flows capping sedimentaries as is the case with so many of the plateaus of this region.[2]

TUSHAR PLATEAU

The Tushar Plateau is highly inclined and is a transition type between the flat plateaus general to the Colorado Plateaus province and the fault-block mountain type of the Great Basin. It is transitional in position as well as topography and structure, and, strictly speaking, lies within the geographic limits of the Great Basin. Its eastern front is steep and mountainous, for it has been developed largely across the edges of the strata; the western slope is down the dip of the strata and though considerably dissected is far less bold. Its summit is crowned by a cluster of peaks, true erosion remnants, which reach above timber line.[3]

WASATCH MOUNTAINS

Although the Wasatch Mountains are not a part of the High Plateaus they are in such close relation to them as to demand a word of explanation at this point. They stand as a great wall upon the northwestern margin of the plateau country overlooking the Great Basin, and consist of a number of abrupt ranges crowned with sharp peaks that attain altitudes of 10,000 to 12,000 feet. Their boldness gives rise to a moderately heavy rainfall, and the mountain slopes bear forests of spruce, pine, and fir, while the broken and drier foothills support a growth of

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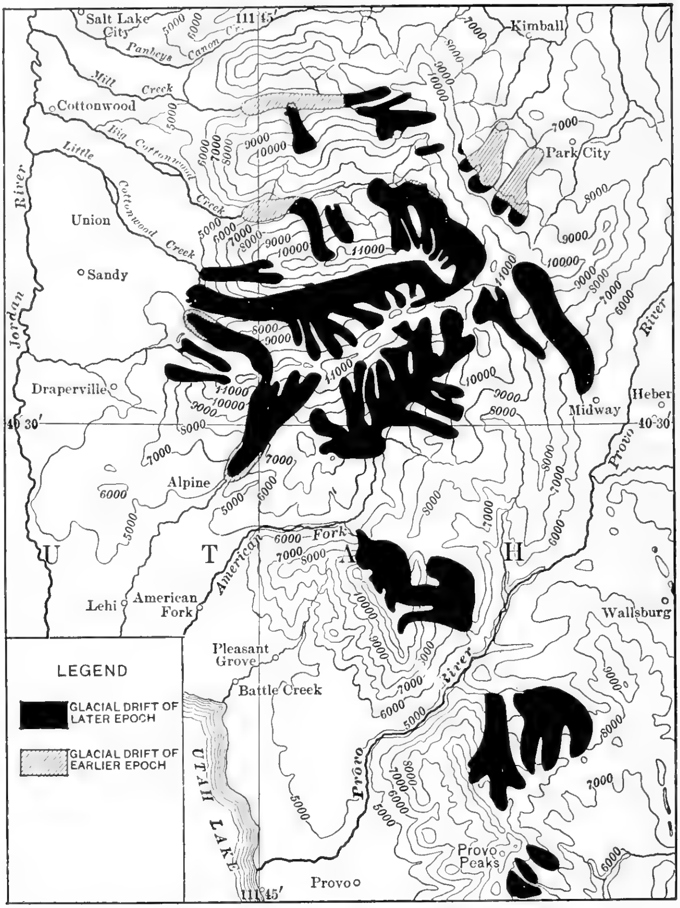
[1] C. E. Dutton, Geology of the High Plateaus of Utah, U. S. Geol. Surv., 1880, pp. 195 et seq.

[2] Idem, pp. 251 et al.

[3] Idem, p. 173.



PORTION OF SALT LAKE QUADRANGLE, UTAH
Showing distribution of glacial formations
Scale of Miles
0 1 2 4 6 8 10 12
Contour interval 1000 feet

Fig. 73.—Former glacier systems of the Wasatch Mountains. (After Atwood, U. S. Geol. Surv.)

piñon pine and cedar. In the valleys there are many natural meadows but no forest growth, merely groves of aspen about the springs and lines of willow, box elder, and cottonwood on the borders of the streams.[1]

The Wasatch Mountains extend about 100 miles south of the meeting point with the Uintas, or about to Mount Nebo, 75 miles south of

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[1] J. W. Powell, Lands of the Arid Region of the United States, U. S. Geog. and Geol. Surv., 1879, p. 96.

Great Salt Lake. Beyond this point the western margin of the plateau country is the western edge of the High Plateaus. These in turn give way to the broad platform of Carboniferous rock that constitutes the surface of the Grand Canyon District, whose western margin is the Grand Wash Cliffs. The eastern slope of the Wasatch Mountains falls off gradually as a 15 to 20 mile belt of broad ridges and mountain valleys whose waters reach Great Salt Lake through gorges that cut across the main western range of the mountains. The gentler eastern slopes are generally well clothed with vegetation. On the west the mountains present a bold abrupt escarpment which rises suddenly out of the broad flat plains of the Utah basin. The degree of abruptness may be appreciated from the fact that the mountains attain elevations of 10,000 feet within 1 or 2 miles of the western base.[1]

The main crest of the Wasatch Mountains is near the eastern border of the range and the western valleys are therefore much longer than the eastern valleys, — generally from two to three times as long. The loftier peaks — 11,000 to 12,000 feet — that are developed upon crystalline or highly metamorphic rock have rugged, pinnacle-like forms, those developed upon horizontal sedimentary beds have pyramidal outlines with alternating cliffs and talus slopes. In both cases the sharpness of form is due to glaciation. Summits that do not reach above 9000 feet, and hence were never glaciated, are rounded and softened and bear a heavy cover of land waste.

The elevation necessary for the development of Pleistocene glaciers in the Wasatch Mountains was 8000 to 9000 feet. Over 50 glaciers were formed exceeding a mile in length. Of these, 46 were west of the crest, and but 4 east of it. Of the 10 exceeding 5 miles in length, 9 lay on the western slope, 1 on the eastern. The greater number and size of the western glaciers were determined by the larger catchment areas and by the heavier snowfall, the west slope being the windward or exposed slope. The western valleys were therefore more completely cleared of loose material, the exposed surfaces more rounded, the main canyons deepened by a greater amount, and more massive moraines developed than in the eastern valleys. The typical relations of the moraines to each other and to

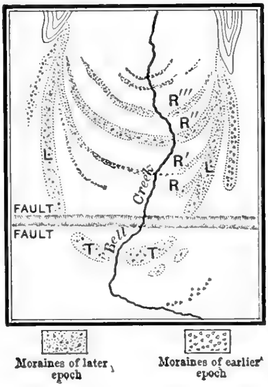

Fig. 74. — Sketch map of morainic ridges near the mouth of Bell Canyon, Wasatch Mountains. (Atwood, U. S. Geol. Surv.)

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[1] S. F. Emmons, U. S. Geol. Expl. of the 40th Parallel (King Surveys), vol. 2, 1877, p. 340.

the drainage features in a single valley are shown in Fig. 74. The extent of the glacial systems and their relation to the topography and drainage are shown in Fig. 73.[1]

Grand Canyon District

The most celebrated and best-known portion of the Colorado Plateaus is the Grand Canyon district. The great north-south crustal fractures of this part of the plateau region are lines of faulting which block out the separate members of the district. Named in order from west to east the plateaus are the Shiwits, Uinkaret, Kanab, and Kaibab. Their elevations increase in the same order: the Shiwits is 5000 feet and the Kaibab, the highest of all, is 8000 to 9000 feet above the sea. These several plateaus lie on the northern margin of the Grand and Marble canyons and constitute in the aggregate a great platform of nearly horizontal strata (Carboniferous) which is bounded on the east and north by the cliffs of the High Plateaus developed upon younger strata (Mesozoic) and on the west and south by its own terminal escarpment that descends to the older rock (Silurian and Archæan) of the Great Basin and Arizona Highlands.[2]

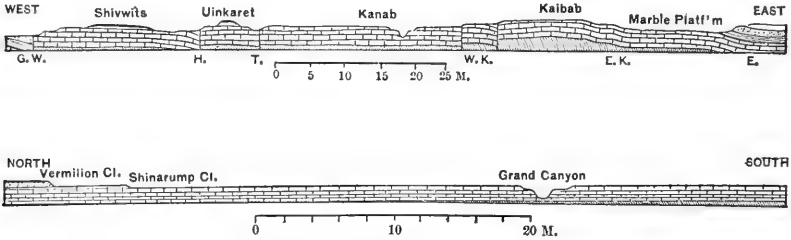

Fig. 75. — East-west (top) and north-south (bottom) sections of the Colorado Plateaus, Grand Canyon district, showing both structure and topography. G.W., Grand Wash Cliffs; H., Hurricane Ledge; T., Toroweap fault scarp; W.K., West Kaibab fault; E.K., East Kaibab monocline; E., Echo Cliffs and monocline. (Davis, Bull. Mus. Comp. Zoöl., modified from Dutton.)

The elevations of all the plateaus except the Kaibab are not great enough to cause a precipitation adequate for a forest growth. In contrast to the hot, dreary, and barren plateaus about it the Kaibab plateau is moist, and bears meadows and parks and forests of spruce and pine. The descent from one flat-topped plateau to another is over a

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[1] W. W. Atwood, Glaciation of the Uinta and Wasatch Mountains, Prof. Paper U. S. Geol. Surv. No. 61, 1909, pp. 73–93.

[2] C. E. Dutton, Tertiary History of the Grand Canyon District, Mon. U. S. Geol. Surv., vol. 2, 1882, p. 19.

high, ragged, westward-facing cliff whose front is constantly battered back by wind and rain. The cliffs are great fault scarps which are strikingly linear and continuous. They are of such prominence as to cause a local rainfall which concentrates the erosive work of the running water; detrital material, due to cliff recession principally, is washed forward from the foot of each cliff in the form of long, sloping, waste fans. The cliffs retreat without being obliterated, in part because of the horizontally bedded rocks, in part because of their recent origin and the small rainfall of the region.

SHIWITS PLATEAU

The Grand Wash Cliffs are the westernmost of the series in the Grand Canyon district and form the western border of the Shiwits Plateau. They are from 1000 to 2000 feet high and overlook the Grand Wash and Hualpi valleys and the rugged sierras and stern deserts of the Great Basin. They form a continuous and bold line of cliffs from the upper Virgin Valley southward across the Colorado River almost 150 miles, to Music Mountain, where they are replaced by the Cottonwood and Yampai Cliffs. There is no river along this western wall of the plateau, "only occasional deluges of mud, whenever the storms from the southwest are flung against the lofty battlements and break in torrents of winter rain." [1] The Grand Wash Cliffs mark the western end of the Colorado Canyon, 5000 feet deep; toward the west the Colorado suddenly changes its character and continues seaward without extraordinary features. Eastward of the Grand Wash Cliffs but still on the western border of the Shiwits Plateau is a second line of cliffs similar to the Grand Wash Cliffs in form but not in origin. It represents merely the eroded upper layers of the geologic series exposed by faulting and pushed back by ordinary erosion to their present position.

The surface of the Shiwits Plateau is diversified by a number of volcanic masses and a few large mesas and buttes, outliers of higher strata capped and so preserved by basalt. The most conspicuous height is Mount Dellenbaugh, 6750 feet high, a central mass of basalt in a large basaltic field.[2]

UINKARET PLATEAU

The Uinkaret Plateau, next east of the Shiwits, is separated from the latter by Hurricane Ledge, a fault scarp 1000 feet high which is con-

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[1] C. E. Dutton, Tertiary History of the Grand Canyon District, Mon. U. S. Geol. Surv., vol. 2, 1882, p. 12.

[2] Idem.

tinued south of the Canyon by the Aubrey Cliffs, of similar height and origin.[1]

The Uinkaret Plateau is the narrowest of the four and its southern portion is the most strongly diversified by basaltic eruptions. Indeed this portion (20 miles from north to south) is so broken as to be known as the Uinkaret Mountains in contrast to the Uinkaret Plateau farther north.[2] In sharp contrast to the rectilinear outlines and vivid colors of the greater part of the plateau region are the irregular profiles and gloomy aspect of the basaltic plateau of Mount Trumbull, a great mesa consisting of horizontal sedimentary strata capped by 500–600 feet of basalt. Its summit (2000–3000 feet relative altitude) reaches to such a height that the climate is cool and moist and the plateau sustains a forest growth of yellow pine. About the mesa or mountain and covering the whole southern end of the Uinkaret Plateau are great lava flows — jagged masses of black basalt, desolate except for an occasional grove of cedar and piñon.[3]

From the summit of Mount Trumbull 120 to 130 cinder cones are visible and upon the whole Uinkaret are 160 to 170 vents in all. None of them in the main field is of great size; the highest are only 700 or 800 feet in altitude, with a diameter of a mile.

KANAB PLATEAU

The Kanab Plateau is separated from the Uinkaret by an inconspicuous boundary. For about 20 miles north of the canyon it is clearly marked by the line of cliffs along the Toroweap fault which gradually dies out northward, and beyond this point no prominent topographic feature forms a dividing line.[4]

The Uinkaret and Kanab plateaus are separated from each other by the twenty-mile long Toroweap Valley, the locus of the Toroweap fault that causes the eastern wall of the valley to be several hundred feet higher than the western. The greatest displacement along the line of the fault is only 700 feet. It extends but 18 or 20 miles north of the canyon, hence is a much weaker boundary than the neighboring faults.

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[1] The heights of the various fault scarps should not be taken as an indication of the amount of faulting. While the Grand Wash Cliffs are from 2000 to 3000 feet high, the fault which gave rise to them exhibits 6000 feet maximum vertical displacement. Likewise Hurricane Ledge is from 500 to 2000 feet high, but it is associated with a maximum displacement of about 12,000 feet 10 miles north of the Virgin River Valley. (Dutton, idem, p. 20.)

[2] See the Mount Trumbull quadrangle, U. S. Geol. Surv.

[3] C. E. Dutton, Tertiary History of the Grand Canyon District, Mon. U. S. Geol. Surv., vol. 2, 1882, pp. 81–84, 103.

[4] Idem, p. 13.

KAIBAB PLATEAU

The Kaibab and Kanab plateaus are separated by the West Kaibab fault. The eastern border of the Kaibab Plateau is not formed mainly by faulting, hence it is an exception to the general rule. Here occurs not a fault but a great monoclinal flexure that is partially and locally faulted on a small scale and with a total descent of about 4000 feet. About mid-length it becomes a double monocline and finally a double fault before reaching the Colorado. The whole displacement dies out south of the Colorado. The Kaibab Plateau is thus a great uplifted block between two parallel lines of displacement, the eastern a compound flexure, the western a fault. The western border fault continues southward for but a short distance before splitting into three secondary faults with associated scarps and these extend almost to the brink of the Grand Canyon.[1]

The northern end of the Kaibab is a great cusp which terminates a little south of the town of Paria. Its southern border is the mile-deep Grand Canyon of the Colorado. Structurally and topographically the Kaibab is continued across the canyon into the southern district, but the strong break of the canyon has caused the adoption of a different name for the southern section, which is called the Coconino Plateau.

It would be reducing to common terms that which is in the highest degree uncommon if no mention were here made of the extraordinary scenic features displayed in this greatest wonderland of North America. Even superlative terms are feeble, and ordinary language is wholly inadequate for the expression of forms and colors that have been the theme of every enthusiastic scientist and every poet who has beheld the great cliffs, profound canyons, and vast expanses of the plateau region. Dutton's rich vocabulary enabled him to write a description which is probably the most satisfactory expression of the ideas and feelings which these great scenic features inspire. We therefore restrict ourselves to two or three quotations from his classic memoirs, *Tertiary History of the Grand Canyon District* and *Geology of the High Plateaus of Utah.* They are not the most enthusiastic passages that may be found; they are rather the most restrained and careful and may therefore be accepted not only as scientific but also as imaginative and interesting. The first description presents the region of terraces and canyons east and south of the High Plateaus of Utah as seen from one of the latter at an altitude of more than 11,000 feet.

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[1] C. E. Dutton, Tertiary History of the Grand Canyon District, Mon. U. S. Geol. Surv. vol. 2, 1882, p. 13.

". . . the eye ranges over a vast expanse of nearly level terraces, bounded by cliffs of strange aspect, which are truly marvelous, whether we consider their magnitude, their seemingly interminable length, their great number, or their singular sculpture. They wind about in all directions, here throwing out a great promontory, there receding in a deep bay, but continuing on and on until they sink below the horizon, or swing behind some loftier mass, or fade out in the distant haze. Each cliff marks the boundary of a geographical terrace sloping gently backward from its crest line to the foot of the next terrace behind it, and each [in northward succession] marks a higher and higher horizon in the geological scale as we approach its face. Very wonderful at times is the sculpture of these majestic walls. Panels, pilasters, niches, alcoves, and buttresses, needing not the slightest assistance from the imagination to point the resemblance; grotesque forms, neatly carved out of solid rock, which pique the imagination to find analogies; endless repetitions of meaningless shapes fretting the entablatures are presented to us on every side, and fill us with wonder as we pass."[1] "Isolated masses cut off from the main formation, and often at considerable distances from it, lie with a majestic repose upon the broad expanse of the terrace. These sometimes become very striking in their forms. They remind us of great forts with bastions and scarps nearly a thousand feet high. The smaller masses become regular truncated cones with bare slopes. Some of them take the form of great domes where the eagles may build their nests in perfect safety. But noblest of all are the white summits of the great temples of the Virgin gleaming through the haze. Here Nature has changed her mood from levity to religious solemnity, and revealed her fervor in forms and structures more beautiful than anything in human art."[2]

"But of all the characters of this unparalleled scenery that which appeals most strongly to the eye is the color. The gentle tints of an eastern landscape, the rich blue of distant mountains, the green of vernal and summer vegetation, the subdued colors of hillside and meadows all are wanting here, and in their place we behold belts of fierce staring red, yellow, and toned white, which are intensified rather than alleviated by alternating belts of dark iron gray."[3] "As the sun nears the horizon the desert scenery becomes exquisitely beautiful. The deep rich hues of the Permian, the intense red of the Vermilion Cliffs, the lustrous white of the distant Jurassic headlands are greatly heightened in tone and seem self-luminous. But more than all, the flood of purple and blue which is in the very air, bathing not only the naked rock faces but even the obscurely tinted fronts of the Kaibab and the pale brown of the desert surface, clothes the landscape with its greatest charm. It is seen in its climax only in the dying hours of daylight."[4]

SAN FRANCISCO PLATEAU

The term is here employed to include the whole region between the Grand Wash Cliffs, the Arizona Highlands, the Grand Canyon District, and the Little Colorado River. It includes the Coconino Plateau on the north, and on the south the broad platform of much greater extent upon which the San Francisco Mountains stand.[5] Its general

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[1] Geology of the High Plateaus of Utah, p. 8.

[2] Description of the scenery of the White Cliffs, developed upon the white Jurassic sandstone. From Tertiary History of the Grand Canyon District, p. 37.

[3] From description of the same region noted in the first quotation from Geology of the High Plateaus of Utah, p. 8.

[4] Impressions of a sunset on the Kanab Plateau in Tertiary History of the Grand Canyon District, pp. 124–125.

[5] It is somewhat confusing to use the term Colorado Plateau for this portion of the district as in Dutton's standard description. The term Colorado had already been established for the entire province. Both the Land Office maps and the maps of the Topographic Branch of the U. S. Geological Survey follow Dutton's usage however. In using the term San Francisco Plateau I am following the excellent suggestion of Robinson (Am. Jour. Sci., vol. 24, 1907).

altitude is from 7000 to 7500 feet, which is distinctly higher than the plateaus immediately north of the canyon, except the Kaibab. The strata of the district are nearly horizontal though with a broad regional slope toward the southwest, and, with few exceptions, the surface is not deeply or extensively scored by canyons. Unlike the Kaibab it has no strongly marked divisional boundaries, since the great fault scarps which form such prominent features of the one are either absent or diminish in height or disappear in the other. Its surface is diversified in some localities by (1) low, lava-capped, and usually forest-clad mesas, as Black Mesa and Mogollon Mesa, and (2) volcanic cones and peaks such as San Francisco Mountains (13,000) and the associated lava flows about their bases.[1] Some of the volcanoes are very recent, as in the San Francisco Mountain region, an example 16 miles north of San Francisco Mountain being probably not more than 100 or 200 years old.[2]

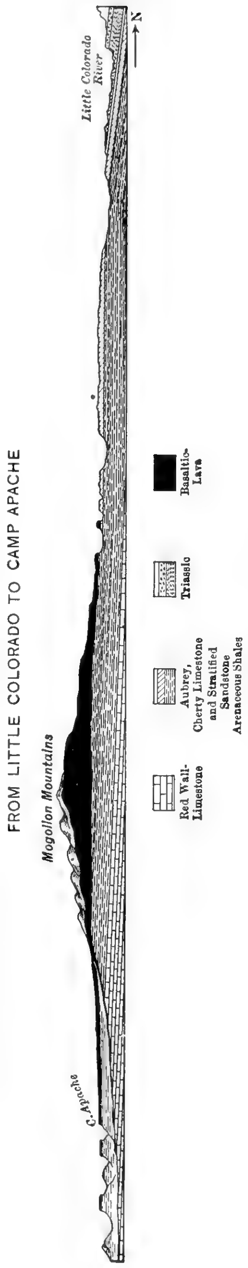

Fig. 76. — Topographic and structural section of the Mogollon Mountains and Mesa. Typical border topography southern edge of Colorado Plateaus, see Plate II. (Modified from Marvine, Wheeler Surveys.)

SOUTHERN PLATEAU DISTRICT

ZUÑI PLATEAU

The Zuñi Plateau (locally called the Zuñi Mountains) is an illustration of a type of structure seen in a number of places in the plateau country, for example in the San Rafael Swell on the eastern margin of the High Plateaus, and is of special physiographic interest. The otherwise flat plateau strata have been somewhat locally

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[1] C. E. Dutton, Tertiary History of the Grand Canyon District, Mon. U. S. Geol. Surv., vol. 1, 1882, pp. 14–15.

[2] D. W. Johnson, A Recent Volcano in the San Francisco Mountain Region, Arizona, Bull. Geog. Soc. Phil., vol. 5, 1907, pp. 2–6.

uplifted, raising the surface well above the general level and exposing it to pronounced erosion. The cross section, Fig. 77, exhibits the main structural features. It will be readily seen that the margins of the uplifted tract have been structurally bent and in places faulted, but that the summit of the uplift is almost flat. The erosion of the superior part of the broad uplift has removed portions of the capping layers and exposed the geologic section ranging from rather young (Cretaceous) to very old rocks (Archæan). Each stratum ends in a cliff facing the central axis of the uplift, and each cliff may be traced in the form of a great oval entirely around the tract. Each stratum also dips outward from the cliff summit and extends below the next cliff of the younger formation overlying it. The heart of the uplift is composed of Archæan gneisses and mica schists, and these constitute the main summit platform or plateau over a considerable portion. Since the summit has this constitution the oldest (stratigraphically the lowest but topographically the highest) sedimentary formation, the Carboniferous, ends at the shoulder or margin of the main platform. Many portions of the summit have strongly marked topographic features and are very rugged and diversified, being deeply scored with canyons. The principal drainage lines cross portions of the uplift regardless of the structure and show that they were determined before the uplift, a feature of common occurrence throughout the plateau country, while it is equally common to find all the lesser stream-ways in close sympathy with the broad structural surfaces of the main plateaus.[1]

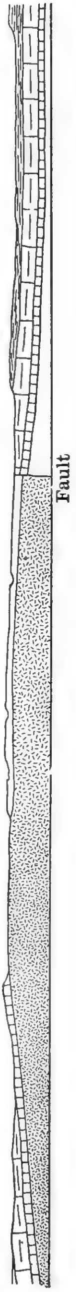

Fig. 77. — Section from northeast to southwest across the Zuñi Plateau. The strata are Archæan, Carboniferous, Jura-Trias, and Cretaceous, in upward succession. (Dutton, U. S. Geol. Surv.)

MOKI-NAVAJO COUNTRY[2]

That part of Arizona bounded by the San Juan, the Colorado, Little Colorado, and Puerco rivers reveals in slightly modified form the typical characteristics of the plateau province. The river valleys are canyons or wide, open washes, the rocks are chiefly sedimentaries of Mesozoic age, the climate is arid, the vegetation sparse, and there is little prospect that the area can be made profitable to civilized man. The only permanent streams are the San Juan, the Colorado, and the headwaters of

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[1] C. E. Dutton, Mount Taylor and the Zuñi Plateau, 6th Ann. Rept. U. S. Geol. Surv., 1884–1885, pp. 162–163.

[2] In the absence of published data on this section of the plateau country Prof. H. E. Gregory has kindly prepared this brief description from his field notes.

a few rivers which come from the highlands; for example, Chinlee, Moencopie, Navajo, and Little Colorado, Plate II.

During the rainy season (July and August) the run-off from the highlands is so rapid and uncontrolled and the flat valley washes are so thoroughly drowned that travel is exceedingly difficult and often dangerous; and the utilization of the extensive alluvial bottoms for agriculture on a large scale is rendered impossible. None of the important streams is reduced to grade throughout its course. All of them are carrying prodigious quantities of waste to be added to the burden of the Colorado. In the absence of running streams the Navajos and Hopis depend for themselves and their stock upon springs and ephemeral lakes, and the supply at best is meager and commonly unpalatable. It is remarkable how little water is used by man and beast.

The broad structural features of the region are easily comprehended. The highlands along the Arizona-New Mexico line include Carrisos Mountains at the north, the Lukachukai, Tunichai, and Choiskai mountains, and the hogback ridges between Fort Defiance and Gallup. The Carrisos (elevation 9420 feet) rise 5000 feet above the San Juan at their base, and constitute one of the most prominent landmarks of the plateau country. The mountains are laccolithic in origin and are caused by irregular intrusions of quartz-monzonite which deformed Triassic, Jurassic, and Cretaceous sandstone into a group of domes. Subsequent erosion has removed the cover here and there, exposing the igneous core, and deeply trenched the heavy sedimentary beds which form the flanks of the uplift. Lukachukai, Tunichai, and Choiskai mountains are composed of sedimentary strata lying approximately horizontal; their elevation is due to a fold of great amplitude, the western limb of which forms the eastern side of the Chinlee Valley. Caps of lava rest upon the Tunichais as well as upon a number of detached buttes at the south, while the covering beds of the Choiskais are Tertiary sediments. The ridges south and east of Fort Defiance are formed by the resistant members of Mesozoic strata which here dip to the east at a high angle.

The area between the lower Chinlee and Colorado rivers is part of a great dome of Triassic and Jurassic sediments intersected by the San Juan River. At Marsh Pass the strata plunge beneath the Cretaceous of the great Zilh-le-jini (Navajo for Black Mountain) mesa, and the hogback rim of the dome is prominently exposed from Marsh Pass, Arizona, to Elk Ridge, Utah. The elevation at Skeleton Mesa and the region about the head of Pahute Canyon is attained by a series of monoclinal folds with steep eastern limbs. As one travels from the Chinlee westward he ascends a series of giant steps until an elevation of nearly 8000 feet is reached. Standing on the plateau at this elevation his view is unobstructed except for Navajo Mountain (10,400 feet), a laccolith with its sedimentary cover still intact. It stands as an island covered with vegetation in the midst of a sea of barren red rock. From the top of Navajo Mountain a more comprehensive view of the plateau province may be obtained than from any other point. From Lee's Ferry the Leupp Echo Cliffs and their southern continuation mark the line to which the Jurassic and Upper Triassic have been stripped by the tributaries of the Colorado and the Little Colorado.

In the center of the Navajo Reservation and including most of the Hopi Reservation is the Zilh-le-jini mesa, attaining an elevation of 6000 to 8000 feet, and bordered on all sides by steep escarpments. In structure this highland is a shallow syncline of Cretaceous strata in which are included valuable beds of coal. On the narrow finger-like mesas forming the southern border of Zilh-le-jini are located the six villages of the Hopis which constitute the ancient province of Tusayan. Between Tusayan and the Little Colorado is an extensive area of lava-capped mesas and volcanic necks and dikes, the remnants of early Tertiary lava flows.

The vegetation is characteristic of the plateau province. Above 7000 feet on the highlands along the Arizona-New Mexico boundary line there grows an open stand of yellow pine which is used for the manufacture of rough lumber for various government projects. Pine in limited amounts grows on the northern rim of Zilh-le-jini mesa and covers the upper slopes of Navajo Mountain. Between 6000 and 7000 feet, piñon and cedar are commonly found, but over wide areas it averages not more than two or three trees per acre. Sage-brush and greasewood grow in limited amounts at elevations below 6000 feet, and grass, which is fairly abundant at higher elevations, is also found in limited amounts below 6000 feet, and in a few favorable localities forms a continuous sod. The extent of bare rock and sand floor is very great, and probably not more than 10% of the Navajo-Moki region is actually covered with vegetation. In fact it is possible to walk from Gallup, New Mexico, to Tanner's Crossing on the Little Colorado, or from the Carrisos Mountains to Lee's Ferry, without stepping on a twig or a spear of grass.

Grand River District

West of the Rocky Mountains of central Colorado, Plate II, and on meridian 107° 30′ is the northeastern edge of the Colorado Plateaus. This portion is called the Grand River district after the main drainage line. It consists of the White River Plateau, Grand Mesa, the Book or Roan Plateau, the Uncompahgre Plateau, and the Dolores Plateau, named in order from north to south. The strata upon which these plateaus are developed as a rule dip toward the west and away from the Rocky Mountains. In the southwestern part of Colorado, along the San Juan Valley, six well-marked groups of hard rock (sandstone) occur and a corresponding number of soft shales alternate with them and form lines of weakness for the attack of the weather. Each group of strata slopes and dips gently westward until a break occurs and a precipitous descent is made across the edges of the rock layers to the next lower group of strata,[1] a succession that is typical of the district, although the number of alternations of strata and to some extent the topographic expression varies from section to section.

Like the other districts the Grand River district exhibits a number of mountain groups of igneous origin scattered upon its plateau surfaces. These include the San Miguel, La Plata, Carriso, Abajo, and other groups, which are as a rule of laccolithic origin. Erosion has removed the once overlying sedimentary beds and exposed the intruded rock.

WHITE RIVER PLATEAU

The White River Plateau is the northernmost of the series in the northeastern part of the plateau province. The general level of its surface is interrupted in many places by higher summits (500–1000 feet above the general level) and ranges of mountains on the one hand and by deep valleys and canyons on the other. While plateau surfaces are still conspicuous features of the region, the upland has been so largely cut away by erosion, so largely modified by uplift or faulting of the once flat-lying strata, so complicated by intruded masses of igneous rocks, that the plateau feature can scarcely be said to be the dominating one, and by some the plateau would be classified as a part of the Rocky Mountains. The best-preserved sections of the plateau are those whose flat upper surfaces have been unbroken and but slightly tilted.

The White River Plateau has been formed largely by lava flows, the borders of which have been cut into deep gorges and ravines in which some of the headwaters of the White and Yampa rivers take their rise.[2] On the west especially this plateau falls off in abrupt and high cliffs to the long slopes of the bordering spurs; the eastern border is marked by high detached masses which give it a mountainous aspect

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[1] C. E. Dutton, Mount Taylor and the Zuñi Plateau, 6th Ann. Rept. U. S. Geol. Surv., 1884-1885, p. 242.

[2] F. V. Hayden, U. S. Geog. and Geol. Surv. of the Terr., 1876, p. 7.

when viewed from the east. North of the White River Plateau the country is mountainous and so broken that no distinct, well-defined topographic system has been determined.[1] On the south the plateau forms the divide between the White and the Grand rivers and loses its distinctive mesa-like quality, being cut by profound canyons.[2]

SPECIAL BORDER FEATURES

In portions of northwestern Colorado the plateau character is largely replaced by hogback or monoclinal ridges, strike valleys, and other features related to moderate complexities of structure developed in a series of alternating hard and soft strata.[3]

One of the most remarkable physiographic features of northwestern Colorado is Grand Hogback, which extends southward from the Danforth Hills to a point beyond Grand River. Indeed under the name of Colorado Ridge it continues far beyond Grand River to the point where its identity is lost in the more rugged West Elk Range. The Grand Hogback is bordered on both sides by long continuous valleys; the ridge itself is at some places a single-, at others a double-crested hogback ridge formed by the outcrop of massive sandstone ridges inclined eastward at steep angles. Its steep inclination has afforded opportunity for the development of an exceedingly rugged topography whose principal elements are precipitous marginal slopes. The most striking features of the Grand Hogback and the Colorado Ridge are their topographic continuity and structural uniformity. The stream valleys in the Hogback Ridge contain a small amount of red fir, while the upper slopes and crest, 2000 feet above the marginal valley bottoms, are covered with a dense growth of oak brush, chokecherry, and juniper.[4]

ROAN OR BOOK PLATEAU

One of the most striking topographic features of the Grand River district is the southern margin of the Roan or Book Plateau, the Roan or Book Cliffs.[5] In places the cliffs rise almost vertically from the edge of the Grand River Valley to their full height; elsewhere the ascent is by a succession of broken steps. Their mean height is about 8600 feet, or

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[1] S. B. Ladd, U. S. Geog. and Geol. Surv. of Colorado and Adj. Terr. (Hayden Surveys), 1874, pp. 437–438.

[2] Idem, p. 439.

[3] H S. Gale, Gold Fields of Northwestern Colorado and Northeastern Utah, Bull. U. S. Geol. Surv No. 415, 1910, p. 24.

[4] Idem, p. 31.

[5] Roan, from their prevailing color; Book, from the resemblance of their characteristic form to a bound book.

3500 feet above the Grand River. They are the southern escarpment of the plateau of the same name which slopes rather gently to the north and northeast and is drained by tributaries of the White River. Nearly half the original surface of the plateau is still intact, so that a rather flat aspect is more common than in the more dissected White River Plateau on the east or the Uncompahgre Plateau on the south. The western is the most dissected portion of the plateau, and here the divide is in places only 30 or 40 feet wide, bordered on the cliff side (south) by a precipice and on the plateau side by a strong slope. The crest of the cliffs has very little water on account of the low elevation (8600 feet); it is covered in the main with grass and sage. Almost the only arboreal vegetation is quaking aspen, which occurs but sparingly; there are but a few occurrences of spruce and pine.[1]

UNCOMPAHGRE PLATEAU

The Uncompahgre Plateau lies between the Uncompahgre Mountains and the Grand River. It is 90 miles long and from 15 to 25 miles wide; its elevation is from 8600 to 10,200 feet (northwest). It is in the form of a broad arch of sedimentary beds about 1000 feet thick over a central core of granite, the latter being well exposed in the steep and beautiful canyon of the Unaweep, where it forms two-thirds of the height of the walls. The tributaries of the Unaweep have all cut down to the granite, and in the season of floods due to the melting of the snows their waters drop from 300 to 2000 feet to the bed of the main canyon below. On the west the plateau is bordered by steep cliffs which descend to the valleys or canyons of the Grand and other streams.

One of the most profound canyons of the whole mountainous western half of Colorado is that of the Gunnison on the northeastern border of the Uncompahgre Plateau. It is 56 miles long and 3000 feet deep in the deepest part. The plateau in which it is incised consists of granite-gneiss capped by 1000 to 1200 feet of sedimentary strata. The canyon is cut through the overlying sedimentary rock and deep into the gneiss, the contact being marked by a sloping bench below which are rough, ragged, and nearly vertical walls which extend to the river margin; above the contact are steeply sloping talus and vertical cliff in alternating series. The tributaries of the Gunnison have incised their courses but little into the gneiss and therefore have very steep descents where they join the master stream.[2]

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[1] F. V. Hayden, U. S. Geog. and Geol. Surv. of the Terr., 1875, p. 346, and 1876, p. 69.

[2] Henry Gannett, U. S. Geol. and Geog. Surv. of Col. and Adj. Terr. (Hayden Surveys), 1874, p. 425.

The influence of elevation upon rainfall and thus upon the character and amount of the vegetation is admirably illustrated in the Uncompahgre Plateau. In the interior of the plateau and down to an elevation of 7000 feet or more are streams and springs in some number, good pasturage, a sprinkling of aspen groves, and game in some quantity; below 7000 feet aspen gives way to piñon, grass to sage, cacti, and bare rock, the streams become muddy torrents or dry up altogether, and in place of the rolling plateau surface are deep narrow canyons and steep precipices.[1]

The influence of elevation upon the character of the vegetation is also well shown on the plateau between the Gunnison and the North Fork of the Gunnison. This plateau has a smooth unbroken summit sloping in a direction slightly west of north. It ranges in elevation from 9000 to 5400 feet, and owing in part to its marked slope, which drains the surface water rapidly away, and in greater part to its low elevation, the plateau is without timber in contrast to the bordering mountains of slightly greater elevation. Its vegetation is piñon pine, cactus, sagebrush, and scrub oak in contrast to the timbered plateau on the east.[2]

DOLORES PLATEAU

The Dolores Plateau lies between the Dolores and San Miguel rivers about halfway between the San Juan and Grand River canyons. The highest portion is known as Lone Mesa and is at 10,000 feet elevation, with an area of about 40 square miles. About it are a number of high flat-topped buttes which like it are erosion remnants with steep bordering scarps. The superior elevation of Lone Mesa gives it a greater rainfall than falls on adjacent tracts and meadows, and forests of pine abound.[3]

The canyon of the Dolores is very narrow and precipitous, with almost no alluvial bottoms except in its shallowest portion at the great bend, Fig. 78. Here are a rich growth of grass, some cottonwood groves and bushes, and vines. On the borders of the canyon below this point is a rather heavy growth of piñon pine and cedar, and on the various headwater branches are forest and meadow, aspen groves, and rich grassy parks in contrast to the desert canyon below.[4]

One of the most remarkable cases of stream direction not in accord with the present slope of the plateau surface (p. 284) is that of the

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[1] F. V. Hayden, U. S. Geog. and Geol. Surv. of the Terr., 1875, pp. 340, 341, 349.

[2] Henry Gannett, U. S. Geol. and Geog. Surv. of Col. and Adj. Terr. (Hayden Surveys), 1874, p. 426.

[3] Idem, p. 266.

[4] Idem, pp. 266–277.

Dolores River, a tributary of the Grand. The Dolores rises in the San Juan Mountains, runs south and west for more than 30 miles, then flows northwest against the inclination of the surface for about 60 miles to the Grand River in western Colorado, in a gradually deepening canyon, Fig. 78. At the turning point it is in a canyon only 100 feet deep; above and below this point the canyon deepens to 2000 feet. Evidently the river gained its course sometime before the present surface conditions were established. The surface is structural in origin, being developed on a great sandstone layer (Dakota). Either the surface was peneplaned and the river now pursues an antecedent course with respect to later uplifts that deformed the peneplain, or its course was developed in response to a structural slope that has since been reversed. While the main stream has thus maintained its earlier course the smaller streams of the region show marked responses to the present attitude of the surface. The tributaries of the San Juan (south) rise almost on the brink of the Dolores canyon, for they have been extended in response to the structural surface now existing and have encroached on the weaker Dolores tributaries until the latter are all but extinguished south of the canyon.[1]

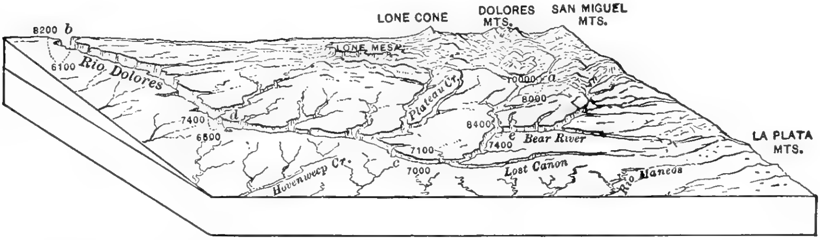

Fig. 78. — Canyon of the Dolores. The canyon is 2000 feet deep at *a*, 2100 at *b*, and 100 at *c*. (Hayden Surveys.)

The Yellow Jacket tributary of the San Juan has encroached so far upon the Dolores at the great bend that a tunnel several hundred yards long has been constructed through the intervening barrier and a large part of the water of the Dolores turned into the Yellow Jacket for the purpose of irrigating the valley flats at Cortez, Plate II.

PHYSIOGRAPHIC DEVELOPMENT; EROSION CYCLES

An understanding of the physiography of the Colorado Plateaus requires at least some knowledge of its recent history as expressed in a number of topographic cycles through which the region has passed. With the long periods of deposition in the plateau region when it stood

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[1] F. V. Hayden, 9th Ann. Rept. U. S. Geog. and Geol. Surv. of the Territories, 1875, pub. 1877, pp. 263–264, and Plate 42, p. 264.

at or below sea level we have little to do; nor is it necessary for an understanding of existing topography to take account of the ancient and now buried surfaces of erosion that are so well exposed in the walls of the Grand Canyon. It is sufficient for our purpose to begin with rather late movements in the evenly bedded mass of strata accumulated by long-continued erosion of the Great Basin and adjacent mountains.

In the Tertiary (latter part of the Eocene or possibly in early Miocene) the plateau region was uplifted and the uplift was accompanied by monoclinal folding. The result of these first deformations was an elevation of the western plateau country above the eastern, and the descent from plateau to plateau was at that time from west to east and not as at present from east to west. The folding probably gave rise to a number of closed basins in which lakes were formed and sediments laid down, although the drainage of the region was probably on the whole through basins draining to the sea. Since this first deformation of the plateau country (in Tertiary time) the region has suffered continuous erosion down to the present, although the character of the erosion, the geologic structure, and the topography, have been modified repeatedly, as outlined in the following paragraphs.

In response to internal forces of the earth a period of faulting followed the first period of monoclinal folding and by it the plateau district was marked out and the eastern and western borders clearly defined through the lowering of the country on either side. The date of this period of faulting has not been closely ascertained, but it may be regarded with a certain degree of accuracy as having occurred at the close of the Miocene.

FIRST EROSION CYCLE

The two geologic events of monoclinal folding and of faulting lent to the relief of the plateau region a pronounced character. But the topographic expression of these structural features was gradually and at last completely obliterated at the close of a cycle of erosion known as "The Period of the Great Denudation." The surface of the entire southern plateau country, and probably also of the northern plateau country, was reduced to a peneplain. At the close of the great denudation cycle there occurred widespread eruptions of basalt. The lava flows capped portions of the surface of the peneplain and thus protected them from the effects of later denudation.

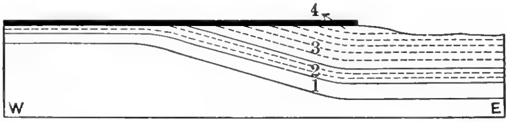

Fig. 79. — Black Point Monocline, Colorado Plateaus, showing remnant of base-leveled surface capped by lava. 1. Kaibab; 2. Moencopie; 3. Shinarump; 4. Basalt. (Robinson).

An instructive locality for the study of those features upon which the foregoing description rests is at Black Point in the Little Colorado Valley, where the Black Point monocline dips eastward as shown in the cross section, Fig. 79. The black basalt which caps the surface of the country and preserves a portion of the ancient peneplain rests upon an exceedingly smooth, almost flat surface, a degree of smoothness that could not have been developed across strata of such variable hardness except at a base level of erosion. The Kaibab cherty limestone is very resistant, while the Moencopie soft sandstone and shales and the Shinarump marls are very soft and easily weathered; above the marls at the eastern end of the section is a compact sandstone of most resistant quality. A similar occurrence is at Anderson Mesa, eight miles southeast of Flagstaff, where a smooth surface was once developed across rocks of very different hardness such as the Kaibab cherty limestone and the soft Moencopie shales. The peneplain is also well shown in the Mount Taylor region on the walls of both the Mount Taylor and the Prieta mesas where it bevels across beds of slight dip. Its character as inferred from the once buried remnants now reëxposed was that of a surface of rather faint relief.[1] Huntington and Goldthwaite[2] have described it in the Toquerville district, Utah, and Davis has interpreted phenomena of the same significance in a number of other localities.

The boundaries of the known portions of the base-leveled surface include about 25,000 square miles of country, and it seems at present as if these peneplain remnants in various portions of the plateau country were at one time united so as to form a surface of very slight relief, out of which the existing plateaus were blocked by faults. Recently the work of Gregory[3] in the Navajo country and the valley of the San Juan has shown the extension of the great peneplain surface far to the north. An excellent locality is between Tuba City and Oraibi, where a remarkably flat surface only partially dissected bevels regularly across strata of pronounced dip and structural variation. The entire extent of the peneplain will only be known when the now little explored portions of the province (which aggregate the greater part of it) are examined and the physiography interpreted.

SECOND EROSION CYCLE

The next important geologic event in the plateau region was the inauguration of a second period of faulting near the close of the Pliocene, a period of faulting in which the plateau region was again strongly blocked out and given those features that are most prominent at the present time. The second period of faulting increased the relief of the plateau region and resulted in the pronounced step-like relation of the different members of the plateau. While the folding of the first period of deformation operated in such a manner as to cause a descending series of plateaus from west to east, the major faults of later dates reversed the order of descent, an order that has been maintained down to the present.

The second period of faulting introduced the second or post-peneplain cycle of erosion, in which there was developed a widespread system of

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[1] D. W. Johnson, Volcanic Necks of the Mount Taylor Region, New Mexico Bull. Geol. Soc. Am., vol. 18, 1907, pp. 307–308. See also idem, cross section, Fig. 2, p. 309.

[2] Huntington and Goldthwait, The Hurricane Fault in the Toquerville District, Utah, Bull. Mus. Comp. Zoöl., vol. 42, Geol. Series, vol. 6, 1903.

[3] Personal communication.

shallow but mature valleys, one of the most persistent features of the better-known portions of the province. The drainage characteristics of this partial cycle have been noted by several writers, among whom Robinson was the first to demonstrate their persistence and their meaning in terms of erosion cycles.[1] The same feature has been described by Noble,[2] who says:

> "The drainage system of the plateau surface (Coconino) consists of a series of mature open-floored valleys with gently sloping sides, which contain no living streams. . . . In tracing one of these mature valleys toward its head . . . [it is] common . . . to find it truncated as a hanging valley by the wall of the Grand Canyon. . . . The same system of mature valleys covers [the] surface [of the Kaibab plateau] which slopes southwesterly to the rim of the canyon."

The surface drainage of the Kaibab now runs through this system of mature valleys into the Grand Canyon; the surface drainage of the Coconino runs through a similar valley system away from the Grand Canyon, and both plateaus have only temporary streams. These mature drainage systems offer the most striking contrast on the one hand to the youthful topography of the deeply trenched canyon developed in the third or next erosion cycle, and on the other hand to the base-leveled surface now preserved in fragments beneath the basalt caps of various mesas.

It should not be thought that the second cycle of erosion brought about any great vertical reduction of the surface. On the contrary the depth to which the streams cut in response to the new base level was only a few hundred feet as against the few thousand feet of the third and last, or canyon cycle of erosion. The chief result of denudation in the second cycle was the broad horizontal stripping back of the strata outcropping on the surfaces of the plateaus and the development of mature valley systems. The stripping of the gently inclined strata proceeded on structural planes, so that the present flat plateau surfaces are structural surfaces developed upon the upper surface of resistant strata. Generally the structure dips uniformly toward the southwest at the rate of about 200 feet to the mile, so that the surfaces of the Coconino and San Francisco plateaus south of the Grand Canyon slope to the southwest from the canyon rim at the rate of about 200 feet per mile. The Kaibab plateau north of the Colorado Canyon slopes southwesterly in the same degree to the rim of the canyon. It is for this reason that the southern plateau drains away from the canyon and that the northern plateau drains into it. The plateau surfaces are

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[1] H. H. Robinson, A New Erosion Cycle in the Grand Canyon District, Arizona, Jour. Geol., vol. 18, 1910, pp. 742–763.

[2] L. F. Noble, Contributions to the Geology of the Grand Canyon, Arizona, The Geology of the Shinumo Area, Am. Jour. Sci., vol. 29, 1910, pp. 374–380.

everywhere accordant with the rock structure.[1] These facts must be thoroughly appreciated because, while the plateau as a whole has been base-leveled, the remnants of the ancient base-leveled surface total a very small area, and in general are preserved only beneath lava caps near the summits of mesas.

THIRD EROSION CYCLE

The third period of faulting and of regional uplift inaugurated a third cycle of erosion, and, because the most striking effects of erosion in this cycle are the great canyons of the region, it has been called the "Canyon Cycle of Erosion." During this cycle a certain amount of plateau stripping has taken place and the cliff profiles have been refreshed, although the chief result has been the development of the profound canyons of the great Colorado and its principal tributaries.

During the canyon cycle of erosion there occurred a third period of volcanic activity characterized by eruptions of basalt from many small volcanic cones. The later eruptions took place, as a rule, before or during the period of glaciation, since they have been glacially modified, although a few cones and flows are of very recent geologic age. The later basaltic flows may be distinguished from the earlier flows capping the surface of the peneplain by their freshness, their undissected condition, and the absence of those displacements which affected the earlier volcanic flows.[2]

With these historical events in mind we may now turn to some features of the existing topography of the Colorado Canyon that require more detailed study. The main section of the canyon is known as the Grand Canyon. Above the Grand Canyon is the Marble Canyon (cut into Carboniferous limestone) a feature of great magnitude but dwarfed by the adjacent highly diversified Kaibab division of the Grand Canyon, more than a mile deep (6000 feet). The length of the Marble Canyon is 65 miles, that of the Grand Canyon about 125 miles.

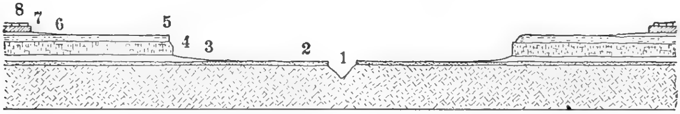

Fig. 80. — Cross-profile of the Grand Canyon of the Colorado River. Scale, one inch = 15,000 feet. 1, inner gorge; 2, 5, 7, sandstone; 4, 8, limestone; 3, 6, shale. (Gilbert and Brigham.)

The two main divisions of the Grand Canyon are the Kaibab and the Kanab, which have certain topographic contrasts of importance. In

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[1] L. F. Noble, Contributions to the Geology of the Grand Canyon, Arizona, The Geology of the Shinumo Area, Am. Jour. Sci., vol. 29, 1910, pp. 374–380.

[2] H. H. Robinson, Tertiary Peneplain of the Plateau District and Adjacent Country in Arizona and New Mexico, Am. Jour. Sci., vol. 24, 1907, pp. 110–112.

the Kaibab division of the canyon the descent of the wall is unusually abrupt over the entire series of sedimentary rock. The only well-defined terrace is that developed upon the summit of the basal sandstone of the Tonto group near the bottom of the canyon — a terrace known as the Tonto platform. Below the platform is an inner gorge formed upon the basement schists (Algonkian). The platform averages a mile wide on either side of the canyon and is well enough defined to make travel upon it possible. In the Kanab division to the west the lower terrace has disappeared and a different terrace has been developed upon the summit of the Red Wall limestone about a thousand feet below the level of the canyon rim. Through it as through the Tonto platform is cut a deep narrow inner gorge. This platform or terrace is known as the Esplanade; it averages two miles in width on either side of the canyon.

Still further differences may be seen in the aspect of these two sections of the canyon. The topography of the Kaibab division exhibits much greater dissection than that of the Kanab. The former is diversified by great amphitheaters thronged with buttes and outliers and trenched by a multitude of tributary gorges. In the Kanab division a very simple topography is found. There is a fairly regular broad outer canyon in which is cut an inner gorge, and the fantastic scenery of the Kaibab division is here wholly absent.[1]

CLIMATIC FEATURES AND VEGETATION

The distribution of temperature and rainfall according to relief or elevation is brought out strikingly in the plateau province. An inch of rainfall is the normal increase for every 500 feet of altitude on the border of the plateaus; about half this increase in altitude is required for an increase of an inch of rainfall within the border of the plateaus. Yet most of the plateaus are dry, almost as dry as the plains of southwestern Arizona at half the altitude above sea level. The dryness is explained chiefly by the effect of the abrupt southwestern and western border in draining the passing winds of water vapor.

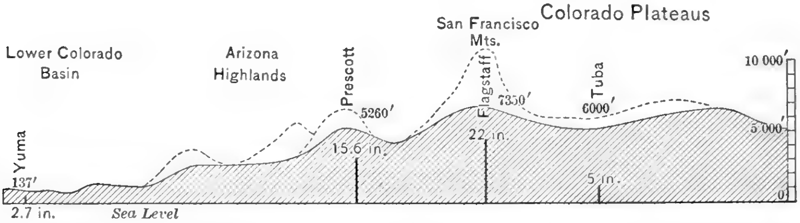

Fig. 81. — Topographic profile in relation to rainfall distribution from southwest to northeast across the three physiographic provinces of Arizona.

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[1] L. F. Noble, loc. cit., p. 375.

Below an altitude of 7000 feet the rainfall of the Colorado Plateaus is probably not more than 8 inches a year. With increase of altitude above that figure there is increasing rainfall and the highest of the High Plateaus receive the equivalent of about 24 inches of rain, though a large part of it occurs in the winter months and is mostly in the form of snow.[1] They are favored however with a summer maximum in July and August. Indeed Dutton estimates their summit rainfall at 30 inches.[2] The High Plateaus are therefore not arid; they are the first prominent topographic barrier which the winds strike east of the Sierra Nevada.

The natural vegetation of the Rio Grande Valley on the southeastern border of the plateau country is limited to scanty grass, cottonwoods, and willows on the river bottoms, and to cacti and other desert forms on the higher slopes. At still greater elevations the junipers begin to come in, at first as gnarled stunted growths, then in better form, and on the slopes of the volcanic mountains, as Mount Taylor and the San Francisco Mountains, and on the summits and to some extent on the slopes of the higher mesas such as Mogollon Mesa, Black Mesa, and the Zuñi Plateau are thousands of square miles of magnificent forests of yellow pine and spruce.[3]

This is the usual succession of vegetation in the plateau country. The altitudinal range of timber species is sometimes not clearly defined on account of diversity of climatic conditions and exposure. At the headwaters of the East Clearwater, a tributary of the Little Colorado, the shady northward facing canyon slopes and walls are timbered with red fir and white fir, while the drier southward facing slopes are covered entirely with yellow pine.[4] The most valuable tree of the region is the yellow pine; the sugar pine is found only on the southern plateaus and is rarely of commercial size; the piñon pine and the pitch pine are common but not valuable growths and usually occur on talus slopes. Engelmann spruce occupies the highest elevations and is the only timber above 11,000 feet, attaining its best growth at 10,000 feet and disappearing at 11,500 feet. The great height at which it grows makes it difficult to secure; and to the altitude is added the difficulty of the

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[1] A. H. Thompson, in Powell's Lands of the Arid Region, U. S. Geog. and Geol. Surv. of the Rocky Mountain Region, 1879, p. 151.

[2] C. E. Dutton, Geology of the High Plateaus of Utah, U. S. Geog. and Geol. Surv., 1889, p. 41.

[3] C. E. Dutton, Mount Taylor and the Zuñi Plateau, 6th Ann. Rept. U. S. Geol. Surv., 1884–1885, p. 125.

[4] F. G. Plummer, Forest Conditions in the Black Mesa Forest Reserve, Arizona, Prof. Paper U. S. Geol. Surv. No. 23, 1904, p. 16.

broken canyoned country between its plateau and mountain home and the valleys where the people live.[1]

The growth of grass is in most places scant, and at lower elevations diminishes in quantity and disappears in the lower and more desert country except where springs occur. The grasses grow characteristically in bunches and are thus in part protected among themselves from wind and blown sand. They have large strong stems and are not easily broken down by the infrequent rains and snows. They cure on the stalk and are highly nutritious, furnishing winter pasturage of great value to stockmen.[2]

The range of climate between the summits of the plateaus and the lower desert country of the canyon terraces and canyon bottoms is great indeed. The high precipitation of the Aquarius Plateau, for example, 25 to 30 inches, is chiefly in the form of snow which accumulates in the forest to a great depth. Settlers find it very difficult to live at an altitude over 7000 feet; their farms are usually found below that level where the climate is hot, arid, or semi-arid, and where irrigation is a necessity. From the cool, lake-besprinkled forests and meadows of the higher plateaus one looks down upon a country of extreme heat and dryness. The range of climate between the two situations is as great as one may find in most regions only by traveling through a considerable number of degrees of latitude, — a common range, however, in the great intermontane country between the Rockies and the Pacific Mountains.

The range in climate between the Kaibab and the bottom of the canyon, for example, is as great as the climatic range between the mountains of Colorado and the Mohave desert. The winters on the Kaibab Plateau are extremely severe and from November until April the snow lies deep in the woods, often accumulating to a depth of 10 feet. Even in midsummer the nights are chilly and the days are cool. The winters in the depth of the canyon are mild, freezing temperatures are rare, and snow rarely falls below the level of the Esplanade (4500 feet), while snow never falls on the Tonto platform (2100 feet).[3]

In contrast to the cool summer days of the plateau is the intense heat of the entire canyon below the Red Wall. The bare rocks become so hot as to burn the hand, and by nightfall a wind like a furnace blast

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[1] J. W. Powell, Lands of the Arid Region of the United States, U. S. Geog. and Geol. Surv., 1879, pp. 98–103. See these pages for a more extended description of the tree species of the plateau province, their habitats and relative commercial importance at the time of Powell's surveys.

[2] J. W. Powell, Lands of the Arid Region of the United States, U. S. Geog. and Geol. Surv. of the Rocky Mountain Region, 1879, p. 110.

[3] Noble, loc. cit.

escapes through the canyon. But the heat is not enervating, for the relative humidity is very low and moisture is rapidly evaporated from the body. The bottom of the canyon is decidedly arid, for much rainfall evaporates before it reaches the great depths. The Coconino Plateau on the south side of the canyon has a lesser altitude than the Kaibab Plateau, and while the latter is decidedly moist the former is semi-arid. Often no rain falls for a month at a time. In both cases there are distinct summer and winter maxima. Powell Plateau on the south-western border of the Kaibab has a high eastern portion, and a low western portion, and from end to end there is a transition in climatic conditions similar to the transition that is experienced in passing from the Kaibab to the Coconino Plateau. In winter it is a resort for game and wild horses driven out of the Kaibab by the snow. The higher eastern end has an abundant rainfall; the lower western end is semi-arid.

One of the finest forests of the whole region is found on the high and better-watered Kaibab. The trees of the Kaibab forest are mostly yellow pine, but at the higher elevations spruce also is common. Pines are found on the sunny slopes of the ravines, spruce on the shady slopes, and both grow only scatteringly upon the valley bottoms. These and the aspens are the three principal genera, but about the borders of the plateau are patches and scattered individuals of cedar (*Juniperus occidentalis*), mountain mahogany (*Cercocaspus ledifolius*), and piñon.[1]

The influence of elevation upon vegetation through temperature and rainfall is admirably shown in the Grand Canyon, where it has been observed by Noble, from whose excellent descriptions the following paragraphs are taken[2]:

> "The surface of the Kaibab Plateau is covered with a magnificent open forest of yellow pine; the trees grow large and far apart and the ground is free from undergrowth, giving its surface the aspect of a great park; Engelmann spruces grow on the north slopes of the washes, and cottonwoods, aspens, and scrub oaks in their bottoms; a minor flora of flowering plants, exceedingly rich in species, covers the floor of the forest. The flora of the plateau surface or the south rim of the canyon differs completely from that of the Kaibab; it is covered with a forest of gnarled and stunted trees of juniper and piñon, with here and there a buckbrush bush; the trees never form thickets, but grow wide apart; while the open stretches are covered with sagebrush and mormon tea, with occasional cactus, mescal, and plants of the century family. This difference between the floras of the north and south rim is due to the differences in precipitation and temperature, which vary directly with the altitude. For this reason the floras of the plateaus furnish an almost unfailing index of the elevation. This is beautifully shown on the southwestward-sloping surface of Powell Plateau, the whole eastern half of which lies at an elevation of from 7000 to 7500 feet and is covered with the open pine forest characteristic of the Kaibab. At about 7000 feet the character of the flora changes, and passes into the

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[1] C. E. Dutton, Tertiary History of the Grand Canyon District, Mon. U. S. Geol. Surv., vol. 2, 1882, p. 132.

[2] L. F. Noble, Contributions to the Geology of the Grand Canyon, Arizona (The Geology of the Shinumo Area), Amer. Jour. Sci., vol. 29, 1910, pp. 374–380.

gnarled and stunted forests of juniper and piñon characteristic of the southern plateau across the canyon.

"Within the canyon itself the variation in the flora is just as great, and is again an index of the elevation.

"The flora of the Esplanade platform, a thousand feet below the south rim, consists of stunted bushes of juniper and piñon, with greasewood as the ground bush in place of the sagebrush of the Coconino Plateau. The cactus, mescal, and plants of the century family are present in greater abundance than on the plateau, but in less abundance and in more stunted development than in the bottom of the canyon. This is due to the fact that the Esplanade level is within reach of the winter snows and frosts.

"The flora of the Tonto platform, three thousand feet below the south rim, and of all the interior of the canyon below the Red Wall, is the flora of a hot and arid desert in its most characteristic form. The dominant plants are the greasewood bush, the mormon tea, and the cactus. The mescal and the plants of the century family here attain their greatest development and size. The cacti are particularly rich in species. Every plant in the flora is either prickly or aromatic; leaf surfaces are reduced to a minimum; devices for storing water attain the greatest perfection; and the dominant color is a somber gray. The somber colors and the reduction of leaf surface are apt to deceive the observer, both in regard to the richness of the flora in species and the abundance of plant life, which is far greater than one would suspect. The only tree is the screw-mesquite, which grows in the beds of those washes that contain living or intermittent streams.

"The vegetation in the bottoms of those canyons of the north side in the Shinumo Amphitheater which contain living streams is beautiful beyond description, and in refreshing contrast to the desert flora of the Tonto platform. Tall cottonwoods grow in the lower canyons; the walls are hung with maidenhair fern in the shady places; and willow thickets border the stream. Grass grows on the banks where there is soil. Higher up in the canyons, caks, maples, and other deciduous trees come in, and often beds of tall rushes. The most characteristic bush of these upper north-side canyons is the manzanita, which does not grow on the south side of the Grand Canyon."

In the northeastern or Grand River district there is a characteristic change in vegetation on ascending from the valley or canyon floors to the plateau summits. In the low valleys and on the dry ridges sagebrush occurs; in the moist valleys are found willow, buffalo berry, service berry, and along the larger streams cottonwood. The quaking aspen requires more water and is found only above 7500 feet, on the plateau summits or in the vicinity of springs or on cool and moist slopes. All the low bluffs and ridges support some piñon and juniper of low height growth, yellow pine occurs infrequently, and what is locally called white pine (*Abies engelmanni*) is found only in some of the gulches and ravines leading down from the summit of the Book Cliffs.[1]

MOUNTAINS OF THE PLATEAU PROVINCE

HENRY MOUNTAINS

The mountains of igneous origin that occur locally throughout the plateau country have been referred to in a number of preceding paragraphs in this chapter. Some of the most important features of the

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[1] F. V. Hayden, U. S. Geog. and Geol. Surv. of the Terr., 1876, pp. 68–69.

Fig. 82. — Relief map of the Henry Mountains, a group of eroded laccolithic domes in the plateau country, southeastern Utah. (Gilbert, U. S. Geol. Surv.)

larger groups deserve a word of detailed explanation. Our first consideration will be the Henry Mountains, which, with the San Francisco and Mount Taylor groups, have been studied in more detail than others of their kind.

The Henry Mountains are in southern Utah and are on the right bank of the Colorado River between the Dirty Devil and Escalante tributaries. They are a group of five individual mountains separated by low passes. Although they are in an arid region their height (7000 to 11,000 feet) is such as to cause them to have a rainfall sufficient to support forests. Mount Ellen is the highest of the five mountains and has a continuous crest line 2 miles long, with radiating spurs and bordering foothills.

The Henry Mountains were formed by the intrusion of great masses of molten rock into surface beds in the form of a laccolith. The overarching strata that were lifted up as a consequence of the intrusion have been so extensively removed by erosion that there is now revealed the heart of the laccolith, and the displaced beds are exposed on the flanks and borders of the mountains for the most part. There is considerable diversity in the degree of erosion; some of the mountains are still largely covered on one or more sides by overlapping sedimentary rocks.

The Henry Mountains in southern Utah stand upon a desert plain having a mean altitude of 5500 feet. A large part of the rain that falls in the region is distributed over the mountains, a fact that is reflected in the distribution of the springs and the vegetation. On the surrounding plain the vegetation is extremely meager, grasses and shrubs and in favored localities the dwarf cedar (*Juniperus occidentalis*). The highest peak of the group is Mount Ellen, 11,250 feet, which bears cedar about its base, piñon a little higher up, then yellow pine, spruce, fir, and aspen. The summits are naked; the upper untimbered slopes are covered with a luxuriant growth of grasses and herbs. Of the forest growths noted the pines grow in a scattering manner, but the cedars and the firs are in dense groves.[1] Among the other four mountains of the five comprising the group, Mount Pennell (11,150 feet) reaches above timber line and has a forest growth similar to that on Mount Ellen except that the timber reaches almost to the summit; on Mount Hillers (10,500) the timber reaches to the principal summit, but is less dense than on the other higher mountains; Mount Ellsworth is so low (8000) that it bears none of the forest trees that grow on the others, its vegetation is cedar and piñon right to the summit, and the grasses are less rank and grow in scattered bunches; Mount Holmes (7775) has a similar growth except that a few spruce trees grow high up on the northern flank.

Among the extinct volcanoes and associated lava flows Mount Taylor, San Francisco Mountain, Sierra Mogollon or the Mogollon Mesa, the Panguitch Lake Buttes of Utah and the Marcou Buttes of New Mexico are important members. These have all been formed by the extrusion

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[1] G. K. Gilbert, Report of the Geology of the Henry Mountains, U. S. Geog. and Geol. Survey of the Rocky Mountain Region, 1877, p. 118.

of lava in one or another form, either as volcanic mountains or as lava flows. Like the laccolithic mountains they have no range forms or structures. Their features are all grouped about centers of structural disturbance, and radiating slopes and spurs and drainage lines are the rule. They have the utmost differences of position with respect to timber lines. Many do not reach above the dry timber line, some do not reach the cold timber line, a few extend above the cold timber line and have unforested summits. Those having a forest cover at all are encircled by a band of forest vegetation from the 7000 or 8000 foot level to the 11,000 foot level, which represents the upper limit of tree growth. In all of them there is a notable canting of the timber lines on passing from the warmer and drier southern slopes to the colder and moister northern slopes. The difference of level amounts in some instances to a thousand feet and is always several hundred feet, being lower on the northern slopes. This condition has been especially well described by Merriam.[1]

More recently Lowell has noted that the degree of canting increases with increasing altitude and appears to be a function of radiation and insolation as controlled by area. With increasing altitude there is decreasing area. The two sides of a cone will therefore show increasingly greater differences in the limiting elevations of the tree zones and a more marked canting of the vegetation belts and timber lines.[2]

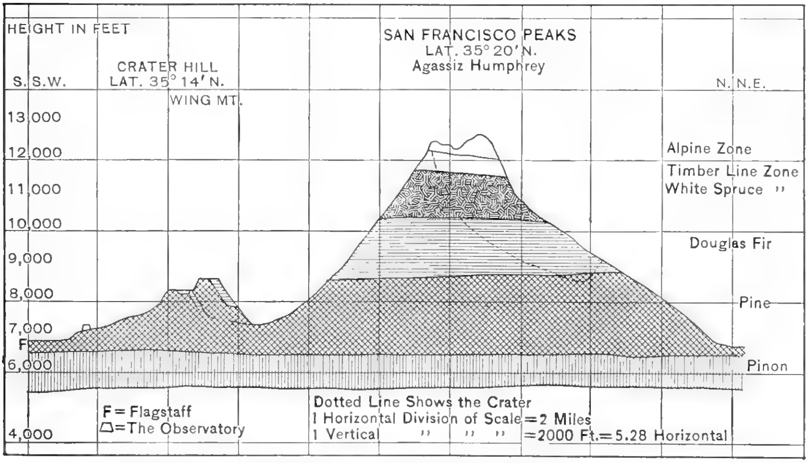

Fig. 83.—Timber zones on San Francisco Peaks, Ariz., showing increase in the degree of canting with increasing elevation. (Lowell.)

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[1] C. H. Merriam, Results of a Biological Survey of the San Francisco Mountain Region in Arizona, North Am. Fauna, No. 3, 1890.

[2] Percival Lowell, The Plateau of the San Francisco Peaks in its Effects on Tree Life, Bull. Am. Geog. Soc., vol. 43, 1911, p. 380.

SAN FRANCISCO MOUNTAINS AND MOUNT TAYLOR

SAN FRANCISCO MOUNTAINS

The San Francisco Mountains are the center of a volcanic field in northern Arizona that includes seven large peaks and several hundred small peaks. Cones and lava flows together cover about 2200 square miles of country. San Francisco Mountain, the highest peak in the group, rises to 12,700 feet above the sea and has 5000 feet of relative altitude. Other prominent peaks are Kendrick Mountain, 10,500 feet, and Bill Williams, Sitgreaves, Elden, and O'Leary mountains, which do not exceed 9500 feet. The smaller volcanic cones are scattered about irregularly and have great variety of topographic detail. The plateau about the base of these mountains and throughout the volcanic field maintains a greater altitude than elsewhere, a fact due to (1) greater initial height of the locality before volcanic activity began and (2) the protective influence of the hard lavas which have preserved the surface from that denudation which later brought the surrounding plateau to a lower level.

San Francisco Mountain is a composite cone built up by the lavas and breccias of five distinct periods of eruption. The chief vents of these periods are near each other, so that the total effect has been to give the mountain a symmetrical outline. The principal lavas are dacite, rhyolite, and andesite.

Twelve principal watercourses drain radially outward from the higher parts of the area. They are irregular in the lava field, but become more direct beyond the borders of the field, where deep canyons generally occur. After a cloud-burst or heavy shower water runs for a few hours in the canyons or washes within the limits of the storm area and then the channels become dry again. But one stream, Oak Creek, runs throughout the year; its more even flow is due to several large forest springs at its headwaters. In an area of 1000 square miles about San Francisco Mountain only about 25 springs and water pockets or "tanks" occur, and at least two-thirds of these are situated near the mountain, so that the surrounding country is extremely dry and difficult to traverse. The "tanks" and lakes which usually occur at the heads of the washes have a most variable supply as regards both quantity and quality. The lakes are due to the damming of the watercourses by lava flows. Some of them have become dry by the cutting down of their outlets and the accumulation of sediments; their floors are now grass-covered and picturesque glades.

The soils of the San Francisco volcanic field vary from "adobe" soils of the floors of temporary lakes and ponds to the pervious cinder and scoriaceous soils of the slopes of volcanic cones and ridges. Between these two extremes are gravelly loams of several varieties moderately pervious to water and best adapted of all the soils to the growth of forests. The coarse cinder soils lose water so rapidly that they are extremely sterile, while the adobe soils crack open when dry and swell when wet and are not adapted to forest requirements.[1]

The San Francisco Mountains are encircled by barren plateau country, but they are themselves covered with a beautiful forest of juniper, pine, and spruce. It surrounds the base of the mountains and stretches westward to the borders of the escarpment of the Colorado Plateaus and down it nearly to its foot. The forest accompanies the escarpment southwestward to the boundary of Arizona and extends in a northwest-southeast direction for over 200 miles. Its greatest breadth is opposite the San Francisco Mountains, where it is nearly 50 miles wide. Elsewhere its breadth is from 12 to 25 miles, thus giving it an area of from 12,000,000 to 23,000,000 acres. It is from all points of view the finest forest in the Southwest and is composed of an almost pure growth of yellow pine except in the higher altitudes of the San Francisco Moun-

Fig. 84.—Mesa forest of western yellow pine in the Mogollon Mountains near Iron Creek, Gila National Forest, New Mexico. (Photograph by DeForest.)

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[1] Leiberg, Rixon, Dodwell, and Plummer, Forest Conditions in the San Francisco Mountains Forest Reserve, Arizona, Prof. Paper U. S. Geol. Surv. No. 22, 1904, p. 15.

tains. It is an open forest with little undergrowth and the trees are of good size for lumber purposes.[1]

The yellow-pine zone extends from 7000 to 8200 feet. Above it and between elevations of 8500 and 9800 feet and occasionally to 10,000 feet is the transition forest type, composed principally of red fir, white fir, aspen, and a few Engelmann spruce. The subalpine forest type extends from 9800 to 12,400 feet and is found only on Kendrick Mountain and San Francisco Peaks. It is composed of aspen, Engelmann spruce, etc. Above the subalpine forest is a treeless belt which is represented only on and near the summit of San Francisco Peaks, Fig. 83.[2]

Below the yellow-pine zone and between 5700 and 6200 feet is a woodland belt where both climate and soil are very dry. Juniper and piñon are the chief species. They stand as a transition type of vegetation between the desert sagebrush and the true forest of the next higher belt.

MOUNT TAYLOR AND MOGOLLON MESA

Northeast of the Zuñi Plateau is Mount Taylor one of the most prominent volcanic elevations of the southeastern section of the province. The central mass and associated lava flows constitute the summit of a mesa whose base consists of sedimentary rock. The mesa is 47 miles long and has an extreme breadth of 23 miles, with an average altitude of about 8200 feet. Mount Taylor itself is 11,390 feet high. It is a lava cone principally and was a central pipe or vent from which the surrounding flows were derived. It is now very much eroded, though it still maintains a roughly amphitheatral form. It is heavily timbered and deeply covered with soil and talus.

In the Mount Taylor district and east of the main volcano are many lesser volcanic elevations now greatly denuded so that only the central core remains. They stand from 800 to 1500 feet above the general level of the plain as steep-sided sharp-crested buttes of great interest as the roots of once active volcanoes now all but swept away.[3]

Among the other areas of higher relief in the Colorado Plateaus is Mogollon Mesa, a timbered plateau 7000 feet above the sea and extending southward from the San Francisco Mountains (Plate II). Limestones and shales form the basement rock upon which the basaltic lavas that

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[1] Henry Gannett, 19th Ann. Rept. U. S. Geol. Surv., 1897–98, p. 47.

[2] Leiberg, Rixon, Dodwell, and Plummer, Forest Conditions in the San Francisco Mountains Forest Reserve, Arizona, Prof. Paper U. S. Geol. Surv. No. 22, 1904, pp. 18–19.

[3] C. E. Dutton, Mount Taylor and the Zuñi Plateau, 6th Ann. Rept. U. S. Geol. Surv., 1884–85, especially Panorama in the Valley of the Puerco, Plate 21, p. 171; also D. W. Johnson, Volcanic Necks of the Mount Taylor Region, New Mexico, Bull. Geol. Soc. Am., vol. 18. 1907, pp. 303–324.

constitute the mass of the mountains have been distributed. These strata dip northward and their edges are exposed on the southern border of the district where the lava cap has been most extensively frayed by dissection, Fig. 83. Here the main margin of the elevation consists of long lava-capped promontories of the plateau fronted by a series of detached remnants in the form of mesas and buttes. The mountains have been extensively dissected and present a bold and varied relief in contrast to the more regular margin of the mesa above which the mountains rise as from a pedestal. Thrifty forests of yellow pine cover both the mesa and the higher slopes and owe their existence to the favorable temperature and rainfall induced by the elevated position of the mountains on the windward border of the plateau country.[1]

[1] Wheeler Surveys, Geology, vol. 3, 1875, pp. 217–587.

CHAPTER XVIII

ROCKY MOUNTAINS. I

NORTHERN ROCKIES

BOUNDARIES AND SUBDIVISIONS

BETWEEN the sensibly flat and only slightly dissected basalt plains of the Columbia River and Snake River regions and the almost equally flat Great Plains of Montana is a broad belt of wild, rugged, mountainous country composed of many northward- and northwestward-trending mountain ranges. Though several transcontinental railway lines cross the region and occasional valleys, as the Bitterroot, are rather thickly settled, the forested mountain slopes and the higher ranges have few trails and fewer roads, and are almost unknown except to the hunter and the explorer.[1]

The chief members of the northern part of the Rocky Mountain System[2] in the United States are the Lewis and Livingston ranges, which form the eastern and front members of the system in northern Montana; the Galton, Flathead, Purcell, Cabinet, and other ranges east of the continental divide; the central Bitterroot Mountains on the boundary between Montana and Idaho; and the Clearwater, Salmon River, Priest River, and Cœur d'Alene mountains on the west, Fig. 86. The close proximity of these ranges to each other, in general their similar alignment and their common participation in certain important events in the physiographic history of the region, are conditions which form an adequate basis for the common association of the separate units under the group name of the northern Rockies of the United States; but there are wide differences in local detail, in the quality of the mountain slopes, the length and disposition of transverse valleys, and the degree of dissection which the individual ranges have suffered. It therefore becomes necessary to distinguish the essential elements of form and the limits of each unit in the system.

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[1] F. C. Calkins, A Geological Reconnaissance in Northern Idaho and Northwestern Montana, Bull. U. S. Geol. Surv. No. 384, 1909, p. 12.

[2] The United States Geographic Board makes the term Rocky Mountain System embrace the whole of the mountainous region between the Rio Grande and the 49th parallel, specifically the ranges of western Texas, New Mexico, Colorado, Wyoming, Idaho, and Montana. In this book the Trans-Pecos Highlands are set off as a separate province. (See p. 387.)

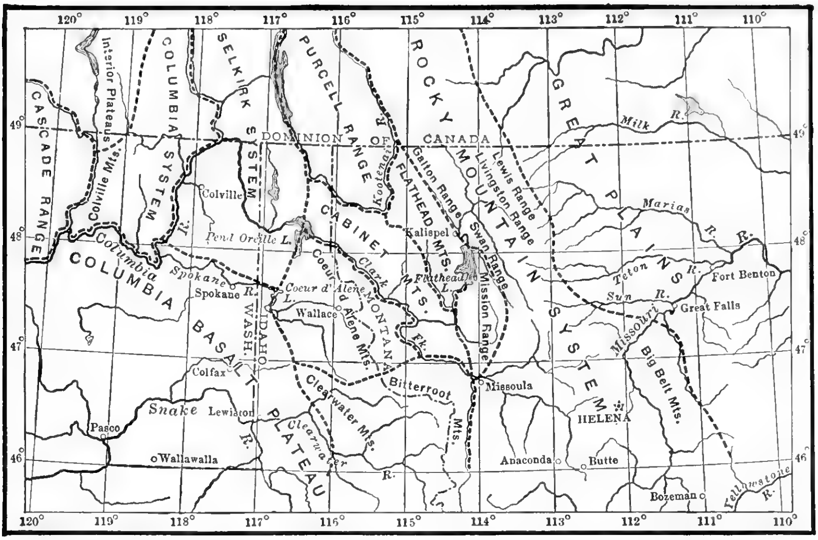

Fig. 85. — Mountain systems and ranges and intermontane trenches, northern Rockies. (Ransome, U. S. Geol. Surv.)

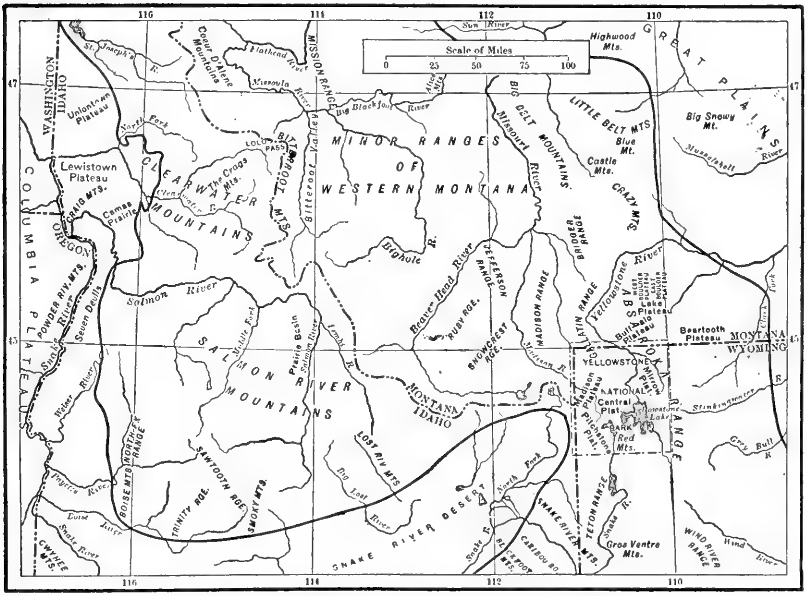

Fig. 86. — Location map of a part of the Northern Rockies.

In naming and describing the different mountain ranges of the northern Rockies that cross the international boundary line it has been proposed that a double and purely topographic principle be employed, the principle of the continuity of crest lines and the positions of the major erosion valleys.[1] Erosion troughs or intermontane trenches are here the natural lines of demarcation between the different ranges, for they have a highly exceptional and remarkable development on a great scale.

INTERMONTANE TRENCHES

In respect of size the major valleys of the region are often quite out of proportion to the streams that now drain them; the longest depression in the whole system is occupied by relatively small streams, the headwaters of the Kootenai, Columbia, Frazer, and others. They have steep though seldom precipitous walls, and rather flat, lake-dotted floors. They are called intermontane or valley trenches. It is certain that they had their direction determined in many cases primarily by fault lines or zones, so that some of them, for example Kootenai Valley, mark the boundary between different rock formations. They have probably been brought to their present form chiefly by the long-continued erosion of valley glaciers powerful enough to override the divides between the heads of the larger streams and to degrade them to a common level.[2]

In this connection it is in point to indicate that valley glaciers of great size supplied by many headwater tributaries are much more powerful agents of erosion in effecting topographic discordances such as appear in the hanging valleys and the mountain slopes adjacent to steep-sided U trenches, and in opening up valleys such as these trenches are to-day, than are continental ice sheets. A continental ice sheet is spread over the entire surface, and though it may erode to some extent differentially there is no such concentration of ice action as is the case in a region of heavy alpine glaciation. The valleys of

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[1] R. A. Daly, The Nomenclature of the North American Cordillera between the 47th and 53d Parallels of Latitude, Geog. Jour., vol. 27, 1906, pp. 586–606. This excellent paper outlines the difficulty of understanding the mountain nomenclature of the Rockies, and on pages 589 and 590 summarizes the various names applied by prominent authorities to the Rocky Mountains. In all at least 26 different names have been employed. It is suggested that greater differentiation be aimed at in designating the various members of the Rocky Mountain system. It is also noted that the authorities variously designate the terminal points of the different mountain ranges (pp. 592–593). The nomenclature is still further confused owing to the fact that some atlases and map sheets give different titles to the same range.

[2] F. C. Calkins, A Geological Reconnaissance in Northern Idaho and Northwestern Montana, Bull. U. S. Geol. Surv. No. 384, 1909, p. 32.

Lake Chelan, the Okanogan, and the Cœur d'Alene are illustrations. In all three instances there are extensive catchment basins which fed prodigious glaciers.

Among the eleven longitudinal valleys or intermontane trenches which serve as convenient lateral boundaries for the members of the Pacific Cordillera are four of first rank; three of these occur in the northern Rockies, and lie west of the front ranges, the Purcell range and the Selkirks respectively. Each is designated a "trench," and as so used the term means "a long, narrow, intermontane depression occupied by two or more streams (whether expanded into lakes or not) alternately draining the depression in opposite directions."[1] The easternmost and much the longest of the series of trenches is the wide valley occupied at the international boundary by the Kootenai River.[2] It extends from near the southern end of Flathead Lake northward to Liard River in British Columbia, about 900 miles, and throughout it has the form of a narrow and remarkably straight depression lying between the easternmost member of the Rocky Mountains and the rest of the system. This depression is unique among all the mountain valleys of the earth for its remarkable persistence. It is not drained by a single great river, but is occupied in turn by the headwaters of the Flathead, Kootenai, Columbia, Canoe, Frazer, Parsnip, Finlay, and Kachika rivers. The name Rocky Mountain trench is now applied to it.

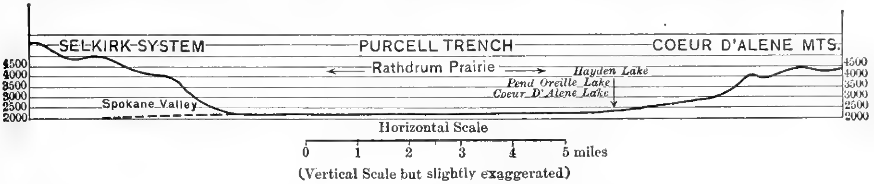

Fig. 87. — East-west section, showing flat floor and steep bordering slopes of a typical intermontane trench. (Data from Cœur d'Alene quadrangle, U. S. Geol. Surv.)

The major valley next in order to the west is occupied at the boundary by that portion of the Kootenai River that returns into Canada after rounding the great bend at Jennings, Montana. This trench begins on the south near Bonners Ferry, Idaho, and is occupied north of Kootenai Lake by the Duncan River. In line with the Duncan River Valley is the 50-mile trough occupied by Beaver River which enters the Columbia at the Canadian Pacific Railroad crossing. The length of this topographic unit, called the Purcell trench, is about 200 miles.

The third major trench is known as the Selkirk trench or the Selkirk

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[1] Daly, op. cit., p. 596.

[2] F. L. Ransome, Geology and Ore Deposits of Cœur d'Alene District, Idaho, Prof. Paper U. S. Geol. Surv. No. 62, 1909, p. 13.

Valley, and is occupied southward by the Columbia River. Its northern extremity is near the 52d parallel, where it is confluent with the Rocky Mountain trench. The southern end of the trench is about 60 miles south of the 49th parallel, where the Columbia River enters the great basalt plateau of Washington.

Besides these three first-rank valleys or trenches in the northern Rockies are a number of second-rank longitudinal trenches. Waterton River, Flathead River, and Zigzag River occupy parallel valleys that still further divide the northern Rockies into the Lewis, Livingston, MacDonald, and Galton ranges. Cross trenches or valleys are employed in indicating the minor subdivisions of the principal mountain systems and ranges, as the Slocan Mountains are separated from the rest of the Selkirk System by a depression occupied by Slocan River, Slocan Lake, and the valley of a creek whose mouth is at Nakusp or Arrow Lake.[1] In a similar way cross valleys divide the Colville Mountains, Pend Oreille Mountains, etc., from the larger ranges.

GEOLOGIC FEATURES

The detailed topographic qualities of the northern Rockies as discussed in succeeding paragraphs may be better understood by a brief consideration of certain fundamental geologic conditions. From Kootenai River or Purcell trench westward to the Columbia there is a much disturbed, highly folded, rock complex in which the metamorphism of the sediments generally diminishes in intensity westwardly.[2] To this metamorphosed complex the rocks east of the Purcell trench are in striking contrast. They consist of a thick series of arenaceous sediments (pre-Cambrian) which show no pronounced regional metamorphism. The essential structural features are open folding and extensive faulting. They are known to extend from the Belt Mountains westward to the Purcell trench. Some of the ranges (Purcell, Cabinet, Cœur d'Alene, Livingston, and Lewis) are composed almost entirely of this group of rocks. In central Idaho the same strata are invaded, displaced, and probably for the most part cut off by a great granite batholith.[3] The most striking structural feature of the western part of the sediments east of the Purcell trench is of course the existence of great faults of northwest trend that determine the courses of the trenches and rivers and block out the individual mountain ranges.

[1] Daly, op. cit., p. 599.

[2] Ransome and Calkins, Geology and Ore Deposits of the Cœur d'Alene District, Idaho, Prof. Paper U. S. Geol. Surv. No. 62, 1908, p. 16.

[3] W. Lindgren, A Geological Reconnaissance across the Bitterroot Range and Clearwater Mountains in Montana and Idaho, Prof. Paper U. S. Geol. Surv. No. 27, 1904, p. 16.

Fig. 88. — Cœur d'Alene Mountains, looking from above Wardner. Shows the mature dissection of a plateau-like uplift. (Ransome and Calkins, U. S. Geol. Surv.)

Fig. 89. — Cœur d'Alene Mountains, looking toward the crest of the range, from valley of South Fork of Cœur d'Alene River. Shows characteristic equality of ridge lines. (U. S. Geol. Surv.)

CŒUR D'ALENE RANGE

The Cœur d'Alene range, rudely triangular in outline, extends from Lake Pend Oreille on the northwest, southeastward to Lolo Pass (lat. 46° 36′ on the continental divide between Idaho and Montana).[1] Its southern boundary is vague but should probably be considered as corresponding to the divide on the northern border of the Clearwater drainage basin, Fig. 86. Its western margin adjoins the Columbia Plateaus; its eastern boundary is constituted by the valleys of Clark Fork, Flathead River, and Jocko Creek. The Cœur d'Alene range, Fig. 89, appears as a rather monotonous expanse of ridges nearly equal in height and with somewhat level crests that do not bear prominent summits.[2] Its broad aspect is that of a maturely dissected plateau, whose general level in its central and highest part is a little above 6000 feet. The rough equality of summit levels becomes less marked toward the west, dissection having there progressed so far that the original regularity of level has now been almost lost. It is tentatively concluded that this topographic uniformity depends upon former base-leveling, but much further work is required for a complete demonstration.

The Cœur d'Alene region had been folded and faulted into essentially its present structure and its topography had been developed by probable base-leveling, uplift, and extensive and deep dissection to essentially the present conditions by the time the great Miocene lava flood occurred, for great quantities of basalt flowed up the existing valleys. This fact for example explains Cœur d'Alene Lake, which occupies a large valley that was partly filled with basalt and afterward recut by the original river, thus leaving terraces of basalt on the older slopes. Later a deposit of Pleistocene gravels dammed the valley on the north, originated the lake, and gave it approximately its present outline, backing up the waters of Cœur d'Alene and St. Joseph rivers.

PRIEST RIVER RANGE

The Priest River range south of the international boundary and east of the Pend Oreille range has been deeply sculptured by glaciers and streams, so that canyons, cliff-bordered cirques, and narrow ridge crests are common. The rocks of the range consist principally of highly fissured granite and syenite; a certain amount of slate and gneiss occurs at the southern end. The average altitude of the range is 5000 to 6000 feet, with a number of elevations attaining 8000 feet. The irregularly fissured condition of the granites results in the better retention of the precipitation than is the case in the schistose rocks of the Pend Oreille range. The latter are either water-tight or else afford too rapid drainage, depending on the dip of the planes of schistosity. About 91 % of the total forest in the Priest River National Forest is white pine and

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[1] W. Lindgren, Prof. Paper U. S. Geol. Surv. No. 27, 1904, p. 23.

[2] F. C. Calkins, A Geological Reconnaissance in Northern Idaho and Northwestern Montana, Bull. U. S. Geol. Surv. No. 384, 1909, p. 14.

tamarack; yellow pine is found below 3500 feet, white pine between 2400 and 4800 feet (best development between 2800 and 3500 feet), and the subalpine fir, of little economic importance, grows above 4800 feet.[1]

CABINET RANGE

This range extends from Bonners Ferry southeastward to the junction of Jocko Creek and Flathead River. Its western border is definitely marked by the Purcell trench and its southwestern border by the nearly straight valley occupied chiefly by Clark Fork, Columbia River, and Flathead River. The eastern border is constituted by the valley of Little Bitterroot River, a short section of Flathead River, and Fishers Creek.

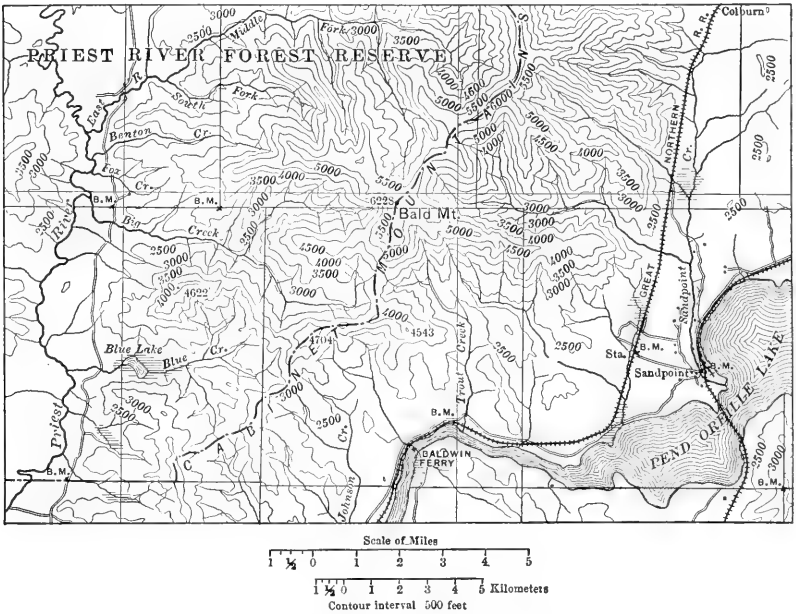

Fig. 90. — Southern end of the Cabinet Mountains, Idaho. The depression on the right is part of a typical intermontane trench. (Sandpoint quadrangle, U. S. Geol. Surv.)

As a whole the Cabinet range is somewhat loftier than the Cœur d'Alene range and far more diversified in character. The eastern part is a dissected plateau, but the quality of the dissection is markedly different from that in the Cœur d'Alene Mountains, for the differences in the hardness of the rock are so pronounced and the region has been so deeply scored by rivers and so intensely glaciated that its

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[1] J. B. Leiberg, Priest River Forest Reserve, 19th Ann. Rept. U. S. Geol. Surv., pt. 5, 1897–98, pp. 218–224.

details of sculpture are highly picturesque. The eastern portion of the Cabinet range has a number of prominent mountain peaks and a deeply serrate sky line in striking contrast to the lower, even-crested ridges toward the west. Some of the peaks are composed of resistant quartzite and overlook many great steep-walled amphitheaters or glacial cirques developed upon their northern, eastern, and western slopes. In the northern cirque of Bear Peak (8500 to 9000 feet) a small glacier may be found to-day, a remnant of those larger Pleistocene glaciers that once flanked all the higher peaks of the region and gave rise to cirques and other glacial features.[1]

PURCELL RANGE

The Purcell range trends north-northwest and is for the most part bounded on the east by the Rocky Mountain trench and on the west by the Purcell trench; the rest of its boundary is defined by the valley of Kootenai River. The greater part of the range is in Canada; only the southern end projects into the United States and is embraced in the great bend of the Kootenai. The section south of the boundary is divided into three subdivisions by Mooyia (west) and Yaak (east) rivers. Five miles south of the international boundary the westernmost range is crossed by a remarkably flat-bottomed, low-grade valley or trench, one of the many of its kind in the region. The crests of the ridges are comparatively even in height and have no conspicuous peaks. The mountains occupying the interstream area between the Mooyia and Yaak rivers are for the most part of gentle profile and are heavily wooded except where they have been swept by forest fires. The main divide is a rocky ridge bearing Mount Ewing just south of the boundary, besides a group of jagged summits (7500) at the southern end of the chain.[2] The easternmost mountain ridge has the same general character as the main central ridge west of it.

Among the other mountain ranges of the boundary section of the northern Rockies are the Pend Oreille on the west and the Flathead and the rugged Mission ranges on the east. These mountains have not been explored to any extent and generalizations concerning them would be too broad to be of any practical value. The easternmost ranges of the region are the Lewis and Livingston ranges, which form the sharp western boundary of the Great Plains. These have been studied with more care than the ranges west of them and may be discussed in greater detail.

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[1] Calkins and McDonald, A Geological Reconnaissance in Northern Idaho and Northwestern Montana, Bull. U. S. Geol. Surv. No. 384, 1909, p. 15.

[2] Idem, p. 16.

LEWIS, LIVINGSTON, AND GALTON MOUNTAINS

The Lewis and Livingston mountains in western Montana constitute the front ranges of the Rocky Mountains in that state and a part of the adjacent province of Alberta. They consist in the main of stratified rocks of Algonkian age; igneous rocks occur but sparingly. The strata are disposed in the form of a broad, northward or northwestward trending, well-defined syncline between two marginal and poorly defined anticlines. The northeastern margin — the Lewis Mountains — fronts the Great Plains; the southwestern margin — the Livingston Mountains — is in part eroded, and in part downfaulted by a normal fault (North Fork Valley). The valleys and ridges of both ranges are closely related to the syncline and anticlines thus defined.

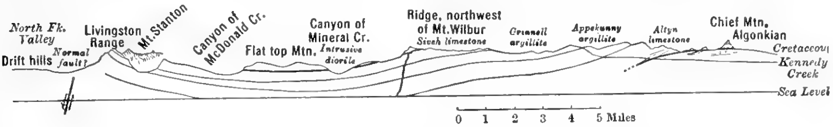

Fig. 91. — Topographic and structural section across the front ranges in Montana. (Willis.)

The eastern border of the Lewis range is an overthrust fault; Algonkian strata have been moved northeastward over Cretaceous strata on the plane of the fault; the displacement on the thrust surface is not less than 7 miles, and the vertical movement is estimated at 3400 feet or more. It is to the upward movement on the fault plane that the Lewis Range owes its present elevation above the Great Plains, and, to a large degree, the abruptness of its eastern border.[1]

The eastern margin of the Lewis range is deeply sinuous and is marked off from the Great Plains by cliffs of prodigious size. The crest of the range is everywhere narrow and in many places is "a knife-edge of jagged rocks." The precipices are frequently more than 1000 feet high and in some instances have an altitude of 4500 feet, with a slope that is nowhere below 50°, Fig. 92. These cliffs are the walls of profound amphitheaters which enclose small mountain basins commonly occupied by lakes. The elevations of the highest summits range from 8500 to

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[1] Bailey Willis, Stratigraphy and Structure, Lewis and Livingston Ranges, Montana, Bull. Geol. Soc. Am., vol. 13, 1902, pp. 307–308.

The eastern border of the Rocky Mountains near the common border of British Columbia and Alberta is also marked by the presence of a great overthrust fault, the continuation northward of the fault at the eastern border of the Lewis Mountains. It runs north by west as indicated on the map of part of Alberta and British Columbia by Dowling. (D. B. Dowling, Cretaceous Section in the Moose Mountain District of Southern Alberta, Bull. Geol. Soc. Am., vol. 17, 1906, pp. 295–302.)

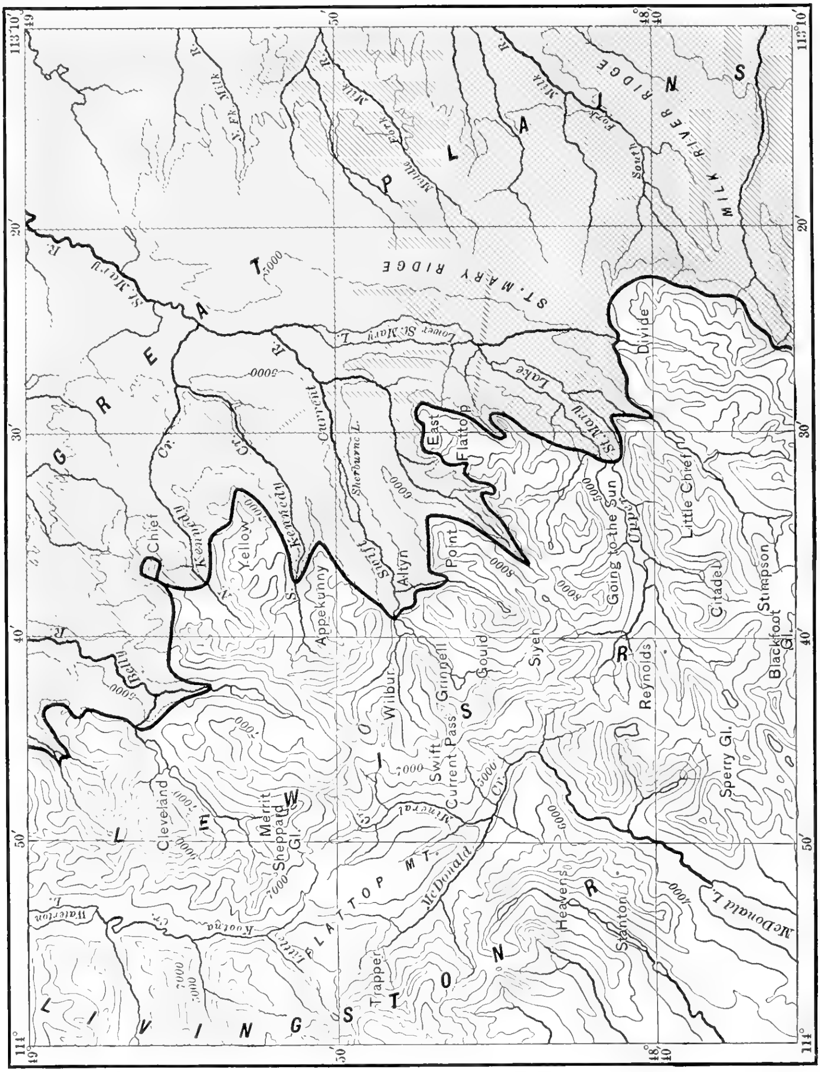

Fig. 92. — Map of Great Plains and front ranges, western Montana. Heavy black line indicates the outcrop of the Lewis thrust plane.

10,400 feet; the elevations of the wind gaps are from 5400 to 6000 feet.

The Livingston range extends from Mount Heavens north of McDonald Lake northwestward to Mount Head in British Columbia. It lies west of the Lewis range in the United States, but the latter range ends near the international boundary and in Canada the front range is

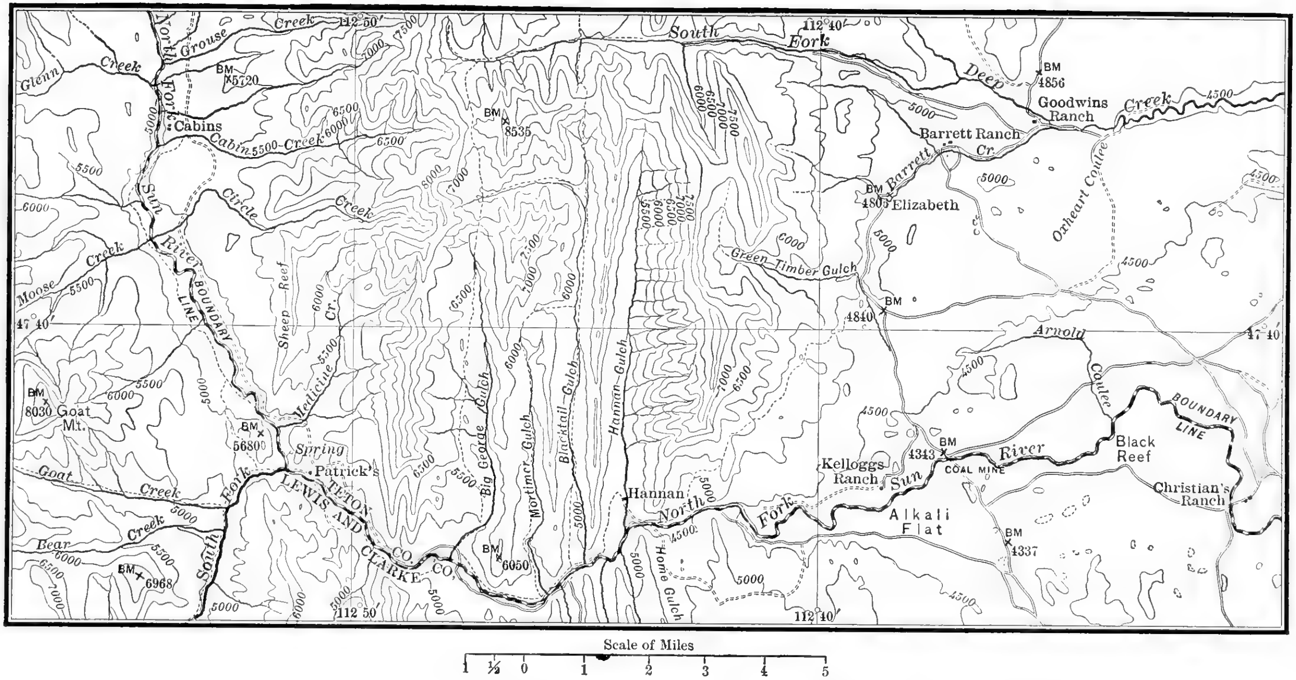

Fig. 93. — Hogback type of mountains border, Lewis and Clarke National Forest, Montana. Contour Interval, 500 feet. (Saypo quadrangle, U. S. Geol. Surv.)

the Livingston. The main continental divide follows the Livingston range for some distance southward of the boundary, descending to Flat Top Mountain and finally to the Lewis range, which it follows southward to latitude 46° 45′. Like the Lewis range the Livingston is often narrow and presents massive mountain peaks of pyramidal outline. Deep valleys diversify its western slope and contain long narrow lakes which vary in length from two to ten miles. The lakes are bordered by slopes of gravel or talus, except at their heads, where cliffs rise precipitously to the range summits. The western limit of the Livingston Mountains is definite, but it has the aspect of a bold mountain face rising from foothills rather than the almost sheer face of the eastern margin of the Lewis Mountains rising abruptly from the plains.

The Lewis and Livingston ranges are characterized by the dominant influence of structure on altitude. In the northern part of the Lewis range and in the Livingston range the greatest altitudes are in general related to the two anticlines; the master valleys are in the intervening syncline, and Flat Top Mountain is the former floor of a broad synclinal valley. A peneplain was formerly developed over the Great Plains and over the Galton range. On the soft rock of the plains it was well developed, but on the harder rocks of the Galton Mountains it was probably imperfect. In the Lewis range it is notable that each peak approaches in height that of its neighbors which stand along the strike in a similar structural position. However in a broad view and taking the Lewis and Livingston ranges as a unit, no general upper limit of heights common to widely distributed peaks may be discerned. If the base-leveled surface was ever in existence in the range, the extreme localized deformation of the mountains has so warped the ancient surface, and intense erosion by both water and ice has so completely dissected it, as to make its determination very difficult if not impossible.

It is truly remarkable how abruptly the well-developed and but little dissected peneplain of the Great Plains of Montana terminates at the foot of the front ranges. The line is almost as definite as a shore. The long-continued erosion which the peneplain represents must have affected the present mountainous area west of it, but was probably offset by repeated deformation terminating or culminating in the great overthrust to which the present mountain height and the deep dissection are largely due. In the Galton range the old surface may be safely inferred; the older features have not been so completely destroyed owing to the relatively small amount of local deformation and the less intense action of water and ice. For the Galton range, although bounded by

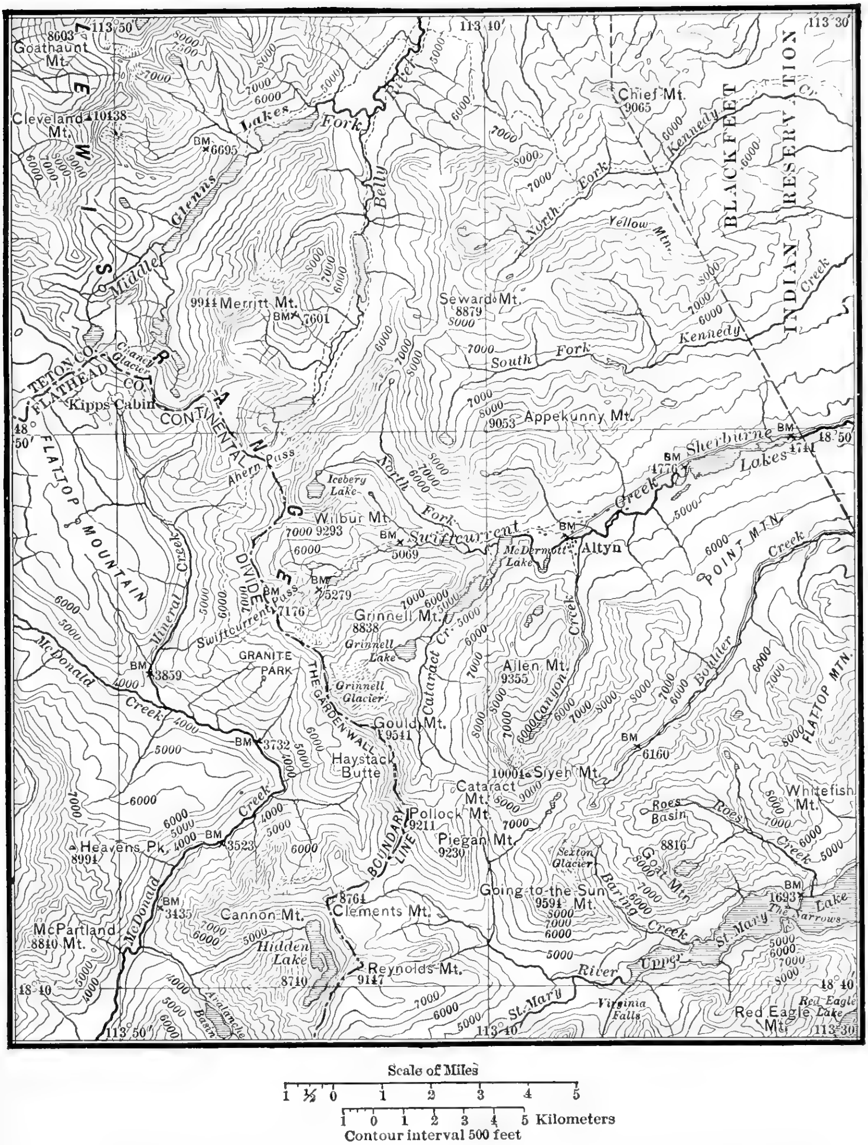

Fig. 94. — Map of a part of the Lewis Mountains, western Montana, representing typical glacial features of the range. (Chief Mountain quadrangle, U. S. Geol. Surv.)

structural limits, is internally but a simple uplifted block whose minor flexures or faults are not sufficiently pronounced to interrupt the ancient surface.

GLACIAL FORMS

Some of the most remarkable erosion features produced by alpine glaciers are to be found in the Lewis range on the continental divide in western Montana. They are represented on the Chief Mountain quadrangle, Montana, Fig. 94, one of the most interesting topographic sheets yet published, not only because of the exceptional nature of the region but also because of the unusual faithfulness with which the topographer has represented the landscape. The strata of the Lewis Mountains are strongly jointed, a quality which is highly favorable to the plucking action of glacier ice; furthermore they lie nearly flat and boldly overlook the adjacent plains: a set of conditions exceedingly favorable for the development of glacial forms on an unusual scale.

Three major topographic features are apparent in the region: (1) numerous reversed slopes occupied by lakes and lakelets; (2) strikingly deep wall-like valley sides; and (3) huge amphitheatral valley heads in which a number of living glaciers are to be found. All these features are normally associated with the work of alpine glaciers whose former existence in large numbers has also been determined by the familiar phenomena of eroded and plucked rock surfaces, terminal and lateral moraines, and hanging tributary valleys. Former glaciers plowed down all the main valleys and built up morainic accumulations which at Blackfoot and Browning, p. 412, merge into the terminal deposits of one of the great continental ice sheets.

An examination of the valley systems in plan shows a remarkable degree of headward cutting on the part of the glacier ice. The amphitheatral valley heads or alcoves on opposite sides of a divide have in many instances cut back to the point where a knife-like ridge has been formed, as south of Gould Mountain and on the continental divide two miles south of Chaney glacier. The process has resulted in the formation of pyramidal mountains such as Going-to-the-Sun Mountain, Cataract Mountain, Little Chief Mountain, Heavens Peak, and others, or in the formation of skeleton mountains of irregular outline such as Almost-a-dog Mountain, Appekunny Mountain, and Merritt Mountain.

The manner in which such headward cutting has taken place has been well set forth by Johnson,[1] who has observed that in glaciated mountains the great curving bergschrund of the snow-field penetrates to the foot

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[1] W. D. Johnson, The Profile of Maturity in Alpine Glacial Erosion, Jour. Geol., vol. 12, 1904, pp. 569–578.

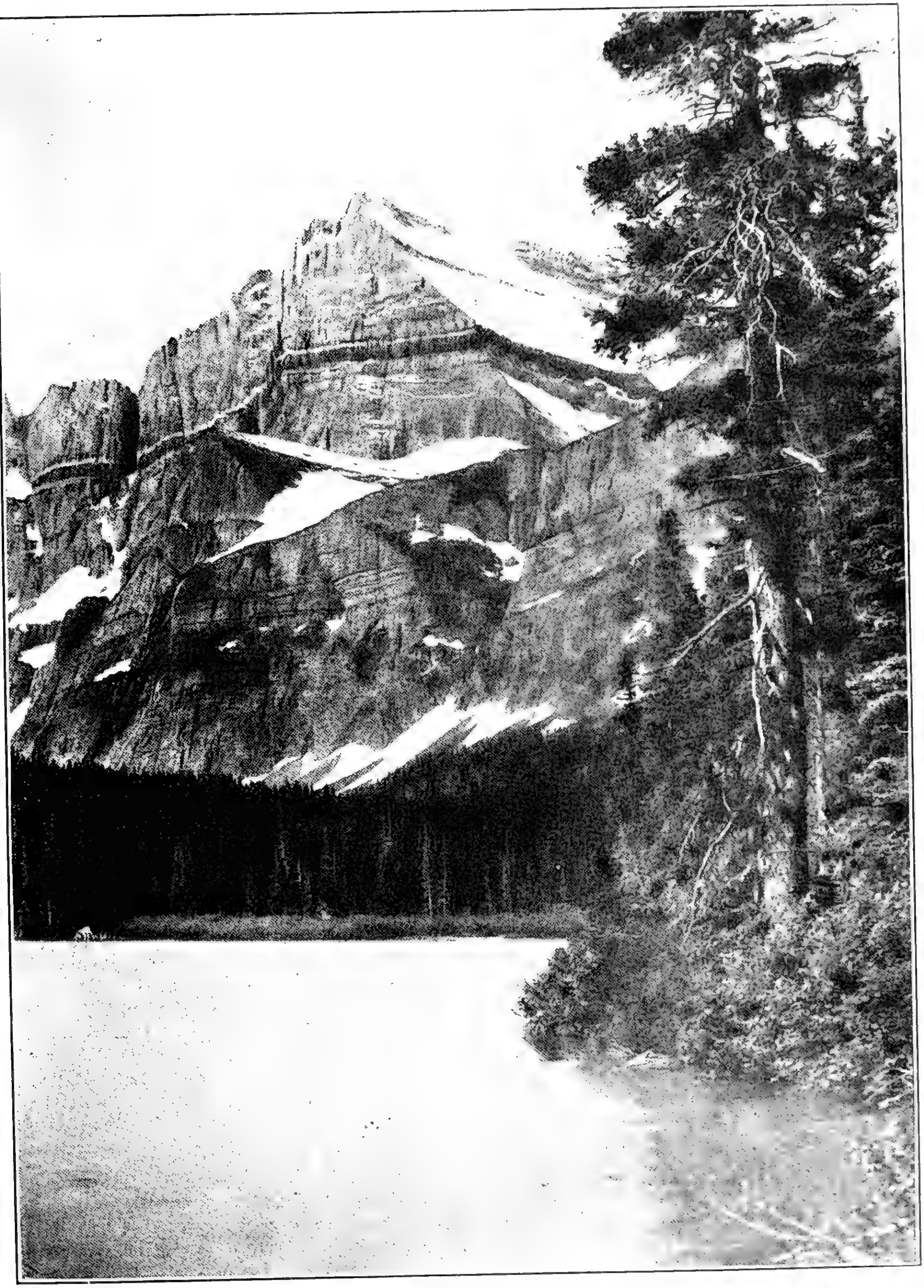

Fig. 95. — Mount Gould, Lewis Range, Montana, looking southwest from South Fork of Swift Current. See Fig. 80 for location. Characteristic cliff of limestone overlooking argillite. The dark band is intrusive diorite. The valley head is a glacial amphitheater developed along joint planes. It is 4070 feet from lake to summit. (Willis.)

of the precipitous rock slope constituting the wall of the amphitheater enclosing the snow-filled cirque. He concludes that a causal relation determines the coincidence in the position of the bergschrund and the foot of the cliff wall. The opening allows air to come into contact with both ice and rock at the bottom of the crevasse. By day there is thawing, by night freezing, and blocks of rock are wedged off and the cirque wall riven. The bottom of the crevasse is therefore a "narrow zone of relatively vigorous frost-weathering." The result is a sapping of the foot of the cirque wall and its gradual steepening and retreat.

The continuance of this action steepens the slopes of the glacial amphitheaters and pushes them back until the slopes on opposite sides of the divide meet. Thus a more or less rounded divide such as may be found a few miles southwest of Point Mountain, at Flat Top Mountain, and other places, was destroyed, the mountain top was reduced to a pinnacle or needle and the divide to a sharp crested arête. It is this action which appears to have taken place in the Lewis range, and to the varying degrees to which the basal sapping was carried may be attributed the variation of mountain forms ranging between pinnacles on the one hand and flat-topped mountains with small bordering cirques on the other. An extreme case of such extension of headwater amphitheaters may be seen in the Hayden Peak quadrangle representing a portion of the Uinta Mountains of Utah. In this case the amphitheatral walls have been pushed back to the point where only skeleton ridges remain, and in one instance at least, as west of Hayden Peak, the divide has been almost completely obliterated, so that the snow-fields on opposite sides must have been confluent during the glacial period.

It may readily be inferred from these considerations that cirques may be (*a*) but slightly developed and the present expression of the mountains closely resemble the preglacial expression; or (*b*) they may be so extensively developed that the upland or mountain region in which they were formed has a fretted appearance; or (*c*) the cirques may be developed headward to a still greater extent and the dividing ridges trimmed to a row of serrate peaks or skeleton ridges. Further contrasts in the present characters of the cirques will depend upon the amount of postglacial cutting or filling that has taken place. Most cirques as left by the ice contain but little loose material. Whether or not loose material is now present will depend upon the friability of the rock, the steepness and height of the cirque walls, the precipitation, etc. In the Lewis Mountains the cirques are especially well preserved and still exhibit, Fig. 94, great expanses of little-modified cirque wall, lakes of considerable size and number, and expanses of bare, glaciated rock.

Concentrated sapping at the foot of the cirque wall results not only in headward retrogression but also in downward excavation, and with the melting of the glacier on account of a warmer period the reversed slope at the foot of the cirque wall is occupied by a lake. It will be noted on the Chief Mountain sheet, Fig. 94, that lakes commonly occur in this position. Lakes are also commonly found some distance down valley where tributary glaciers have caused local overdeepening or the bottoms of the glacial channels and the production of reversed slopes back of which the present drainage is impounded. A third group of lakes is frequently found some distance down valley where the drainage has been blocked by morainal accumulations that mark the former limit of glacial ice.

The valley sides and bottoms in this region usually bear one, two, or more terraces. The lower ones represent a valley filling which the streams are at present cutting away. The higher ones represent interrupted valley widening in horizontally bedded rock.[1]

The mountain valleys of these ranges are all noted for their steep walls and lake-dotted and rather flat floors. Their forms are chiefly the result of earlier glacial action. The main glaciers were wide and thick and eroded their channel floors below the channel floors of their tributaries. Upon the disappearance of a glacier the former glacial channel became a large part or all of the present valley. Hence the characteristic features of the glaciated valleys and the hanging condition of their tributaries. (See Figs. 96, 97, and 98.)

GALLATIN, MADISON, JEFFERSON, AND BRIDGER RANGES

In southwestern Montana is a group of mountains whose most important members are the Gallatin, Madison, Jefferson, and Bridger ranges. A small part of the southern end of the Madison range and the greater part of the northern end are composed of gneiss. The central part of the range is an immense laccolith, the uplift due to intrusion having carried portions of the sedimentary rocks almost to the summit of the range and overturned, broken, and changed the strata along the western and northwestern edges of the range, causing a varied and highly irregular topography. The Jefferson range consists in the north largely of granitic rocks. The southern section is divided into two parts; the eastern is plateau-like in character, the western is a monocline in which the sedimentary rocks are overturned to greater or lesser degrees from place to place. The Bridger range also consists of three sections, the southern extension being an overturned monocline of stratified beds that rest upon gneisses which form the western spurs and foothills and also a large part of the main moun-

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[1] Bailey Willis, Stratigraphy and Structure, Lewis and Livingston Ranges, Montana, Bull. Geol. Soc. Am., vol. 13, 1902, p. 310.

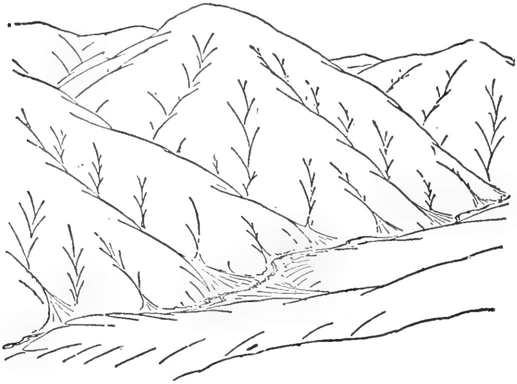

Fig. 96. — A normally eroded mountain mass not affected by glacial erosion. (Davis.)

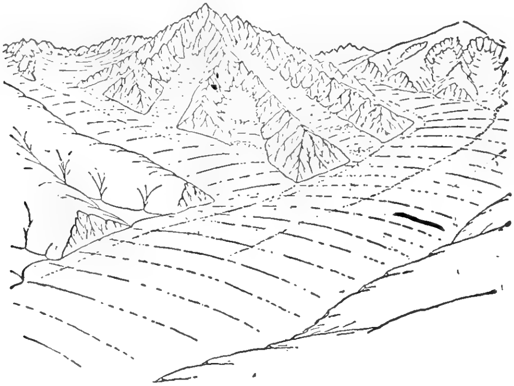

Fig. 97. — The same mountain mass as in Fig. 96, strongly affected by glaciers which still occupy its valleys. (Davis.)

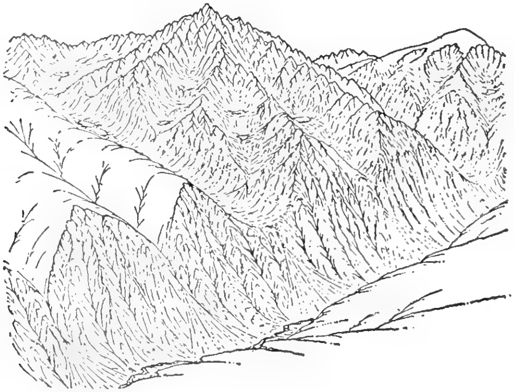

Fig. 98. — The same mountain mass as in Fig. 97, shortly after the glaciers have melted from its valleys. (Davis.)

tain mass. The overlying stratified beds form a sharp crest with peaks. The central portion of the range is composed chiefly of sedimentary beds and gneisses are absent. The northern section is also composed of stratified beds of sandstones, shales, and limestones which curve around the ends of the range.

The Gallatin range is plateau-like at its summit and is composed largely of volcanic breccias which dip eastward and have their greatest elevations, about 10,000 feet, along the western border. Mount Blackmore, one of the most prominent peaks of this range, rises to a height of 10,196 feet.

During the general elevation of the region in which these mountains occur the strata were folded and eroded (Cretaceous) and lakes, some of them of great extent, were formed in enclosed fresh-water basins. The lake period lasted for a long time (Neocene to Pleistocene), and during the earlier part of the period there was tremendous volcanic activity. Great quantities of volcanic dust were carried hither and thither by the winds and at length deposited in part on the lake floors as white dust beds; deposition of vast amounts of dust took place upon the adjacent land surfaces, whence the deposits were later washed in large part into the lakes. Later cutting down of the lake outlets allowed these water bodies to become drained and the lake beds themselves to be dissected. The last phases of volcanic activity in the region were flows of basalt and rhyolite, and these now form the summits of mesas, as in the southern part of the Three Forks district.[1]

The last geologic episode which has had an influence on the topography and drainage of the district has been glaciation, but the glaciers were local and the drift deposits in the valleys are of local origin. The low elevation of the ranges, 7000 to 10,000 feet, did not allow vigorous glaciation, and glacial forms have weak expression except in a few favorable localities.

MINOR RANGES OF WESTERN MONTANA

In western and southwestern Montana is an extensive area hemmed in by the Madison, Jefferson, and other ranges on the south and the Lewis, Livingston, and other ranges on the north. On the east it extends to the Big Belt Mountains, on the west to the Bitterroots, Fig. 86. The tract includes no prominent mountain chains, only short ranges which reach up to a more or less common level. The geologic conditions are somewhat complex, the rocks consisting of greatly deformed sedimen-

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[1] A. C. Peale, Three Forks Folio U. S. Geol. Surv. No. 24, 1896, p. 1, col. 4.

Fig. 99. — Effects of slope exposure on forest distribution, western Montana, looking east from Mt. Belmont; see topographic map below. A and C are cool, moist, forest-clad northern exposures, B and D are warm, dry, unforested southern exposures. The trees in the foreground grow on a northeastern exposure. For the position of these slopes on the map see corresponding letters in Fig. 100. (Barrell, U. S. Geol. Surv.)

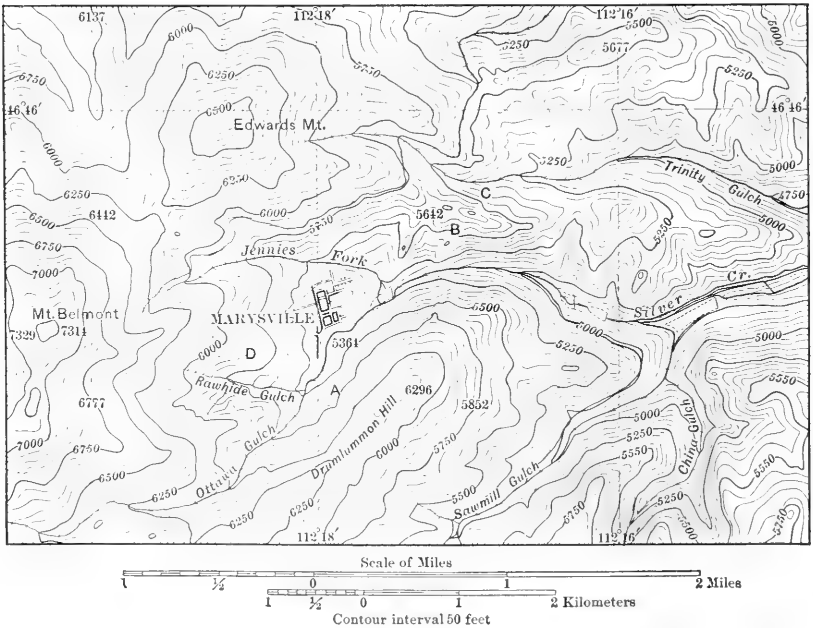

Fig. 100. — The positions of the letters A, B, C, D, on the map correspond to the positions of the same letters on the photograph. Culture omitted except in case of Marysville.

taries intruded by granite and other igneous rocks. After the deformation of the rocks of the region erosion swept away great quantities of the surface material and reduced the topographic profiles to maturity, Fig. 99.

From the standpoint of forestry this great district in western Montana is of special interest because of the strong topographic control of forest distribution, not by control of rainfall distribution but by control of the water supply through variations in slope exposure. Its special significance may be appreciated by contrast with the physical conditions in the Cascades. The western slopes of the Cascades are wet, the eastern slopes are dry, a rainfall distribution that is directly dependent upon topography and that has a marked effect upon the distribution of the forest trees (p. 164). Among the minor ranges of Montana, on the other hand, there are no great topographic features to obstruct the rainfall and to occasion the climatic contrasts so marked in the Cascades. Slope exposure is here the factor of primary importance in forest distribution. The rather evenly distributed rainfall is more quickly evaporated on the sunny southern slopes than on the shady northern slopes, hence the latter are moist and forest covered, the former dry and almost treeless. Since the daily maximum temperature of soil and air is generally attained about two or three o'clock in the afternoon, the driest slope is the one facing southwest. Hence eastern and northeastern slopes are also forested, while western slopes are forestless. The effect of these conditions is heightened by the action of the prevailing southwest winds which not only dry the southwest slopes but also sweep them clear of snow in winter. The snows accumulate on the northeastern or leeward slopes, where they linger until midsummer and supply the ground and the vegetation it supports with the necessary moisture. These features are exceptionally well developed about Marysville and the district therefore merits a somewhat detailed description.

In the Marysville district the Rockies are developed in the form of a broad tract extending westward nearly to the Bitterroot Mountains. The eastern portion is a rather flat-topped granite batholith. The entire district has the features characteristic of topographic maturity — "fairly steep slopes, rounded hill crests, and few cliff exposures. On the lower elevations the topography is . . . softened, the view showing successive tiers of well-dissected foothills with slopes of 10° to 20°."[1] The surface is in general covered with a residual soil so thin on the upper slopes as to show a large number of rock outcrops especially on

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[1] J. Barrell, Geology of the Marysville Mining District, Montana, Prof. Paper U. S. Geol. Surv. No. 57, 1907, p. 4.

the more resistant formations. The lower elevations are covered with a slightly deeper soil, while the main valley floors are deeply filled with alluvium.

The Marysville region is in the transition belt between the lower, drier Great Plains on the east and the higher, abundantly watered and forested mountains on the north and west. While the soil covering, though thin, is suitable for a forest growth, the rainfall and snowfall are so light as to support a forest only in favored situations. Marked contrasts in climate occur and are due to marked variations in elevation and exposure. The result is a striking contrast in vegetation on different slopes and at different elevations, Fig. 99.

"The trees are confined largely to the northern and eastern slopes, since these suffer least from the drying action of the summer sun on the thin soil and also in spring hold the snow longest around the roots. The prevailing winds are from the southwest, with the result that the southwestern slopes are swept more or less bare of snow, which accumulates on the leeward side of the hills. Here, protected by the evergreen trees, stray banks linger until about the first of July.

"The bottoms of the deeper gorges are especially picturesque, offering the contrast of dark, forested southern[1] or western walls and grassy northern slopes, while cottonwoods and willows grow in clumps and lines along the courses of the streams.

"On the northern hill slopes the trees continue down to elevations of about 5000 feet, the limit varying considerably with the nature of the soil. Below this level the low hills of the northern half of the district are bare of trees and almost without grass, but in the gulches which trench them scattered pines have found enough moisture to give them a foothold. On the lowest levels the prickly pear and bunch grass hold sway. The most desolate portion of the district is north of Little Prickly Pear Creek, for here the sandy, porous nature of the surface renders it doubly difficult for vegetation to maintain a foothold, and large areas are covered with nothing but shaly shingle or ancient river cobbles."[2]

MOUNTAINS OF NORTH-CENTRAL IDAHO

The mountain ranges of the northern Rockies that we have examined thus far lie chiefly east of the Bitterroot axis. An examination of Fig. 86 will show a vast mountain region north of the Snake River and west of the Bitterroots, a labyrinth of sharp peaks and ridges whose steep slopes descend to deep steep-sided canyons. As a rule the mountains rise suddenly from the bordering plains and ultimately to sharp ridges that attain 11,000 and even 12,000 feet.

The origin and nature of a large portion of this wild mountain region may be appreciated best from a view that embraces the contrasting features of the plains country formed upon the flat basalt sheets that rim about the margins of the mountains and extend far westward into Washington, as far as the eastern wall of the Cascades. The summit of Bald

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[1] It should be remembered that the southern wall of a valley has the same slope exposure as the northern slope of a hill.

[2] Idem, p. 6.

Mountain near the common border of the two regions (lat. 46° 25′) affords an extensive view eastward over the level crests and maze of ridges and canyons that constitute the principal features of the Clearwater Mountains (lat. 46°). So thoroughly dissected are these mountains that little of their original flat outline may now be seen. For the first 80 miles eastward toward the Bitterroot Valley the lonely trail does not disclose a settlement or even a miner's cabin.[1] The irregular canyon courses are the chief routes for transportation by pack mule. It is the worst part of the Kentucky and West Virginia "mountains" set upon the western fringe of the Rockies.

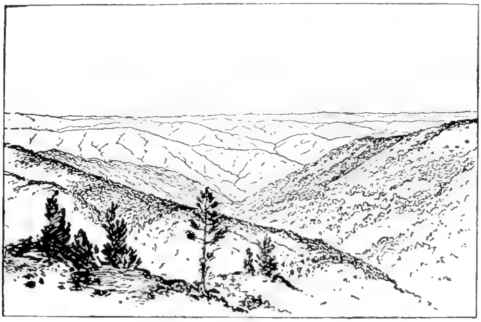

Fig. 101. — View south across Salmon River Canyon, from south slope of Caseknife Mountain, showing plateau character of Salmon River Mountains. (Lindgren, U. S. Geol. Surv.)

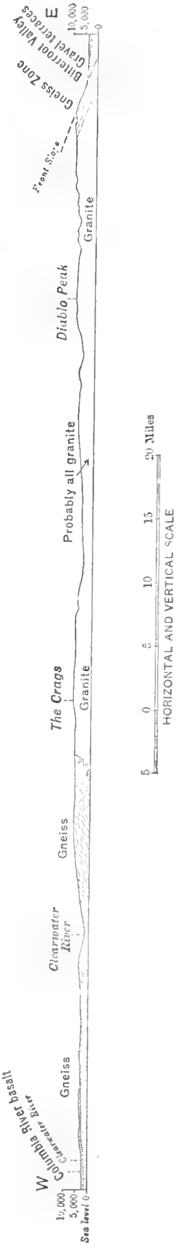

Fig. 102. — Profile across Bitterroot Mountains, Clearwater Mountains, and Columbia Plateau, showing the plateau quality and the rock character. (Lindgren, U. S. Geol. Surv.)

Four thousand feet below the level of Bald Mountain is a scene of far different quality. The lava plain of the Columbia, only gently undulating, stretches out apparently without limit westward. The undulating Camas and Kamiah prairies are checkered with waving wheat fields or wild grass, and cultivation and prosperity are brought into close contact with mountain wilderness.

Here we have two regions of great difference in relief but also with many features that indi-

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[1] W. Lindgren, A Geological Reconnaissance across the Bitterroot Range and Clearwater Mountains in Montana and Idaho, Prof. Paper U. S. Geol. Surv. No. 27, 1904.

cate peculiar similarities. The basalt plain is comparatively flat to-day; once it was still flatter; as time goes on it will become more and more irregular, will become indeed very much like the Clearwater Mountains are to-day. The even accordance of hill and ridge top levels in the Clearwater Mountains and the manner in which the plane of the ridge tops cuts across rock of diverse hardness and structure are clear indications that the region was once base-leveled and has since that time been uplifted and maturely dissected so that flat land is nowhere visible. Dissection has progressed so far that the once flat tabular summits have been transformed into sharp ridges, but it has not yet progressed far enough for the rivers to have begun to form valley flats. The result is a typical hill-and-valley country, whose resources of forest and mine are difficult of access, and where agriculture and related industries are practically unknown.

The sudden descent of the Clearwater Mountains to the level of the lava plain is due not to differential erosion but to pronounced crustal warping or faulting, for there are no structural features that would enable erosion to work out a mountain border of this character. The sudden and notable descent from the level of the plateau to the level of the plain was brought about probably at the time of uplift, for deep canyons were cut following the uplift and before the extrusion of the lava (Miocene) that runs up the old valleys now extending westward under the lavas. A similar abrupt border characterizes the plateau of the Boise Mountains where these descend to the lower valley of the Snake River. About the western base of the Clearwater Mountains the basalt flooded the foothills to a height of 3000 feet and greatly reduced the relief of the region, for the foothills in many cases had a sharply accentuated topography. Above the level to which the lava rose the courses of the streams draining the Clearwater Mountains have been steadily deepening.[1]

Both the Clearwater and the Salmon River mountains are portions of a once gently undulating plateau that has been so deeply eroded by powerful streams that they stand out with great distinctness. The plateau which their crests outline is from 1000 to 3000 feet below the summit of the Bitterroot Mountains, causing the latter to appear as a boldly raised block.[2]

Throughout the mountain region of central Idaho the canyons are so deep and steep-sided that many of them are quite impassable.[3] The

[1] W. Lindgren, A Geological Reconnaissance across the Bitterroot Range and Clearwater Mountains in Montana and Idaho, Prof. Paper U. S. Geol. Surv. No. 27, 1904, p. 78.

[2] Idem, p. 13.

[3] G. H. Eldridge, A Geological Reconnaissance across Idaho, 16th Ann. Rept. U. S. Geol. Surv., pt. 2, 1894–95, p. 220.

canyon walls are precipitous, sheer drops of 1000 feet being quite common, and the adjacent mountain slopes rise by steep ascents 2000 to 3000 feet higher. The most rugged canyons are those of the South Fork of the Boise River, numerous branches of the Clearwater, and the Middle Fork of the Salmon. A stream with typical characteristics is the Salmon River, which heads at the foot of the Bitterroot range, then flows westward through a wide open valley to a point near Shoup, where it enters a profound canyon through which it flows without interruption for about 250 miles to its junction with the Snake. The canyon extends through one of the wildest and least-known parts of the state, and is itself so narrow and abrupt and so deep (3000 to 5000 feet) as to be almost untraversable.[1]

The mountainous country north of the Snake River and west of the Bitterroot divide may be divided on the basis of structure into three parts:

(1) A great central granite area 100 miles wide and 300 miles long, extending from the Snake River plains northward to an unknown distance but at least as far as 45° 30′; it probably ends near the northern border of the Clearwater drainage.[2]

As thus outlined it forms one of the largest granite batholiths on the continent. Near the lower Salmon River and also near the Seven Devils in the Snake River Valley it is margined by sedimentary rocks. A similar contact occurs on the eastern border of the granite, and from the nature of the intruded beds it is known that the granite mass is probably of Cretaceous age and is an intrusive body similar to the great granitic batholiths of the Sierra Nevada. The granite is remarkably uniform in character except in places upon its margin as on the eastern border of the Bitterroot Mountains where it has a gneissoid structure owing to metamorphism at the time of the formation of the range.[3]

(2) Partly metamorphosed rocks of sedimentary origin — slates and limestones accompanied by schists — occur on the western border of the granite area and form the western border of the mountains.

(3) Partly metamorphosed rocks — quartzites, conglomerates, slates, shales, and limestones — occur on the eastern margin of the great granite batholith.[4]

Two types of mountains have been developed upon these rocks and structures: (1) those consisting of masses of rock without any definite range trend and developed upon the almost structureless granite of

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[1] W. Lindgren, The Gold and Silver Veins of Silver City, De Lamar, and Other Mining Districts of Idaho, 20th Ann. Rept. U. S. Geol. Surv., pt. 3, 1898–99, p. 78.

[2] W. Lindgren, A Geological Reconnaissance across the Bitterroot Range and the Clearwater Mountains in Montana and Idaho, Prof. Paper U. S. Geol. Surv. No. 27, 1904, p. 17.

[3] Lindgren and Drake, Silver City Folio U. S. Geol. Surv. No. 104, 1904, p. 1, col. 4.

[4] W. Lindgren, The Gold and Silver Veins of Silver City, De Lamar, and Other Mining Districts in Idaho, 20th Ann. Rept. U. S. Geol. Surv., pt. 3, 1898–99, pp. 79, 86–89.

homogeneous texture. The Clearwater Mountains north of the Salmon River and the Salmon River Mountains south of the Salmon River are the best representatives of this type. The second type of mountain occurs in ranges and is the result of erosion of sedimentary rock and foliated schists, or a rock complex, whose secondary structures on erosion give a rough trend to the elevated portions.

In some of the granites of the western half of Idaho east-northeast-trending structures show chiefly in lines of jointing, in the strike of foliation planes, or in the trend of the fissures. West of the Sawtooth range the divides between the drainage basins are with few exceptions due to early structural features — folds, faults, joints — but over most of the tract the granite is homogeneous, the structural features are only slightly pronounced, the disposition of the topographic elements is a response to the disposition of the early drainage systems, and no well-defined outlines of a range system can be identified.[1]

The irregular ranges that rise above the general level as in the Sawtooth Mountains seem to owe their existence to greater resistance to erosion rather than to folding and faulting. A few exceptions to this rule are (1) Boise Ridge, which seems to have been partly outlined by orographic disturbances, and (2) smaller ranges which have been developed where the granite is strongly foliated.

The mountains of the range type occur chiefly in the eastern part of Idaho near the continental divide in a region of pronounced uplift. They trend in two different directions, east-northeast and west-northwest, depending upon the strike of the beds upon which they are developed. They are composed of altered or unaltered quartzites, schists, and limestones. The Smoky Mountains are an illustration of this type; the Bitterroots are a larger and better known unit and receive more extended description in the succeeding paragraphs.

BITTERROOT MOUNTAINS

From Hamilton or Missoula in the Bitterroot Valley and in the heart of the northern Rockies one may look west at the bold front of the Bitterroot Mountains. For many miles it maintains a quite remarkable regularity of form and straightness of trend. The slope descends at angles between 18° and 26°. The rectilinear quality is owing to a fault whose locus is the foot of the scarp and whose throw approximates the present difference in elevation between range top and valley bottom.

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[1] W. Lindgren, The Gold and Silver Veins of Silver City, De Lamar, and Other Mining Districts in Idaho, 20th Ann. Rept. U. S. Geol. Surv., pt. 3, 1898–99, p. 77

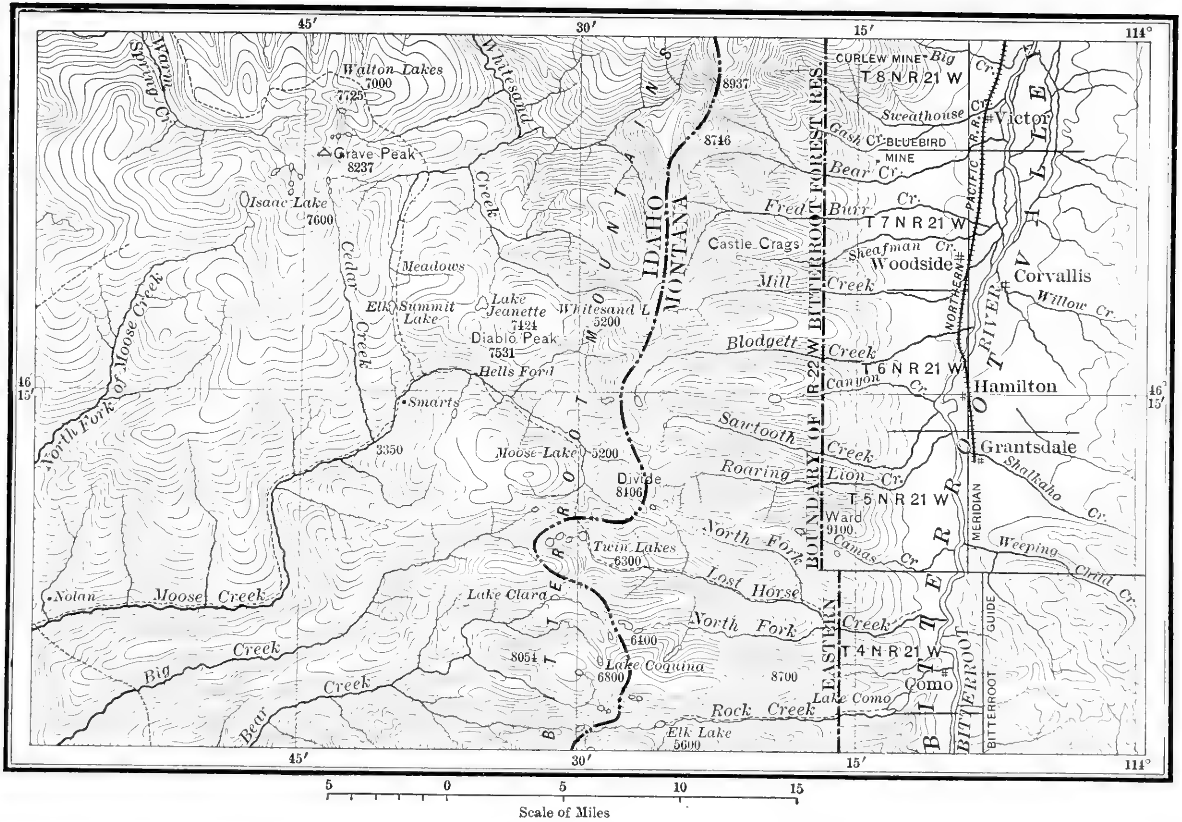

Fig. 103.— Topographic map of a part of Bitterroot Mountains, Idaho and Montana. Sketch contours only, about 300 foot interval. (Lindgren, U. S. Geol. Surv.)

At least two groups of facts strongly support this explanation. (1) Faulting occurred in the region so recently as 1898, when for 1500 feet along the base of the mountains a displacement of from 1 to 2 feet was effected and may be observed in favorable localities to-day. (2) All the streams flowing eastward down the regular mountain front have remarkably straight courses, and all have steepened gradients in the last mile or more before debouching upon the valley flat bordering the Bitterroot River. The steepened gradients are an expression of progressive faulting which has prevented the attainment of a profile of equilibrium, approach to such a profile being counteracted by a repetition or continuance of faulting.[1]

The remarkable regularity of the eastern slope of the Bitterroot Mountains is the more interesting because of the preservation of the fault plane throughout the slope up to the eastern summit, a fact which appears to be explained by the flat angle at which the slope was formed, the uniform character of the crystalline rock (gneiss and schist) composing the eastern front of the range, and the original regularity of the fault.

The main divide of the Bitterroots is a succession of sharp craggy peaks alternating with deep saddles at the heads of the large canyons where glacial cirques have opened up the valley heads. The western slope is more rugged than the eastern, although even the latter is almost unknown except to prospectors. The immense steep-sided gorges, sheer precipices, and extensive rock slides make the western slope entirely impassable toward the crest.[2] The trails, originally located by the Indians, follow the divides or primary ridges as closely as possible, tortuous as they are; only grading would make the canyons passable.

CLIMATIC FEATURES; VEGETATION

The character of the primeval forest of northern Idaho and northwestern Montana varies according to latitude, altitude, and conditions of exposure. The size of the trees decreases toward the north; on the slopes of the Cœur d'Alene Mountains it is not uncommon to find trees 2 or 3 feet in diameter, while tamarack, spruce, and lodgepole pine along the international boundary are seldom more than 1 foot in diameter. The valley terraces along the principal rivers support large groves of yellow pine and tamarack, almost without underbrush. The moun-

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[1] W. Lindgren, A Geological Reconnaissance across the Bitterroot Range and Clearwater Mountains in Montana and Idaho, Prof. Paper U. S. Geol. Surv. No. 27, 1904, p. 49.

[2] J. B. Leiberg, Bitterroot Forest Reserve, 20th Ann. Rept. U. S. Geol. Surv., pt. 5, 1900, p. 319.

tain slopes have a denser cover of fir, spruce, and tamarack, which with increasing elevation becomes an open growth of spruce, with a luxuriant cover of grass. Snow does not persist throughout the year upon any of the slopes much exposed to the direct rays of the sun, though perennial banks form on the steep northward-facing sides of the higher peaks and one or two small glaciers occur in the Cabinet range. There is a wet and a dry season, the latter beginning about October 1, the former about June 15, and the summers are very mild and agreeable. The mountainous part of northern Idaho and northwestern Montana has a thin population engaged in lumbering, agriculture, and mining.[1]

The vegetation of the mountainous area immediately north of the Snake River plains consists of forests of fir and pine, above an elevation of 5000 feet and gradually increasing in luxuriance northward. The southern foothills of the main mountain area below 5000 feet are barren. The agricultural population of the Snake River Valley is concentrated chiefly where the tributaries issue from the mountains and on the limited flats along the main river, where irrigation is possible. Besides these plains settlements are others in the intermontane valleys on the Weiser, Payette, and upper Salmon. Scattered mining settlements are also found from south of the mountains to Florence, and from the Seven Devils to Challis. Many of them are in places very difficult of access and at elevations ranging from 4000 to 8000 feet.

In the Bitterroots the soils of the mountain slopes are composed of granite débris below and loam above; in the canyon bottoms similar conditions obtain, but the top layer is usually heavier; in the subalpine meadows the subsoil is a pure granite gravel and the surface layer a loam varying from 6 inches to 6 feet in depth.[2]

Forests of economic value are found in the Bitterroot Mountains, in the upper valleys of the branches of the Bitterroot River, in the canyons of its tributaries farther north, and on the lower slopes of the mountains. At greater altitudes and upon the sides and summits of the mountain spurs the forests are thin and of little value. Two zones of forest distribution may be distinguished, the dividing line lying about 5800 feet above sea level. The lower is the yellow-pine zone, the upper the alpine-fir zone. The timber of the lower zone consists

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[1] F. C. Calkins, A Geological Reconnaissance in Northern Idaho and Northwestern Montana, Bull. U. S. Geol. Surv. No. 384, 1909, pp. 20–21.

[2] J. B. Leiberg, Bitterroot Forest Reserve, 19th Ann. Rept. U. S. Geol. Surv., pt. 5, 1897–98, pp. 262–267.

mainly of red fir and yellow pine in the proportions of 60% and 30%; in the subalpine zone nine-tenths of the timber consists of lodgepole pine of little commercial value.[1] The former type of growth prevails on the lower slopes and in the canyons; the latter occurs on the summits and ridges and on the steep upper slopes.

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[1] Henry Gannett, 19th Ann. Rept. U. S. Geol. Surv., 1897–98, p. 57.

CHAPTER XIX

ROCKY MOUNTAINS. II

Central Rockies

Between the northern and southern Rockies is a group of ranges whose principal members are the Absaroka, Wind River, Gros Ventre, Teton, Laramie, and Medicine Bow mountains. Part of them form a belt of broken, rugged country with alpine characteristics on the western border of Wyoming, such as the Teton and Gros Ventre ranges; another part, including the Wind River and Laramie ranges, extends eastward and southward, making a great curve through central and southeastern Wyoming in continuation of the Colorado Range of central Colorado.

All these ranges (and many others of lesser extent not described here) are sufficiently alike in certain general characteristics and in geographic position to form a family of ranges with prominent traits. Many of them are anticlinal in structure, the anticlinal uplift being directly related to the mountainous relief, so that uplift along axial lines is responsible for the trend of the range heights. The asymmetry of the folds is another group quality and in the anticlinal ranges always causes one mountain flank to be relatively less steep than the other. Erosion is of course variable in degree, because the degree of folding and the height of the folded strata are not everywhere the same nor are the resistances of the different strata uniform.

It is sometimes ventured that these structures and forms resemble those of the long, narrow, Appalachian ridges of Pennsylvania. The comparison is not good as regards structure, for the Wyoming ranges have a far less regular structure and trend than the Pennsylvania ridges. In regard to form the comparison is wholly at fault. No central core or axis of crystalline rock is found in the latter case, and no such heights are reached. The Pennsylvania mountains are ridges; the Wyoming mountains are ranges. In the one case the even sky line is the result of base-leveling; base-leveling has not been generally determined in the other case and the sky line is serrate, the crests and peaks rugged and in some places lofty. Some of the foothill ridges developed upon the

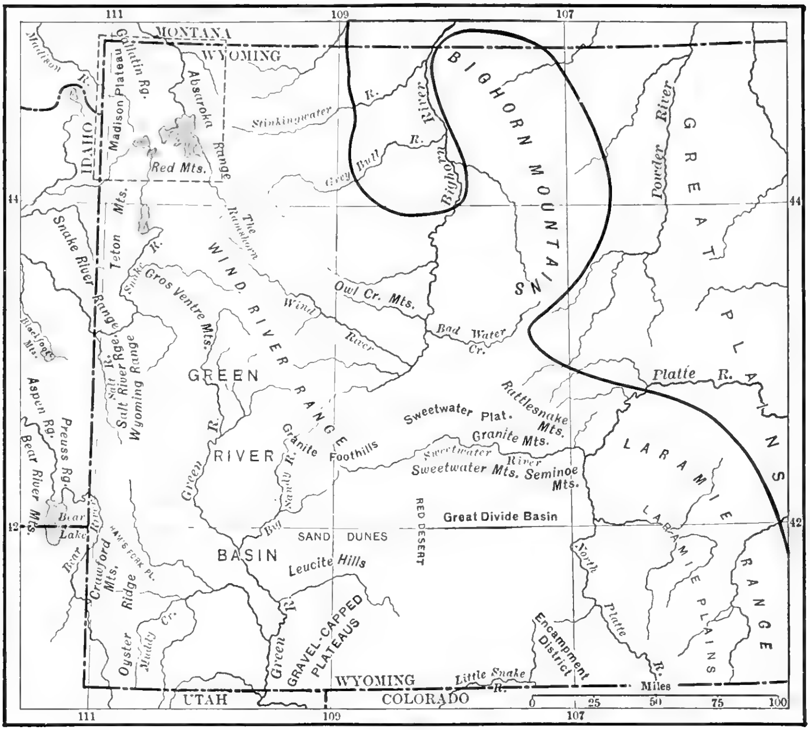

Fig. 104. — Outline map of the central Rockies, showing location of principal ranges.

edges of flanking strata are nearly level for miles, have subsequent valleys developed upon soft strata alternating with hard, and in general show a rough resemblance to Appalachian mountain topography; but on the whole there are far more contrasts than resemblances.

LARAMIE MOUNTAINS

The great Colorado or so-called Front Range terminates near the Colorado-Wyoming line and the mountain axis of which it is but a part continues northward in a double line of uplifts known as the Laramie Mountains on the east and the Medicine Bow Mountains on the west. The southern end of the Laramie Mountains is near the North Fork of the Cache la Poudre River and is surmounted by a confused mass of peaks of considerable height. The front range is also elevated north of the Laramie River, where it rises in rugged granite hills. But between the North Fork of the Cache la Poudre on the south and the Laramie

River on the north is an 80-mile division of the front range[1] of the Rockies whose topographic features are in strong contrast to the rugged groups both north and south. The average elevation of this section is only 7800 to 8300 feet and all but one of the few isolated peaks that rise above the general level are under 9000 feet above the sea. Sanders Peak, 9077 feet, Central Peak, 8744 feet, and Arrow Peak, 8683 feet, are the principal eminences.

The so-called Laramie Mountains are really an elevated plateau some 1500 feet above the Laramie Plains on the west and somewhat more above the Great Plains that lie beyond their eastern foothill ridges. The plateau is cut by many canyons and roughened somewhat by numerous knobs and short ridges, but these features do not wholly obscure the expression of the uplifted peneplain (early Tertiary) formed alike upon granite and schist. The interstream areas are smooth or gently rolling and even the ridges have rounded summits. The latter together with the knobs are residual with respect to the peneplain. The rocks are deeply decayed and thick residual soil mantles the remnants of the ancient surface.

The main divide of the Laramie Mountains is a distinct ridge of sandstone and limestone bordered on the east by a scarp from 50 to 200 feet high; on the west this ridge descends regularly to the Laramie Plains as a dip slope. East of the main divide is a broad area of gneiss and schist, the core of the anticlinal axis. Farther east are the hogback ridges of sandstone and limestone that form the eastern foothills. The Laramie Mountains are structurally a great anticline whose summit has been worn away. To the fact that it is an asymmetrical anticline is due the gentle western and the steep eastern slopes of the mountains. Locally, faulting has occurred on the eastern border and heightened these topographic contrasts. At other places the contrasts are lessened by an extensive overlap of Tertiary deposits which on the east extend far up the mountain slopes concealing the underlying harder rocks and affording easy ascents to the mountain or plateau summit.[2]

There is a noticeable lack of timber over this entire section. Small groves of pine, aspen, and other types of tree growth are found in sheltered localities, as in the larger basins, but on the whole the timber is of little practical importance.[3]

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[1] The name applied to the easternmost great range of the Rocky Mountain System. In Colorado the front range is the Colorado Range; in Wyoming it is the Laramie and other mountains; in Montana it is the Lewis Mountains, etc.

[2] Darton, Blackwelder, and Siebenthal, Laramie-Sherman Folio, U. S. Geol. Surv. No. 173, 1910, pp. 1, 2, 13.

[3] Arnold Hague, U. S. Geol. Expl. of the 40th Parallel (King Surveys), vol. 2, 1877, pp. 5–7.

WIND RIVER RANGE

The Wind River Range trends southeast and is one of the eastern border ranges of the central Rockies, Fig. 104. It continues toward the north in line with the Laramie Range, and like it is one of the front ranges of the system. The general structure of the Wind River Range is that of a complex anticlinal whose short and steep dips and corresponding steep slopes are toward the southwest; the northeast descents are less steep. The latter aspect is varied by two parallel mountain ridges formed upon hard strata, the intervening soft strata having been cut away by strike or subsequent streams. The main summit of the mountains consists of a broad plateau-like tract of granite and gneiss whose northeastern and southwestern faces are precipitous and deeply scored by large canyons.[1]

In the Wind River Range spruce and fir constitute the main tree species, with occasional groves of yellow pine and quaking aspen. Below the foothill elevations the willow and the quaking aspen grow along stream courses; at still lower elevations and in dry interstream situations sage-brush and cacti are the characteristic plants, as in the low country east of the Wind River Range and north of the Sweetwater Plateau. On dry ridges and steep dry bluffs piñon and cedar, or more properly, juniper, are found.[2]

BEARTOOTH AND NEIGHBORING PLATEAUS

The Yellowstone River after leaving Yellowstone Park makes a great northerly bend between which and the Bighorn basin are the Beartooth Mountains or Plateaus, East and West Boulder plateaus, Lake Plateau, etc., and the northern end of the Absaroka Mountains. In fact the three last-named tracts, together with the Buffalo Plateau and other minor subdivisions, constitute the northern part of the Absarokas as shown in Fig. 105. They are drained northeasterly by the Stillwater, Clarke Fork, and other tributaries of the Yellowstone, through deep canyons bordered by wall-like cliffs from 1500 to 3000 feet high. The region is everywhere extremely rough, and scored by deep, narrow, rocky canyons between which are (1) narrow ridges often only a few feet wide at the top or (2) broad, massive, rolling, bowlder-strewn, plateau-like surfaces like the East and West Boulder plateaus. The

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[1] Orestes St. John, U. S. Geol. and Geog. Surv. of the Terr. (Hayden Surveys), 1877, pp. 228 et seq.

[2] F. M. Endlich, U. S. Geol. and Geog. Surv. of the Terr. (Hayden Surveys), 1877, pp. 59–60.

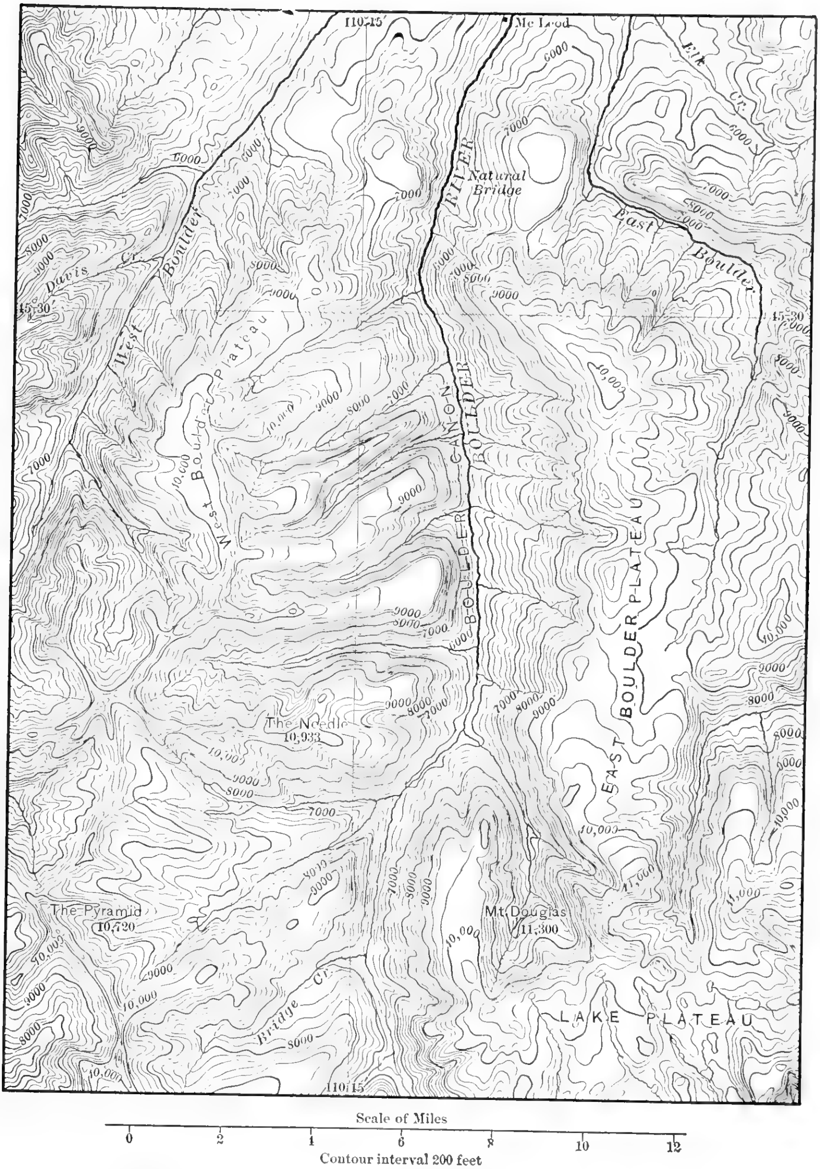

Fig. 105.— Topography of East and West Boulder plateaus, northern end of the Absaroka Range, southwestern Montana. (Part of Livingston quadrangle, U. S. Geol. Surv.)

average elevation is about 8000 feet; the canyon floors are at 4000 and the highest peaks at 11,000 feet.

The Beartooth Plateau, the main mass of high, rolling, inter-canyon country, and the associated ranges or plateaus, lie east of the Stillwater and at higher levels, 9000 feet, with peaks reaching to 13,000 feet. The canyons are here also steep and deep and end in rock-bound glacial cirques whose development about the bases of the mountains has sharpened the latter from a more rounded form into peaks and pinnacles of the matterhorn type that give an aspect of profound relief. The main plateau is pitted with glacial depressions, many of which have lakes and marshes bordered by alpine meadows. On the western border of Beartooth Plateau is the deep canyon of the Stillwater; on the east the plateau ends in a great frontal scarp in some places more than 3000 feet high. The steepness of most of the forms is owing to the late uplift of the region, the profound dissection by both water and ice, and the resistant gneisses and other crystallines out of which they have been carved. Some of the canyons are mere rifts between almost perpendicular walls; most of the headwater cirques are sheer cliffs; the peaks are generally glaciated and their bases carved by ice and water to such an extent as to give them great steepness and sharpness of form both in general outline and in detail.

The plateaus and canyons in the entire region as well as in the Absaroka and Gallatin ranges on the west were entirely covered with snow and ice during the glacial period; in addition all were profoundly dissected even before glaciation set in. Each range therefore repeats the general features of its neighbor. All are characterized by broader or narrower plateau-like tracts between deep canyons; all have some surmounting peaks; all have glacial lakes (1) on the cirque floors, (2) on the plateau summits, and (3) in the valleys, where either unequal cutting or morainic damming originated basins of variable size.

The forests of the region are almost wholly coniferous. Limber pine grows in belts from 5500 to 6000 feet high; lodgepole pine grows at elevations ranging from 5000 to 8000 feet; red fir is most commonly found on dry rocky slopes; and Engelmann spruce grows along the canyon bottoms or along seepage lines. Above the lodgepole pine forest are subalpine fir, white-bark pine, and Engelmann spruce. Timber line is at 9300 feet on northern and western slopes and at 9800 feet on southern slopes. Toward the east it rises and on the eastern edge of the Beartooth Plateau is at 11,000 feet. At the upper limit of tree growth the spruce and the white-bark pine decrease in height and become mere crooked shrubs. Grass grows in the alpine zone in such abundance as to form a thick turf capable of storing water and adding to the effect of lakes and tarns in preventing too rapid run-off and gullying. Overgrazing immediately starts gully erosion and results in effects as important as the overcutting of the forests at lower elevations.[1]

ABSAROKA RANGE

The Absaroka Range extends in a north-south direction for over 80 miles, with an average width of nearly 50 miles, Fig. 105. The southern end of the range is closely related to the Wind River Plateau and the Owl Mountains and is made up of enormous volcanic flows. The Absaroka mountains are to be considered as a broad deeply-eroded plateau rather than a sharply outlined range, Fig. 105. Profound erosion has carved the former more extensive summit into a topographic complex of rugged peaks and jagged pinnacled mountains bordered by bold escarpments which rise to heights of hundreds and even thousands of feet above the surrounding country. The walls encircling the mountain groups are usually abrupt and owe much of their steepness to ice action.

After the volcanic materials of which the Absaroka mountains are largely composed had accumulated the streams cut the range into isolated mountains and broadly-spreading spurs and its deep broad valleys were occupied by glaciers. All the upper valleys on the eastern slopes of the mountains have been sculptured by ice action, and lateral and terminal moraines are abundant. In addition, many narrow canyons are broadly benched a thousand feet or more above the valley floors, and rounded and polished forms are characteristic features of the scenery wherever gneisses and granites occur.

The chief effects of glaciation are, however, to be found upon the western slopes of the Absaroka Range, where a heavy ice cap developed, — one of the largest local glacial centers developed in the Rocky Mountains south of the great continental ice sheet. This local ice cap was confluent with that in the Yellowstone National Park, where a broad area of elevated country supplied favorable conditions for extensive glacial accumulations which fed marginal glaciers deploying down the valleys.[2] In the deep basins of some of the higher valleys facing northeast, a few snow-fields are still to be found and even small glaciers. The glaciers lie in broad,

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[1] J. B. Leiberg, Forest Conditions in the Absaroka Division of the Yellowstone Forest Reserve, Montana, and the Livingston and Big Timber Quadrangles, Prof. Paper U. S. Geol. Surv. No. 29, 1904, pp. 10–21.

[2] W. H. Weed, The Glaciation of the Yellowstone Valley North of the Park, Bull. U. S. Geol. Surv. No. 104, 1893, p. 13.

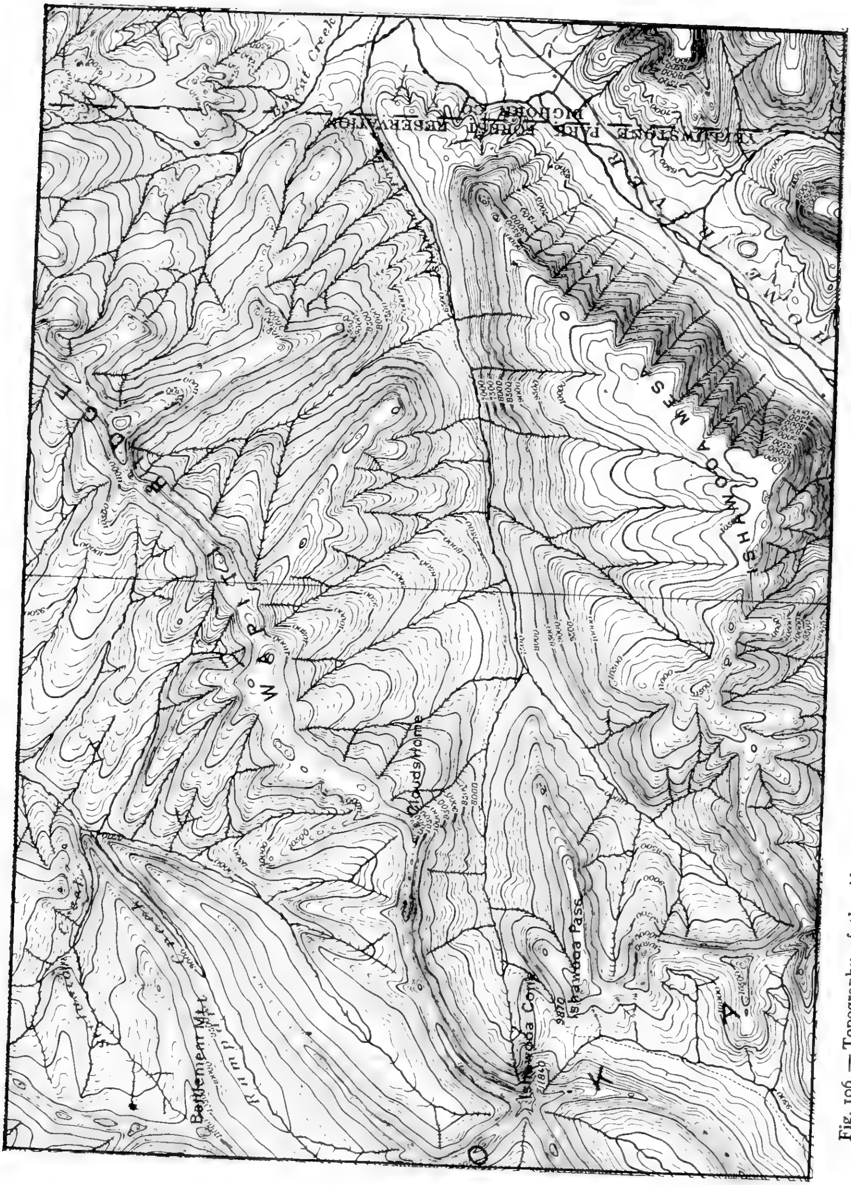

Fig. 106.—Topography of the Absaroka Range 10 miles east of Yellowstone National Park. Scale, 2¾ miles to the inch; contour interval, 100 feet. (Ishawooa quadrangle, U. S. Geol. Surv.)

rock-bound amphitheaters in great measure protected from the direct rays of the sun between high walls, and in localities where the prevailing southwest winds deliver vast quantities of snow during the winter season.[1]

The greater part of the Absaroka Range in the Yellowstone National Forest is clothed with coniferous forests broken by open glades. The isolated peaks and irregular crests of the main ridges are above timber line, and bear only scattered and stunted growths of weather-beaten trees. The western side of the range has a more continuous forest cover than the eastern. Lodgepole pine is the prevailing tree, limber pine is found at higher altitudes, and balsam and spruce are scattered widely though they nowhere attain great height or size. The most stately and vigorous tree of the Absarokas is the Douglas spruce, but it has a scattered growth. None of the timber of the Absaroka region is of superior quality, though sufficient for local requirements may be obtained by judicious use of the forest.[2]

MEDICINE BOW RANGE

This range is about 100 miles long and diverges slightly with respect to the front range. Included between it and the front range is a high intermont basin, so-called Laramie Plains. Its broadest part, in the region of Medicine Peak, is from 30 to 35 miles across, but the southern end is only 10 or 12 miles wide. The highest peaks named from the southern end northward are Mount Richthofen, 13,000 feet; Clark's Peak, 13,100 feet; Medicine Peak, 12,200 feet; and Elk Mountain, 11,500 feet. North of the 41st parallel the range becomes double crested in response to the double anticlinal structure, but toward the south its unity is preserved. Between the double crests of the northern section is a high, gently undulating, intermont plateau 10,000 feet above the sea, whose surface is covered with timber and dotted with lakes. All the higher portions of the range have been glaciated, and some of the glacially carved amphitheaters are very striking, with steep walls 1500 feet high cut in extremely hard quartzite.

The greater part of the range is covered with coniferous forest which is in places quite dense. Douglas spruce, Engelmann spruce, and yellow pine are the chief species. The cold timber line is about 11,000 feet above sea level.[3]

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[1] Arnold Hague, Absaroka Folio U. S. Geol. Surv. No. 52, 1899, p. 6, col. 3.

[2] Idem.

[3] Arnold Hague, U. S. Geol. Expl. of the 40th Par. (King Surveys), vol. 2, 1877, pp. 94–97.

BASIN PLAINS OF SOUTHERN WYOMING AND MINOR RANGES ON THEM

An accurate relief map of the Rocky Mountains represents a broad and flat tableland between the Laramie Mountains and the ranges west of the Green River. Through the eastern portion of this tract runs the Medicine Bow Range and through the central portion run the Leucite Hills, etc., so that the tract is partially divided into three sections. The portion east of Medicine Bow Range is called the Laramie Plains; the central section is known as the Red Desert, etc.; and the westernmost section is known as the Green River Basin. These three main divisions are, however, continuous about the northern end of their mountainous boundaries.

Fig. 107. — Laramie Plains, looking southwest from near Mandel, Wyo. (U. S. Geol. Surv.)

The Laramie Plains are 7000 feet above sea level, have a relatively smooth and gently undulating surface, Fig. 107, with gentle slopes and rounded outlines, so that they appear practically level over broad expanses except where a few bench-like ridges or very low buttes of circumdenudation occur. Shallow lakes, none more than a few square miles in extent, are scattered over the surface of the plain, whose waters range from fresh to brackish or strongly alkaline; some of them disappear during the dry season and leave saline incrustations. The whole tract is a great natural pasture; trees grow only along the broad stream valleys.[1]

The Laramie Plains apparently owe their flatness to the general horizontal attitude of the underlying strata (Cretaceous). The highest observed dips in the central portions of the basin are 12°, the average 5° to 8°. On the borders of the basin the dips increase somewhat and the eroded strata present steep bluffs toward the older rocks that form the cores of the bordering ranges. One of the most typical portions of the high intermont plains of southern Wyoming is the central division, which extends west of Rawlings. There are but few exposures of the flat-lying beds, and these occur only in escarpments a few feet high. The barren surface is but slightly dissected by the dry, shallow watercourses that traverse it. It is a flat, monotonous region as far as the Leucite Hills and is broken only at long intervals (1) by hills of eruptive material, or (2) by lines of moving sand dunes and drifts, as west of the Red Desert and north of the Leucite Hills, or (3) by local uplifts of small extent as at Rawlings. No marked drainage features are found in this section, but the section west of the 109th meridian is drained by the upper tributaries of the Green and along their courses an important amount of dissection has taken place.[2]

The westernmost section of the Wyoming Plateau is also underlaid by nearly horizontal strata (Tertiary and Cretaceous). The general nature of the relief is similar in most respects to that of the eastern divisions. The central depression of the tract is occupied by the valley of Green River, which on the north flows through the basin in a wide alluvial bottom; farther south it flows through a 1000-foot canyon cut in nearly horizontal strata (Tertiary). It then enters the Uinta range at the Flaming Gorge, where it cuts through the hardest quartzite, turns out of the mountains, flows eastward, and finally cuts straight across the Uintas in a superb 3000-foot quartzite canyon known as the canyon or gate of Ladore.[3]

The Green River drains a great basin whose eastern portion is somewhat diversified by low, strike ridges of irregular outline and whose western portion bears ridges of similar structural nature but of more regular topographic development, the horizon being always bounded

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[1] Arnold Hague, Rocky Mountains, U. S. Geol. Expl. of the 40th Par. (King Surveys), vol. 2, 1877, pp. 73–75.

[2] S. F. Emmons, The Green River Basin, U. S. Geol. Expl. of the 40th Par. (King Surveys), vol. 2, 1877, p. 164; and Geol. Map by Peale, St. John, and Endlich, accompanying Report.

[3] Idem, pp. 192–193 and 287, with Plate 8.

by an almost perfectly horizontal line.[1] The southern portion of the region north of the Park Range, known as the Savory Plateau, likewise presents a horizontal sky line, but for a different reason. The surface strata (Tertiary) are horizontal here and overlie the upturned and eroded edges of Cretaceous and older beds and present smooth plain surfaces.[2] From these stratigraphic relations it is reasonable to conclude that a mountain-making period at the close of the Cretaceous or in early Tertiary deformed the underlying beds and erosion planed them off, some perfectly, others imperfectly, and that upon the subdued, partially reduced surface thus developed, Tertiary beds of great thickness (up to 1000 feet) were deposited. Erosion dissected (1) the Cretaceous strata that were never buried, causing the development of a ridge and valley type of topography, and (2) the Tertiary cover, in some

Fig. 108. — Terrace and escarpment topography of nearly horizontal beds (Eocene), Green River Basin, southwestern Wyoming. (Veatch, U. S. Geol. Surv.)

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[1] S. F. Emmons, The Green River Basin, U. S. Geol. Expl. of the 40th Par. (King Surveys), vol. 2, 1877, p. 192.

[2] Idem, p. 164.

instances, laying bare the Cretaceous beneath, in others exposing only Tertiary material in the valley sections.

Similar relations have been identified in southwestern Wyoming and on the southwestern border of the Green River Basin. The basin floor is here developed chiefly upon Tertiary strata dipping gently eastward, and in general has been eroded so that the strata present their outcropping edges as westward-facing escarpments, a typical terrace topography. In places the mantle of nearly horizontal Tertiary deposits has been worn away and the underlying older beds with steep inclination are now exposed. Since there is considerable difference in the exact degree of dissection of the capping strata and of the exposed portions of the underlying, deformed rocks, the topography also varies from place to place. Two main types of topography have been developed: (1) flat table-like forms in places with bordering escarpments of considerable length between benches that rise in regular succession, a topographic type developed upon the uppermost and horizontal beds; (2) long ridges, often sharp, separated by equally long valleys, the whole in a markedly parallel arrangement and developed upon the steeply inclined older rock composed of alternating hard and soft layers. Hard

Fig. 109. — Hogback topography of inclined beds (pre-Eocene), southwestern Wyoming. The crests of the ridges are developed upon sandstone underlain by shale. (Veatch, U. S. Geol. Surv.)

sandstones are the ridge makers; soft shales underlie the valleys and the lowlands.[1]

The greater portion of the Green River Basin presents a gravel-strewn surface almost everywhere in process of dissection. The gravel cap was formed (1) by the weathering in place of the partly consolidated or wholly unconsolidated deposits filling the basin, or (2) by detrital accumulations washed into the basin during an earlier period of aggradation. The latter material is abundant about the mountainous border of the basin and originated in the form of desert-fan deposits. Its origin may be related to the renewed growth of the bordering ranges. Its deposition was preceded by a long erosion interval in which a local peneplain was formed, a fact which partly explains the extent of the gravel cap. It was followed by erosion now in progress.[2]

The Leucite Hills, which partially break the continuity of the plains of southern Wyoming, consist of a number of small conical peaks of volcanic origin. Some of them are capped by lava flows, others have crater-like forms and appear to have been centers of eruption.[3] They have no great topographic prominence and are of little interest in the present connection.

SIERRA MADRE RANGE

Continuing with the mountain ranges of the central Rockies it should be noted that in south-central Wyoming (Encampment District, south of Rawlings and west of the Medicine Bow Range) the mountain topography is on a whole of a subdued type. Steep slopes are confined to the middle courses of a few of the main streams and to a few basins or amphitheaters near the main divide formerly occupied by glaciers. The Sierra Madre mountains here form the main or continental divide. Their summits are generally broad and form a flat surface whose elevation ranges from 9200 feet in the lowest pass to 11,000 feet on the highest summit. The steep headwater declivities on opposite sides of the divide are often a mile or more apart, and the soft, broader-spaced contours of the mountain summits are frequently continued out upon the marginal spurs for several miles. The high portion of the range, Fig. 110, thus appears as an elevated plateau submaturely dissected by existing streams. The topography is subdued rather than rugged, and wagon

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[1] A. C. Veatch, Geography and Geology of a Portion of Southwestern Wyoming, Prof. Paper U. S. Geol. Surv. No. 56, 1907, pp. 34–35, and Plate 1.

[2] J. L. Rich, The Physiography of the Bishop Conglomerate, Southwestern Wyoming, Jour. Geol., vol. 18, 1910, pp. 601–632.

[3] S. F. Emmons, U. S. Geol. Expl. of the 40th Par. (King Surveys), vol. 2, 1877, p. 236.

roads have been constructed on almost every portion of the area without that excessive expense that is usually required in opening transportation routes in mountainous regions.[1]

The general structure of the Sierra Madre Mountains is a low arch or anticline the axis of which is parallel with the mountain crest. This arch was gradually uplifted and eroded and the Mesozoic rocks removed from the axial portion, revealing older pre-Cambrian rock which forms the main mass of the mountains. The Mesozoic formations outcrop on the foothills on either side and dip away beneath the surrounding plains.

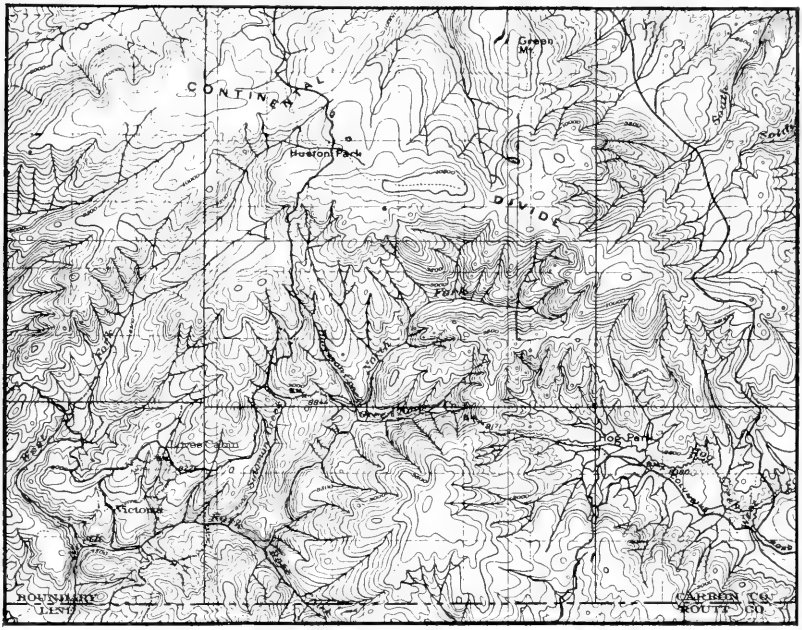

Fig. 110. — Mature profiles, long gentle spurs, and rounded summits of the mountains of the Encampment district, south-central Wyoming. (Encampment Special quadrangle, U. S. Geol. Surv.)

TETON RANGE

The Teton Range extends almost due south from the southwestern corner of Yellowstone Park and just east of the Idaho-Wyoming line. It is about 40 miles long and from 10 to 15 miles wide, with a central cluster of exceptionally high peaks, the highest of which, Mount Hayden and Grand Teton, attain elevations of 13,700 feet and 13,800 feet respectively. The only practicable pass is Teton Pass at 8400 feet. There are still in existence several small glaciers occupying cirques high

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[1] A. C. Spenser, The Copper Deposits of the Encampment District, Wyoming, Prof. Paper U. S. Geol. Surv. No. 26, 1904, pp. 12–15.

up in the range. The Tetons consist of a great longitudinal axis of uplift and folding; the steep and short descent is on the east, the longer and gentler is on the west. The steep eastern front is cut into a number of great buttress-like spurs faced by bold precipitous cliffs. On the west are a number of long narrow canyons separated by broad westward-descending slopes. These features are very uniformly developed along the entire eastern and western mountain fronts and are the most important in the range. The main mountain forms have a very intimate relation to a single great anticlinal uplift greatly eroded, exposing a central core or nucleus of crystalline rock, chiefly gneiss and granite, the latter forming the sharp peaks and aiguilles as well as the highest peaks as in Mount Hayden; the gneiss tends to erode into the form of sharp ridges. The crest of the range does not everywhere follow the granite however. At the south it is developed chiefly upon sedimentary rocks that have not yet been stripped from the crystalline foundation.[1]

In general the climatic conditions in the Tetons favor forest growth, yet but little forest exists owing altogether to the repeated and destructive fires which have swept over the tract. The lodgepole pine has been temporarily driven out in many places and former timbered areas have become grass-covered parks or aspen groves. Besides lodgepole pine and aspen the principal species are Engelmann spruce and red fir, the former in damp, the latter in dry situations.[2] Timber line is at 10,000 feet in this locality, and as the average altitude of the range is about 12,000 feet, large portions of the Tetons rise well above the upper limit of the forest.

GROS VENTRE RANGE

The Gros Ventre Range consists of two parallel mountain folds or anticlines about 5 miles apart, the axes trending southeast. Erosion has unroofed both anticlines and given them corresponding topographic features. Had the anticlines been symmetric, long, gentle, dip slopes would, in the present state of erosion, be found upon the outer flanks of the ridges, and steep, short slopes would be found cutting across the inner edges of the strata. The folds are, however, not symmetric, for the axes lie near the southwestern margins, hence the southwestern slopes are steep, the northeastern slopes relatively gentle and uniform in character. The contrast is identical in general kind, though

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[1] Orestes St. John, U. S. Geol. and Geog. Surv. of the Terr. (Hayden Surveys), 1877, pp. 411–416.

[2] T. S. Brandegee, Teton Forest Reserve, 19th Ann. Rept. U. S. Geol. Surv., pt, 5, 1897–98 pp. 195–197.

somewhat dissimilar in detail to that afforded by the eastern steep and western less steep slopes of the Tetons. As in the latter case also, erosion has denuded the sedimentary cover and exposed portions of the underlying crystallines. These do not, however, form any notable portion of the mountain crest, for denudation is here far less advanced and the mountain summits are still largely developed upon sedimentary rock.[1]

Extra-Marginal Ranges

On the eastern and the western borders of the central Rockies are two mountain ranges which stand out prominently at a little distance forward from the main mountain front. The eastern range is the Bighorn Mountains; the western range is the Uinta Mountains. Although they are here classified as a portion of the central section of the Rockies they should be regarded as having no very close geologic or geographic affinities with the Wyoming ranges described above.

UINTA MOUNTAINS

The Uinta range is peculiar in trending in an east-west direction in a mountain region where the prevailing trends are north-south. It is not altogether unique in this respect, however, for the Owl Creek range is a fold having a similar trend, and others in Wyoming and elsewhere having the same trend have been discovered.[2]

The Uintas form a rather flat, elliptical dome or elongated arch 150 miles long from east to west and with an average width of 20 to 25 miles. The interior of this elongated dome is a deeply dissected, plateau-like region, in general about 10,000 feet high, from which rise narrow ridges and peaks 12,000 to 13,000 feet high developed upon horizontally bedded quartzites.[3]

The strata of the interior plateau nowhere depart more than 5° or 6° from a horizontal position except in a small number of local instances. On the margins of the mountain belt the beds dip more steeply, in some cases over 45° and in extreme instances nearly 90°. The marginal zones of highly inclined strata are also affected by minor faults and folds, the principal displacement being along the northern side of the arch, Fig. 111.[4]

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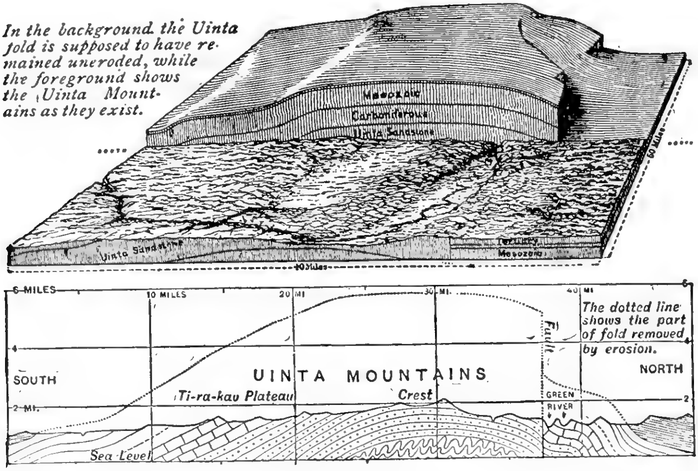
[1] Orestes St. John, U. S. Geol. and Geog. Surv. of the Terr. (Hayden Surveys), 1877, pp. 208 et seq.

[2] N. H. Darton, Senate Document No. 219, 1906.

[3] S. F. Emmons, Uinta Mountains, Bull. Geol. Soc. Am., vol. 18, 1907, pp. 287–302.

[4] W. W. Atwood, Glaciation of the Uinta and Wasatch Mountains, Prof. Paper U. S. Geol. Surv. No. 61, 1909, p. 9. See also J. W. Powell, Geology of the Uinta Mountains, 1876.

The physiography of the Uinta Mountains is closely related to the geologic structure. The broad open valleys of gentle contour depend upon sculpturing of soft horizontal strata beneath a capping of harder beds. The steeply inclined strata on the flanks of the range have been eroded to the point where they stand out as a series of hogback ridges separated by parallel trough-like valleys. The streams run in a series of rapidly deepening canyons with nearly vertical walls 3000 to 4000 feet high, and are deepest where they cross the hogback ridges on the margins of the anticline. The axis of the Uinta uplift is near the northern margin and the canyons of the northern slope are therefore shorter than those of the southern slope. The inter-canyon spurs are broad and flat and are overlapped by gently sloping Tertiary beds in places up to elevations of 10,000 feet.



In the background the Uinta fold is supposed to have remained uneroded, while the foreground shows the Uinta Mountains as they exist.

The dotted line shows the part of fold removed by erosion.

Fig 153.

Fig. 111. — Stereogram and cross-section of the Uinta Mountains arch. (Dryer, adapted from Powell.)

The Green River enters the northern flank of the Uinta Mountains at the Flaming Gorge, then swings out again, only to return and cross the main axis of the range at the eastern end through the Ladore Gate or Canyon. Powell described the Green River as an excellent illustration of an antecedent stream that had maintained its course across the Uinta Mountains during the period of their uplift.[1] The later studies of Emmons show that Powell's hypothesis must be modified, for it involves physical impossibilities.

[1] J. W. Powell, Geology of the Uinta Mountains, 1876.

The upturned and truncated edges of the various formations of the Uinta arch are partly covered by overlapping Tertiary beds in a nearly horizontal position. These beds reach altitudes of 9000 to 10,000 feet at various points on either flank of the higher western portion of the range. The Green River Canyon, at the Flaming Gorge, has an elevation in the eastern portion of the range of 7500 to 9000 feet. From these conditions it seems clear that (1) the mountain-making movements which gave rise to the Uintas were accomplished principally at the close of the Cretaceous, though a small subsequent movement is allowable on stratigraphic grounds (each of the three series of Tertiary beds is marked by an erosion interval between successive beds and by a slight upturning on the flanks of the Uinta Mountains); (2) the Green River had its course directed as a consequent stream upon the surface of the overlying Tertiary deposits; (3) the dissection of the Tertiary beds allowed the river to become superposed upon the buried portion of the Uinta arch; (4) further erosion both within and on the borders of the range has intensified the topographic expression of the Uinta arch and to some extent obscured the origin of the course of the Green River.[1]

FORMS DUE TO GLACIATION[2]

In addition to the influence of alternating hard and soft beds on the valley outlines, glaciation has operated to widen and deepen the canyons and in many cases to give them characteristic U-shaped profiles. The floors of the basins in the western part of the range are about 9000 feet in elevation and every large canyon that heads near this part of the crest has been glaciated. The glaciers in the central portion of the range were 20 to 27 miles long; elsewhere they were but 4 or 5 miles long. The ice slopes about Bald Mountain and Reed's Peak near the western end of the range coalesced to form a great ice cap, Fig. 112. The greater portion of the divide was, however, not covered by ice and the loftier peaks rose above the snow-fields. The basins at the heads of the canyons on the northern slope vary in area from 1 to 12 square miles, while many of those on the southern slope are 20 to 30 square miles in extent, a difference which is due to the fact that the southward-flowing streams have developed valleys in the plateau-like summit where the beds are nearly horizontal and where the conditions are therefore most favorable for glacial plucking and sapping and for the development of broad flat-bottomed cirques. The northward-flowing glaciers worked upon steeply inclined strata and were resisted by every hard stratum in the section instead of a single hard stratum; hence they were but little assisted by sapping, for the soft beds whose removal gave rise to the sapping of the harder beds above them soon dipped down beneath the plane of effective action. The result was not only a greater amount of work to be performed by the northward-flowing streams but also a restriction of the fields of nourishment which correspondingly decreased the intensity of glaciation.

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[1] S. F. Emmons, Science, n. s., vol. 6, 1897, p. 131 et al.

[2] W. W. Atwood, Glaciation of the Uinta and Wasatch Mountains, Prof. Paper U. S. Geol. Surv. No. 61, 1910.

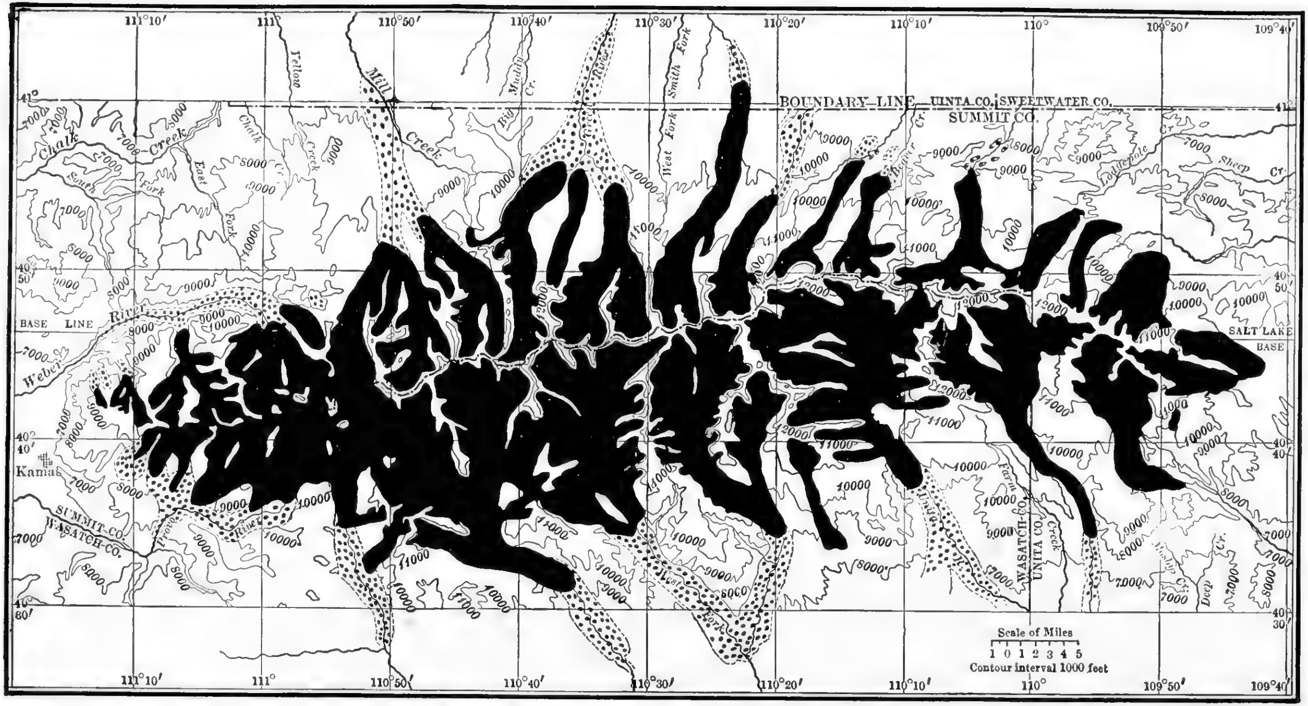

Fig. 112. — Glacier systems of the Uinta Mountains in the Pleistocene. Solid black represents area covered by later glaciers, solid black and dotted represent area covered by earlier glaciers. (After Atwood, U. S. Geol. Surv.)

FOREST GROWTH

In the higher portions of the range the forest growth is extremely scanty, but in the lower valley basins there is a heavy growth of coniferous forest. The upper limit of forest growth is about 11,000 feet, the lower limit on the southern slopes is beyond the base of the range in the Uinta Valley and is less than 7000 feet, while on the northern slopes it is 9000 feet owing to differences of relief and to corresponding differences of exposure. The prevailing species are white pine, yellow pine, Engelmann spruce and Douglas spruce, besides species of lesser importance.

"The view from one of the mountain lakes, with its deep-green water and fringe of meadowland, set in the somber frame of pine forests, the whole enclosed by high walls of reddish-purple rock, whose horizontal bedding gives almost the appearance of a pile of cyclopean masonry, forms a picture of rare beauty."[1]

BIGHORN MOUNTAINS

The Bighorn Mountains rise from 4000 to 5000 feet above the Great Plains to from 10,000 to 13,000 feet absolute altitudes. The range trends north-northwest in its northern portion, due north and south in its central portion, and east and west where it joins the main Rocky Mountain System whose border ranges are known here as the Bridger Range and the Owl Creek Mountains.[2] It is in effect an extension or prodigious spur of the Rockies jutting far out beyond their border.

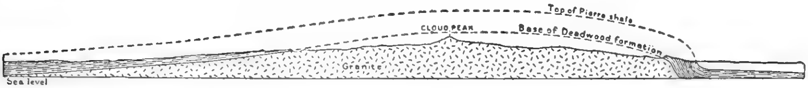

Fig. 113. — East-west section across highest part of Bighorn Mountains, showing extent of erosion and the contrast in dip on the two slopes of the range.

The Bighorn Mountains are a great anticline lifted many thousands of feet and composed of a thick series of sedimentary rocks (Paleozoic and Mesozoic) and a central core of granite and schist (pre-Cambrian).[3] The sedimentary rocks arch over the northern and southern portions of the uplift, and give rise to elevated plateaus about 9000 feet high at the north and 8000 feet high at the south. On the divides these plateaus often present broad tabular surfaces though they are trenched by numerous large canyons. The central plateau terminates in high cliffs at certain places in the border region, but in others and especially

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[1] S. F. Emmons, Geol. Expl. of the 40th Par. (King Surveys), vol. 2, 1877, pp. 194–195.

[2] N. H. Darton, Geology of the Bighorn Mountains, Prof. Paper U. S. Geol. Surv. No. 51, 1906, pp. 10–11.

[3] Darton and Salisbury, Cloud Peak-Fort McKinney Folio U. S. Geol. Surv. No. 142, 1906, p. 1, cols. 2, 3.

Fig. 114. — Sharp upturn of strata on the east side of limestone front ridge of Bighorn Mountains, Wyo. The topographic expression of the upturned beds are clearly shown in the sharp ridges of the photograph. (Darton, U. S. Geol. Surv.)

along the eastern side of the mountains it is flanked by a distinct ridge of limestone that rises slightly above an inner valley and slopes steeply toward the plains. These plateaus are covered by forests with many park-like openings and are extensively used as grazing grounds for cattle and sheep during the short summer season.

The subordinate topographic features of the Bighorns depend upon local flexures on the flanks of the main uplift and a number of faults, the latter being especially marked northwest of Buffalo and on the eastern border of the range, where one of the faults has a throw of about 9000 feet. The effect of the sharper flexing and of the pronounced faulting has been to increase the development of precipitous slopes, and to cause a greater development of hogback topography especially on the eastern side. The hogback ridges rise from 100 to 200 feet above the adjoining valleys, and are due to the outcrop of sandstone of moderate hardness, while the valleys follow the outcrop of the "Red Beds" composed largely of soft shales.

The general configuration of the central cluster of high mountains in the Bighorns is very rugged and presents some of the boldest alpine scenery in the United States. There are many precipices over 1000 feet high, particularly in the glacial cirques along the higher summits. Some of the cirques still hold glaciers; one on the eastern side of Cloud Peak is nearly one-half mile long. Extensive snowbanks remain the entire summer in many higher portions of the range.[1]

GLACIAL FORMS

At the time of maximum glaciation in the last glacial epoch the snow and ice accumulations of the Bighorns were two or three times as extensive as those of Switzerland to-day and the largest glacier was considerably larger than the largest existing Swiss glacier.[2] For thirty miles the crest of the range has been glaciated and signs of glaciation are everywhere abundant. The topographic and climatic conditions governing the distribution and growth of former glaciers were unusually favorable. Glaciers started from approximately one hundred sources, but in descending they combined in many cases, so that the number of separate glaciers or glacier systems was but nineteen. A specific instance is the Pear Rock Glacier, which started from not less than twenty sources.

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[1] Darton and Salisbury, Cloud Peak-Fort McKinney Folio U. S. Geol. Surv. No. 142, 1906, p. 1.

[2] Idem, p. 9, col. 4.

Fig. 115. — Wall at head of cirque, upper end of a tributary of West Tensleep Creek, Bighorn Mountains. A. View from above rim, showing old rounded surface. B. View from below rim, showing granite walls nearly 1000 feet high. (Blackwelder, U. S. Geol. Surv.)

During both the advance and the retreat of the ice the number of separate glaciers was greater than during the time of maximum glaciation, for the ice was melted out of the lower glacial troughs, while it still lingered in the separate tributary valleys. The glaciers on the west side covered almost twice as great an area as those on the east and they were also somewhat longer, a difference due to the heavier precipitation on the west side (prevailing westerly winds) and the wider catchment basins. The surviving glaciers are now found wholly on the east side, a condition probably due to the better protection of the cirques

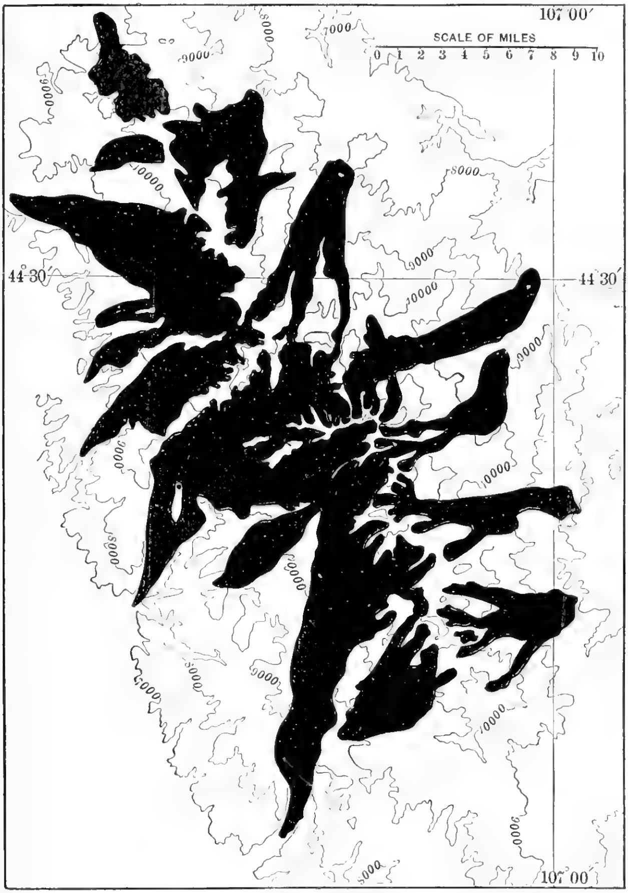

Fig. 116. — Glacier systems of the Bighorns at the time of their maximum development. (After Blackwelder, U. S. Geol. Surv.)

on that side from the sun and in part to the westerly winds which drift snow over the crest of the range and into the cirques and alcoves on the lower side. The lower limits of the glaciers were from 6500 feet to 10,500 feet, the necessary elevation for the generation of glaciers in the Bighorn Mountains during the last glacial epoch ranging from 9500 to 11,500 feet.[1]

Glacial cirques and hanging valleys are of frequent occurrence, though arêtes and needles are absent because glacial sapping did not continue long enough to allow the junction of snow-fields on divides.[2] The cirque walls have not been notably denuded in postglacial time because of the compact and relatively structureless granite in which they were carved and in part because of the recency of formation. The cirques have been formed on a huge scale, for the original valleys were often far apart and neighboring cirques were thus developed without mutual interference on the lateral divides.[3]

Below the cirques are steep valleys whose gradients range from 600 to 800 feet per mile. Where the valleys cross the great central granite plateau they are shallower and more open; but where they cross the sedimentary rim they become narrow gorges. Some of the longest glaciers entered these gorge-like marginal valleys, but none of them reached out upon the plains. Among the most important features of the present drainage are the large numbers of lakes due to glacial overdeepening or to the presence of morainic dams. Some of the terminal moraines of the Bighorns are of great size, the undulations of their surface reaching as high a value as 800 feet. The terminal moraine of North Fork is 300 feet above the level of the valley floor and its topography is very irregular.[4]

FORESTS

Nearly all the trees of the Bighorn National Forest (which includes most of the forested area of the mountains) are lodgepole pine (*Pinus murrayana*, locally called white pine), yellow pine, and jack pine. Another species is limber pine of scattered growth. Engelmann spruce occurs in some of the moister areas along the mountain slopes and the higher portions of some of the canyons. The dry or lower timber line

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[1] Darton and Salisbury, Cloud Peak-Fort McKinney Folio U. S. Geol. Surv. No. 142, 1906, p. 10, col. 1.

[2] F. E. Matthes, Glacial Sculpture of the Bighorn Mountains, Wyoming, 21st Ann. Rept. U. S. Geol. Surv., pt. 2, 1899–1900, p. 175.

[3] Idem, p. 176.

[4] Darton and Salisbury, Cloud Peak-Fort McKinney Folio U. S. Geol. Surv. No. 142, 1906, p. 11, col. 3.

occurs at 6000 feet, and the cold timber line at 10,000 feet, so that the upper portions of the range do not generally support a timber covering of any importance, but on the whole expose bare rock-strewn summits. The wood of the white pine, the predominating species, is coarse-grained, knotty, and small. The lumber warps and cracks considerably, and it is therefore not regarded as valuable.[1]

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[1] For detailed distribution of the timber of the Bighorns, etc., see 19th Ann. Rept. U. S. Geol. Surv., pt. 5.

CHAPTER XX

ROCKY MOUNTAINS. III

Southern Rockies

In contrast to the irregularly arranged mountains of the Central Rockies with variable trend, numerous offsets, and plain and plateau interruptions are the northward-trending, somewhat regular, and continuous mountain ranges that constitute the southern Rockies. There

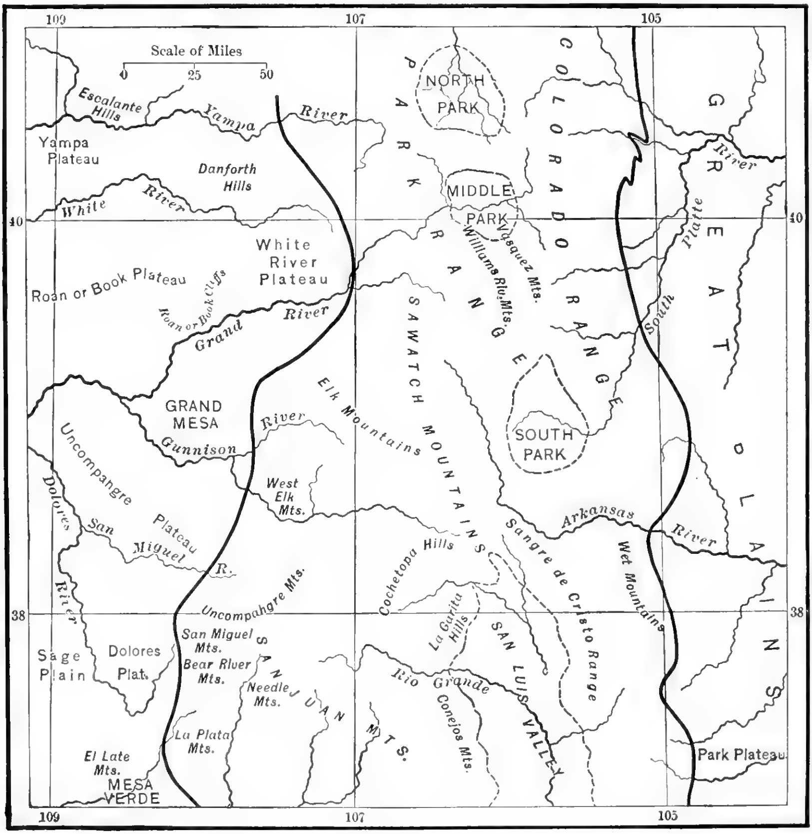

Fig. 117. — Location map of the southern Rockies.

appears to be a rather well-marked and consistently developed mountain plan in the eastern and central ranges of the district; the westernmost ranges are of more diverse structure, topographic texture and origin, and occur in groups of longer and shorter lengths arranged on the whole with less regularity.

Fig. 117 represents the locations of the main topographic features of the region, which fall readily into five categories:

(1) The eastern foothills, of varied origin and commonly exhibiting the hogback type of topography.

(2) The Colorado or Front Range and the Wet Mountains, consisting in a broad way of a great anticlinal from whose central granite axis the flanking sedimentary beds dip east and west.

(3) The Park, Sawatch (Saguache of some maps), and Sangre de Cristo ranges, all of which lie nearly on the same meridian, trend northward, have roughly equivalent structures and topographic forms, and are parallel to the Colorado Range, from which they are separated by

(4) a chain of "Parks," North, Middle, South, and Huerfano, four intermont basins of exceptional character, primarily of structural and secondarily of alluvial origin (San Luis Park, the largest of all the intermont parks of Colorado, lies between the Sangre de Cristo range and the southern continuation of the Sawatch Mountains — the Conejos, etc.).

(5) Irregular mountain knots or groups of igneous origin which lie beyond the Park-Sawatch axes, such as the Elk, La Plata, San Juan, and Uncompahgre mountains.

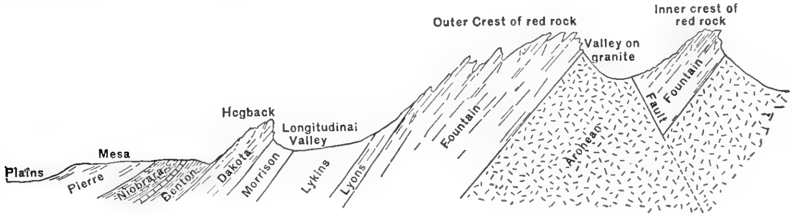

Fig. 118. — Generalized east-west section near Boulder, Colorado, showing the structure and topography of the South Boulder Peaks and the hogback ridge of Dakota Sandstone. (Fenneman, U. S. Geol. Surv.

EASTERN FOOTHILLS

HOGBACK TOPOGRAPHY

The eastern foothills of the southern Rockies are generally formed upon a belt of sedimentary beds upturned at steep angles along the mountain slopes. The most characteristic feature is the hogback ridge, Fig. 118, developed in the form of long narrow ridges of harder beds that stand like a fringing and often a serrated wall at a little distance from the base of the mountains. They occupy a belt about two miles wide involving portions of all valleys intervening between them and the main range. The easterly dip of the sedimentary beds of the foothills is quite general, and ordinarily varies from 35° to 50°, though locally it is from 80° to 90°

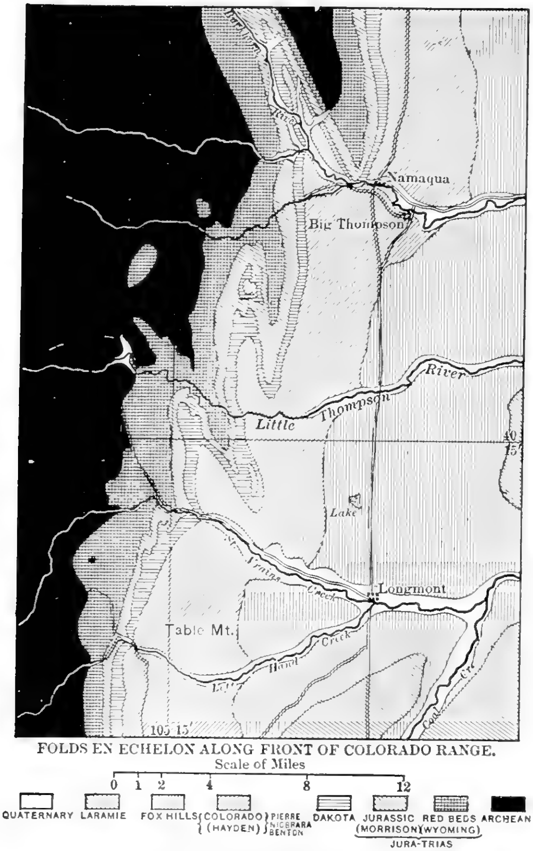

Fig. 119. — Cross folds on eastern border of Colorado Range. (U. S. Geol. Surv.)

Besides the general flexing of the strata, which is due in part at least to the uplift of the Colorado Range, there has been a considerable amount of minor crumpling along lines parallel with the general trend of the range or diverging from it to some degree. The latter process resulted in a series of secondary folds reflected in the topography by successive offsets. In such localities the ridges are arranged *en échelon.* Their general appearance is shown in Fig. 119, which represents a series occurring between St. Vrains and Cache la Poudre creeks, north of Denver.

VEGETATION

The vegetation of the Pueblo region is closely related to climate and soil, and in this respect and in its general character it is typical of the vegetation of the hogback ridges of Colorado. The uplands above 6500 feet bear a forest of yellow pine, and straggling pine growths occur on sheltered hillsides down to 5300 feet; in the same zone rocky slopes are sometimes covered with aspens. Hackberries and other hard-wooded trees grow to moderate size in the moister valleys, while cottonwoods fringe the lower streams; juniper and piñon pine extend down to 5000 feet and are associated chiefly with dry rock-strewn ledges of resistant limestone and sandstone.

OTHER TYPES OF FOOTHILL TOPOGRAPHY

While the hogback type of mountain border or foothill topography is the predominating one there are a number of other types that require examination. They are not all confined to the southern Rockies, but are assembled here for comparison with the well-developed foothill types of Colorado. The hogback ridges are absent (1) where the harder beds rest directly upon the crystalline rocks of the mountain slopes, without the presence of a soft valley stratum between the crystallines and the hard sedimentary formations overlapping them, of which some of the foothills on the eastern border of the Bighorns are perhaps the best illustrations; or (2) where the upturned edges of other sedimentary (Mesozoic) beds are still covered by a capping of younger (Tertiary) beds in a horizontal position; or (3) where faulting has brought the sedimentary rock in a nearly horizontal position against the deformed crystallines as at Pueblo, Colorado. (4) The eastern border of the Rocky Mountains in Montana is developed upon strata that have been deformed in such a manner that they dip westward and present a reversed border, (*a*) a single, steep, precipitous, eastern scarp overlooking the Great Plains, such as marks the eastern front of the Lewis Mountains, Fig. 92, or (*b*) a series of scarps and flats formed upon alternate soft and hard layers — short, steep, eastern slopes and long, gentle, mountainward or western slopes, Fig. 93. In the Bighorn Mountains and in the Colorado Range, on the other hand, the marginal strata in general dip steeply eastward, with the consequence that typical hogback ridges are characteristic. (5) Lava flows have occurred locally and have caused the formation of a mesa type of topography or (6) volcanic cones surmount the eastern border. Besides the hogback type six types of foothill topography are thus distinguishable along the eastern border of the Rockies. Instead of being everywhere formed simply upon the basset edges of the sedimentary beds exposed along the mountain flanks, the border has been formed in diverse ways and exhibits diverse topographic features. While each of the types indicated has distinctive features the first five types are so closely related as not to require detailed explanation. The sixth type — the igneous border — is well developed in the southern Rockies and has rather complex features that merit further consideration.

IGNEOUS BORDER

SPANISH PEAKS

In southern Colorado and locally elsewhere in that state, as at Golden, the strata have been deformed or to some extent concealed and the border given an unusual character by the occurrence of igneous masses which in the case of the Spanish Peaks consist of volcanoes and associated dikes and lava flows. The type of mountain border exhibited is wholly unlike that found anywhere else along the eastern face of the Rockies from Alaska to New Mexico.

The most prominent feature of this kind is the volcanic nucleus known as the Spanish Peaks. The two culminating points, West Peak and East Peak, are about 2 miles apart and have elevations of 13,623 feet and 12,708 feet respectively. They rest upon a small platform that descends eastward gradually and terminates in an irregular and deeply dissected line of steep bluffs that descend abruptly 500 feet to the gently rolling plains. The average elevation of this platform is about 7500 feet. Its surface is a succession of mesa-like ridges and narrow valleys of extremely rugged development. The peaks themselves consist of stock-like masses occupying nearly vertical fissures, and from them the flanking strata dip steeply away with various structural complexities. The general ruggedness of the country about them is emphasized by

Fig. 120.—West Spanish Peak, from the northwest. One of the large dikes of the region is seen in the foreground. (U. S. Geol. Surv.)

many dikes which have a rude radial arrangement with respect to the peaks which were the centers of eruption. They were formed in crustal fractures related to the deformation of the surface strata, deformations produced by the intrusion of great masses of igneous rock.[1] They are from 2 to 100 feet in thickness. Some of them are practically vertical and project above the surface as smooth wall-like masses from 50 to 100 feet high. Their crests are sometimes straight for long distances, although curved crests are most common. They range in length from a few hundred yards to 10 and 15 miles, and intersections are common.[2]

The upland portion of the region adjacent to the Spanish Peaks is rather heavily timbered and the eastern borders of the plateau support a dense growth of piñon and juniper, scattered pines, and scrub oak, with occasional park-like openings. The more elevated central, southern, and western borders support forests of pine; a certain amount of spruce, fir, and aspen grows at the base and on the lower slopes. The summits of the peaks are from 1000 to 1500 feet above the cold timber line. The plains eastward of the plateau upon which the Spanish Peaks stand are practically destitute of timber except for fringes of cottonwood along the running streams. The whole plateau portion is subject to frequent summer showers. The summits of the Spanish Peaks are rarely free from snow for more than two months in the year, while along the narrow valleys cut below the level of the plateau irrigation is necessary, as also upon the surface of the plains country toward the east.[3]

NORTH AND SOUTH TABLE MOUNTAIN

Among the various types of foothill topography one of the most important is the flat-topped mesa type, which is well shown in the vicinity of Golden. Here the hogbacks completely disappear and in their place are two basalt-capped, sedimentary masses known as North and South Table Mountain. They were originally continuous but have since been cut through and isolated (Clear Creek). The basalt was extruded after the strata had been flexed into steep attitudes and somewhat eroded. It consists of two fissure flows with no sedimentary rock between them.[4] They protect the underlying beds from erosion; their present elevation indicates the degree of dissection that has taken place in the vicinity since their formation.

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[1] R. C. Hills, Spanish Peaks Folio U. S. Geol. Surv. No. 71, 1901, p. 3, col. 1.

[2] Idem, p. 3, col. 4.

[3] Idem, p. 1, col. 1.

[4] Emmons, Cross, and Eldridge, Geology of the Denver Basin in Colorado, Mon. U. S. Geol. Surv. No. 27, 1896, p. 285.

FOOTHILL TERRACES

The foothill terraces are among the important features on the eastern border of the Colorado Range. They are mesalike remnants of stream terraces carved in rock, Fig. 118, standing out with special prominence along the base of the foothills south of Boulder where they rise from 100 to 300 feet above the lower plains. They vary in width from a fraction of a mile to three miles, and descend eastward with slopes varying from 1° to 10°. They appear to be due to a leveling of the rock margin of the plains by meandering streams and the deposition upon the plains surface of a thin sheet of unassorted gravel.[1] The terraces always slope toward the streams, with which they once had flood-plain relations.

COLORADO OR FRONT RANGE

The Colorado or Front Range is the easternmost of the imposing chains that form the southern Rockies. Its elevation above the surrounding country is represented in Fig. 121.

On the north the Colorado Range is a high, heavily timbered, plateau-like range separated from the Medicine Bow Mountains by the Big Laramie River, and from the Laramie Mountains by the North Fork of the Cache la Poudre; but throughout most of its extent it is alpine in character, with sharp serrated summits bordered by great glacial amphitheaters.[2] The broad anticlinal of the range has a very flat summit arch, with increasing dip toward the flanks of the anticline on the borders of the range.[3] The rocks of the Colorado Range are almost exclusively crystalline granites, gneisses, and schists.[4] The topographic features are not uniform throughout and we shall therefore describe them by groups.

West and northwest of Denver and north of Arapahoe Peak, the serrated crest of the Colorado Range is exceedingly formidable, with many peaks rising to 13,000 and 14,000 feet. Even the passes are high and difficult, and on either side are steep-sided and deep mountain gorges. The irregularity of the mountains and their steep descents are suggested by the northeast face of Long's Peak (14,270), which consists of an almost perpendicular cliff over 3000 feet high which

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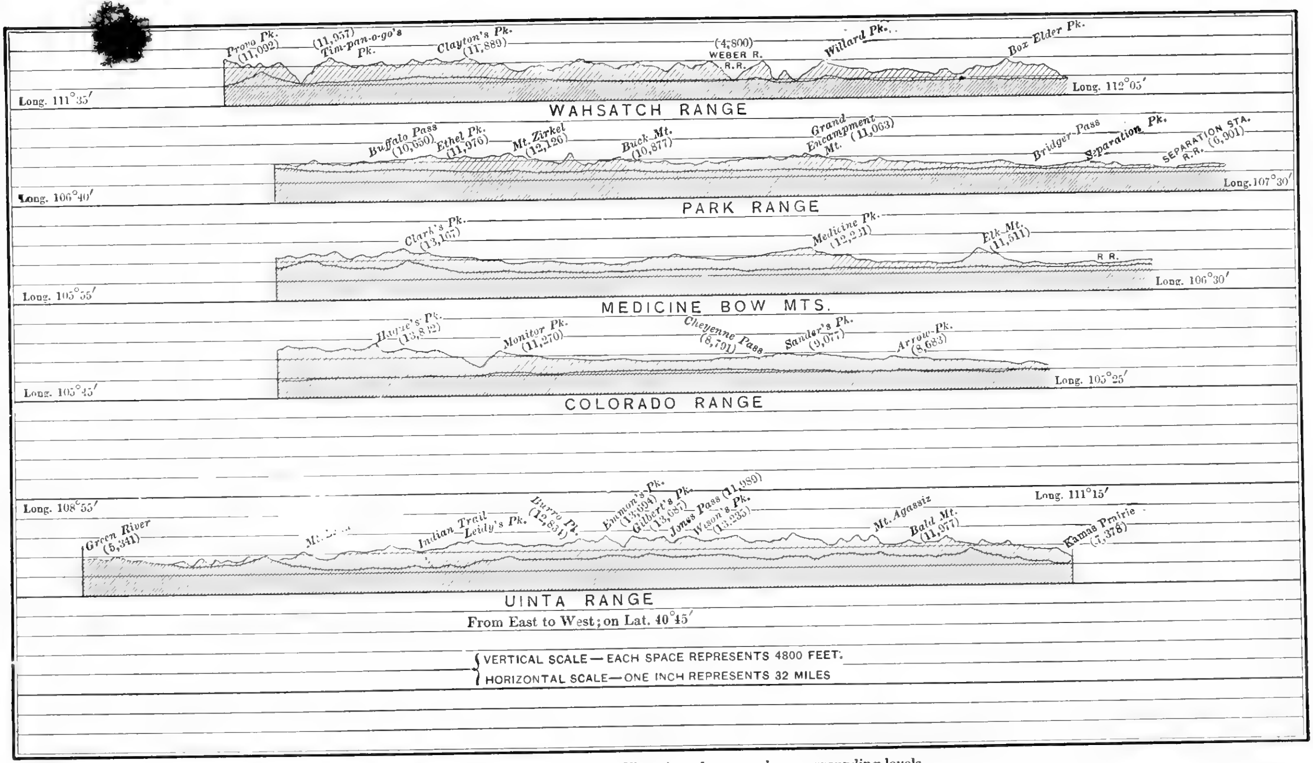
[1] N. M. Fenneman, Geology of the Boulder District, Colorado, Bull. U. S. Geol. Surv. No. 265, pp. 13–15.

[2] S. B. Ladd, U. S. Geol. and Geog. Surv. of Colorado and Adj. Terr. (Hayden Surveys). 1873, p. 436.

[3] Clarence King, U. S. Geol. Expl. of the 40th Par. (King Surveys), vol. 1, 1878, p. 21.

[4] Arnold Hague, Rocky Mountains, U. S. Geol. Expl. of the 40th Par. (King Surveys), vol. 2, 1877, p. 22.



Base lines - Sea level. Lighter tint Elevation of ranges above surrounding levels.

Fig. 121. — Longitudinal profiles of five prominent ranges in the Rocky Mountain province. (King Surveys.)

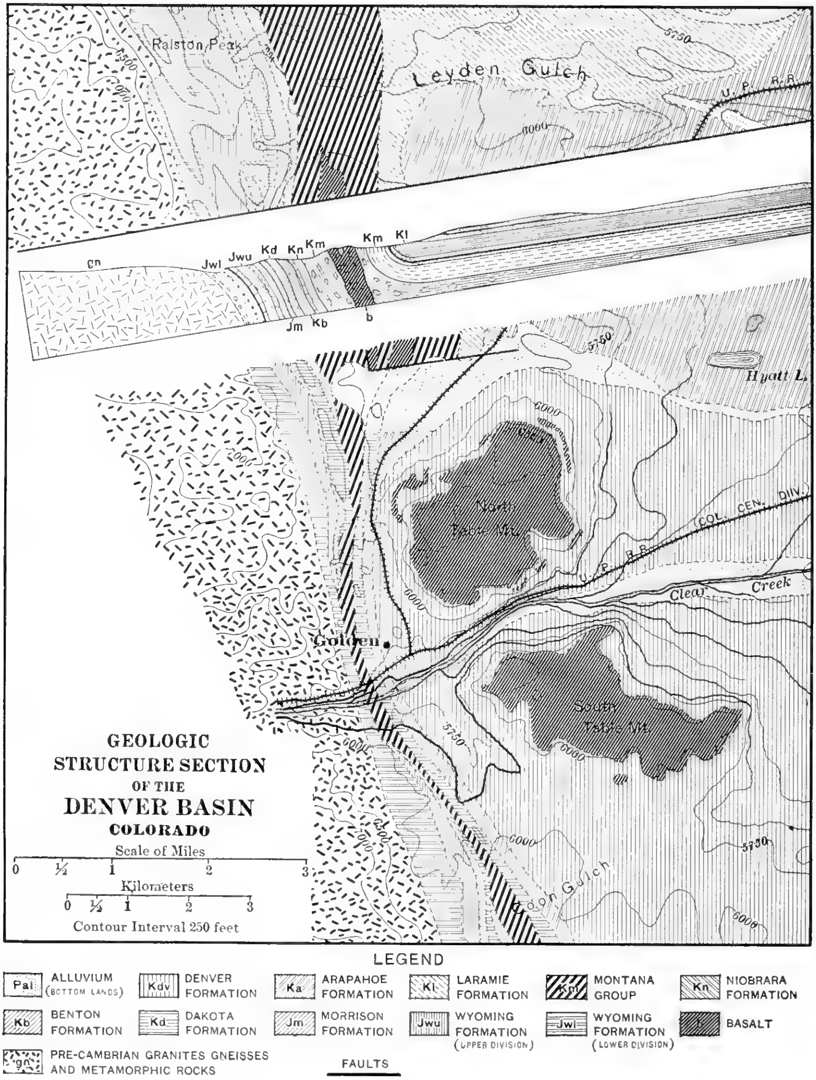


Fig. 122. — Section on the common border of Great Plains and Southern Rockies, showing structure and topography and the lava-capped mesas near Golden, North Table, and South Table mountains. (U. S. Geol. Surv.)

extends from timber line (11,000 feet) to the mountain summit. Its eastern face presents an almost continuous line of steep-walled amphitheaters; the western side of the range is a zone of high mountains 5 to 10 miles across which have steep but not precipitous slopes that descend to the valley of the Grand and are cut by profound canyons.

Southward for 12 miles from Arapahoe Peak the topography changes. The crest presents a very uniform ridge but little above timber line. Like the section north of Arapahoe Peak the eastern face of this section is diversified by amphitheatral valley heads between which are broad rounded spurs of such regular descent that wagon roads ascend some of them. The western face of this portion of the range is marked by massive spurs with rounded forms not separated by canyons.[1]

The whole eastern border of the Colorado Range is usually well defined and even sharply defined, and all along it the mountain spurs end abruptly. They rise from 5000 or 6000 feet, the level of the border of the plains, to 8000 feet at the foot of the main range, and involve a belt about 8 miles wide. The streams draining the border have cut deep parallel valleys and the intervening ridges therefore have an east-west alignment. They are not sharp but massive and have rounded or level summits and steep margins. Their crests fall into a general level in a quite remarkable manner. On the western border of the Colorado Range the descent is also rather abrupt to a general plateau between 8500 and 10,000 feet high which stretches westward for many miles.[2]

These border plateaus have been studied in detail in the Georgetown region west of Denver and their topographic relations clearly defined. It has been found that the Colorado Range here exhibits three sets of topographic forms: (1) an old, mountainous upland, (2) young V-shaped valleys incised in the upland, (3) glacial cirques developed in the valley heads.

The old upland surface, but little modified by recent erosion, occurs in remnants preserved on the ridge crests, which in part accounts for their regularity of elevation, form, and alignment. This mountainous upland was an ancient land surface whose relief in the preceding topographic cycle would be adequately shown by filling the deep valleys cut into it.[3] Dome-shaped mountains and broad soft-contoured ridges stood where sharp peaks and more rugged ridges now are, and the valleys between were broader and less steep than those of the present streams. The surface was well adjusted to that of the underlying rocks and to their varying resistances to erosion. Precipitous slopes were rare and occurred under special conditions, as on the southeastern border of the Alps Mountains of Colorado. Shallow valley heads led

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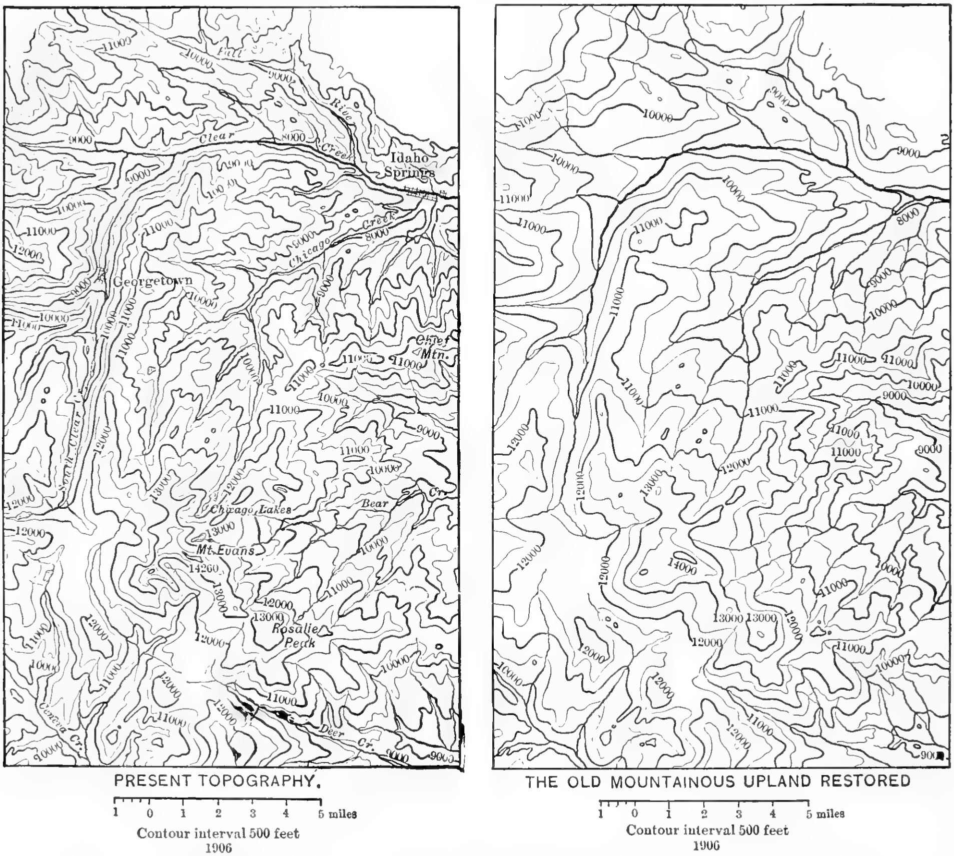
[1] F. V. Hayden, U. S. Geol. and Geog. Surv. of Col. and Adj. Terr., 1873, pp. 86–87.

[2] Idem, pp. 88–89.

[3] Spurr and Garey, Geology of the Georgetown Quadrangle, Prof. Paper U. S. Geol. Surv. No 63, 1908, pp. 31–36. N. M. Fenneman some time ago called attention to the fact that these features appear to indicate an imperfectly base-leveled surface that has been trenched by streams invigorated by recent uplift: Geology of the Boulder District, Col., Bull. U. S. Geol. Surv. No. 265, 1905.

down gently from the dome-shaped mountains of the old upland and joined wide gentle valleys that were broad and basin-like. All these members of the ancient stream systems had normal profiles and no reversed slopes existed; consequently lakes did not then exist. Although both normal and glacial erosion have modified this old upland, remnants of it may still be seen and such remnants bear residual elevations and in many places are covered by deep soil, conditions that were probably general over the larger portion of the area before uplift and glaciation took place, so that rock exposures were comparatively uncommon except on the steepest slopes.[1]



PRESENT TOPOGRAPHY.

THE OLD MOUNTAINOUS UPLAND RESTORED

Fig. 123. — Old mountainous upland of the Georgetown district, Colorado, and present topography. (Spurr and Garey, U. S. Geol. Surv.)

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[1] Spurr and Garey, Geology of the Georgetown Quadrangle, Prof. Paper U. S. Geol. Surv. No. 63, 1908, p. 32.

The mountainous upland of the Colorado Range, formed in late Tertiary time, was then uplifted and tilted eastward so that valley carving was begun. Canyons of considerable size were opened up before the glacial period and these the streams are still enlarging. Clear Creek is in places 2½ miles wide, while the gorges along the Deer, Elk, and Bear creeks, all in the eastern slope of the range, are in general not more than one-half mile wide. The valley walls approach each other upstream and the valleys finally become narrow V-shaped notches in the old upland surface. Rock projects from the valley sides and huge bowlders lie along the courses of the swift streams. The old upland surface is comparable with similar uplands (*a*) in the vicinity of Pikes Peak,[1] (*b*) in the Sierra Madre Mountains of south-central Wyoming,[2] (*c*) remnants of an ancient surface widely distributed over other portions of Colorado,[3] and (*d*) mature profiles widely developed in other portions of the Rockies as in western Montana, p. 318. The character of the old mountainous upland is brought out clearly in the maps of the Hayden Surveys of 1877, where the summits of the long table-topped spurs of various plateau and mountain groups appear to indicate a rather general development of moderate slopes. All of these surfaces are approximately contemporaneous and of late Tertiary age. The mountainous surface is now exposed only in remnants on the spur tops and in certain of the unglaciated valleys.

The present-day expression of the detailed topography of the Colorado Range west of Denver is affected rather intimately by the character of the rock wherever dissection has partly destroyed the older graded surface. The country underlain by schists has very distinctive topographic qualities. Where the dip of the schistosity is low, smooth-contoured slopes are developed upon the exposures; where it is approximately vertical the topographic forms are craggy and serrate as on the north side of Chief Mountain. The gneisses weather into exposures which at a distance have the bedded aspect of sedimentary rocks except where there is a prominent development of joints. The rugged crags found almost continuously along stream valleys carved in gneiss are controlled in their minor details by rectangular joint systems and have very characteristic features. Turrets and buttresses and castellated forms are seen throughout the area covered by the granite-pegmatite, which is one of the most resistant massive rocks of the region.

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[1] W. Cross, Mon. U. S. Geol. Surv., vol. 27, p. 202.

[2] A. C. Spenser, Prof. Paper U. S. Geol. Surv. No. 26, 1904, p. 12.

[3] F. V. Hayden, U. S. Geol. and Geog. Surv. of the Territories, Atlas of Colorado, 1877, Sheets 5, 6, 7.

Below timber line the granite weathers into typical dome-shaped forms, the domes being from 200 to 300 feet high and from 300 to 400 feet in diameter; above timber line the domes are absent owing to the strong temperature changes and their shattering effect.[1]

In the Pikes Peak district of the Colorado Range the chief topographic feature is a great plateau developed upon granite and gneiss and modified by large extrusions of volcanic rock that form mountains upon it. Sedimentary beds, formerly of greater extent, are now confined chiefly to the borders of the tract and to small local basins on the plateau.[2]

GLACIAL FEATURES

The higher parts of the main ranges of Colorado were for the most part covered with ice during the last glacial epoch, only the narrow crests of the inter-valley ridges projecting above the glacial cover.

The ice was deepest and most powerful in the larger mountain valleys down which it extended as valley glaciers for great distances, in some cases out over the piedmont plains or plateaus below.[3] The number of glaciers which existed in the Colorado Range during the glacial epoch may be appreciated by the fact that within the Leadville quadrangle alone, p. 371, there were 26 large glacial systems and 11 smaller ones, or 37 in all, in an area of 945 square miles.[4] The glaciers ranged in elevation from a minimum height of 8800 feet to a maximum height of 13,700 feet. Since many peaks of the Park Range reach elevations approximating 13,000 feet it follows that all the larger valleys were occupied by glaciers. The larger and more vigorous glaciers developed on the eastern slopes, a condition due probably to the greater size of the preglacial valleys rather than to any advantages of exposure or precipitation. As a result of glaciation in the Colorado Range cirques and glacial lake basins were formed. The cross sections of the valleys were developed into a pronounced U shape, so that a shoulder now occurs between a lower, younger, and slightly modified glaciated portion and an upper, older, unglaciated portion. The floors of both cirques and glaciated valleys are very uneven and

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[1] Spurr and Garey, Geology of the Georgetown Quadrangle, Col., Prof. Paper U. S. Geol. Surv. No. 63, 1908, pp. 35–36.

[2] W. Cross, Pikes Peak Folio U. S. Geol. Surv. No. 7, 1894, p. 3.

[3] The extent of any glacier depends upon the following features: (*a*) the height of the surrounding mountains; (*b*) the shape and size of the catchment basins; (*c*) the number and size of the tributary valleys; (*d*) the slope and shape of the valley floor; (*e*) the exposure; and (*f*) the precipitation.

[4] S. R. Capps, Jr., Pleistocene Geology of the Leadville Quadrangle, Col., Bull. U. S. Geol. Surv. No. 386, 1909, p. 9.

smooth rock ledges protrude above the till. Lateral moraines, sometimes double, form prominent narrow ridges of till on either side of the valley walls and are here the most striking types of glacial deposits. The terminal moraines have an irregular surface marked by hillocks, ridges, and depressions and many of them have very steep fronts over which the streams descend in a succession of waterfalls. The cirques are the most striking feature of glacial erosion in the region; the deepest are in the vicinity of Mount Evans, where one cirque wall rises 1700 feet in less than a mile. The steeper cirques have bare, rocky, unscalable walls and frequently have postglacial talus accumulations along their bases. Some of them are compound, as in the case of the three well-defined cirques at different elevations in the valley of the stream that heads in Summit and Chicago lakes, a mile west of Mount Evans. In a number of cases a knife-edge ridge or arête was formed by the headward erosion of two cirques on opposite sides of a divide in the mountainous upland.

TREE GROWTH

The main portion of the Colorado Range was heavily timbered below the cold timber line (11,250 to 12,000 feet) when the valleys of the region were first settled. At altitudes over 8500 feet western yellow pine and Douglas spruce grow on dry areas. On higher and moister ground lodgepole pine and Engelmann spruce are found; these are superseded in turn by dwarf spruce and finally near timber line by mountain white pine. Large areas have been burned over and are now covered with second-growth lodgepole pine and aspen. Above timber line there is an alpine flora of many species.[1]

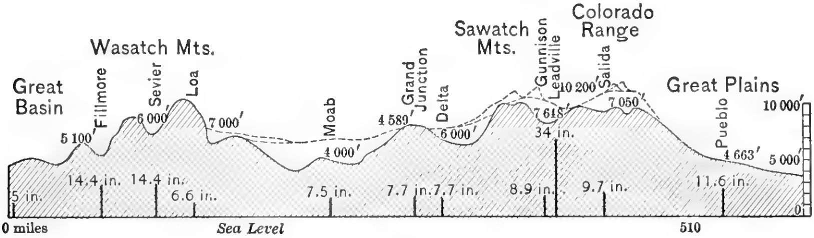

Fig. 124. — Topographic profile and distribution of precipitation across the Wasatch and the southern Rockies.

PARK RANGE

North of the Grand River Valley the Park Range is not high and rugged but a great, rolling, heavily timbered, even-contoured plateau of

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[1] Spurr and Garey, Economic Geology of the Georgetown Quadrangle, Col., Prof. Paper U. S. Geol. Surv. No. 63, 1908, pp 30–31.

crystalline rock with massive marginal slopes. For 50 miles south of the Grand River Valley its character is entirely different. The summit ridges are rugged and sharp and bordered by great amphitheaters with steep, cliffed sides. Deep glacier-scored canyons alternate with the secondary ridges; at their mouths are belts of morainic drift formed by ancient glaciers whose courses were the present valleys or canyons and whose névé fields occupied the existing amphitheaters of the valley heads.[1] Glacial action was carried so far that parts of the range were thoroughly skeletonized. Some of the eastern spurs are flat-faced and have gentle descents. At the higher elevations the western slopes are precipitous being formed upon hard crystalline rock, but at lower elevations where sedimentary rock occurs they become gentler. On both flanks of the range the sedimentary formations seldom rise more than a few hundred feet above the bordering plains and plateaus. The culminating summits of the range are of granite.[2] In structure the Park Range is a great overthrust extensively eroded. The movement was directed westward, hence the western border is abrupt, for it has been developed upon the edges of the overthrust beds in a manner in some respects similar to the eastern border of the Lewis range of Montana (p. 311).[3] The highest peaks are much lower than those of the Colorado Range; Mount Zirkel alone reaches above 12,000 feet, and this in spite of the equivalent elevations of the main summits of the two ranges.[4]

TREE GROWTH

The Park Range is covered with large timber similar to that found on the Colorado Range. The main types are pines above and aspens and small low trees along the lower or dry timber line. In the local alluvium-floored basins timber is wanting, as in Egeria Park and the parks along the Yampah, except for a fringe of cottonwoods bordering the streams.[5]

SAWATCH RANGE

The Sawatch Range extends for over 80 miles from the Mountain of the Holy Cross (lat. 39° 28′) southward to the San Luis Valley. "For this entire distance [it] literally bristles with lofty points about 10 of which rise above 14,000 feet and many more are 13,000 feet above sea

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[1] Hayden Reports, 1873, pp. 178, 188, 189, 436, 437.

[2] Idem, pp. 65–66.

[3] Idem, 1874, p. 71.

[4] Arnold Hague, U. S. Geol. Expl. of the 40th Par. (King Surveys), vol. 2, 1877, pp. 130–132.

[5] S. B. Ladd, U. S. Geol. and Geog. Surv. of Col. and Adj. Terr. (Hayden Surveys), 1874, p. 441.

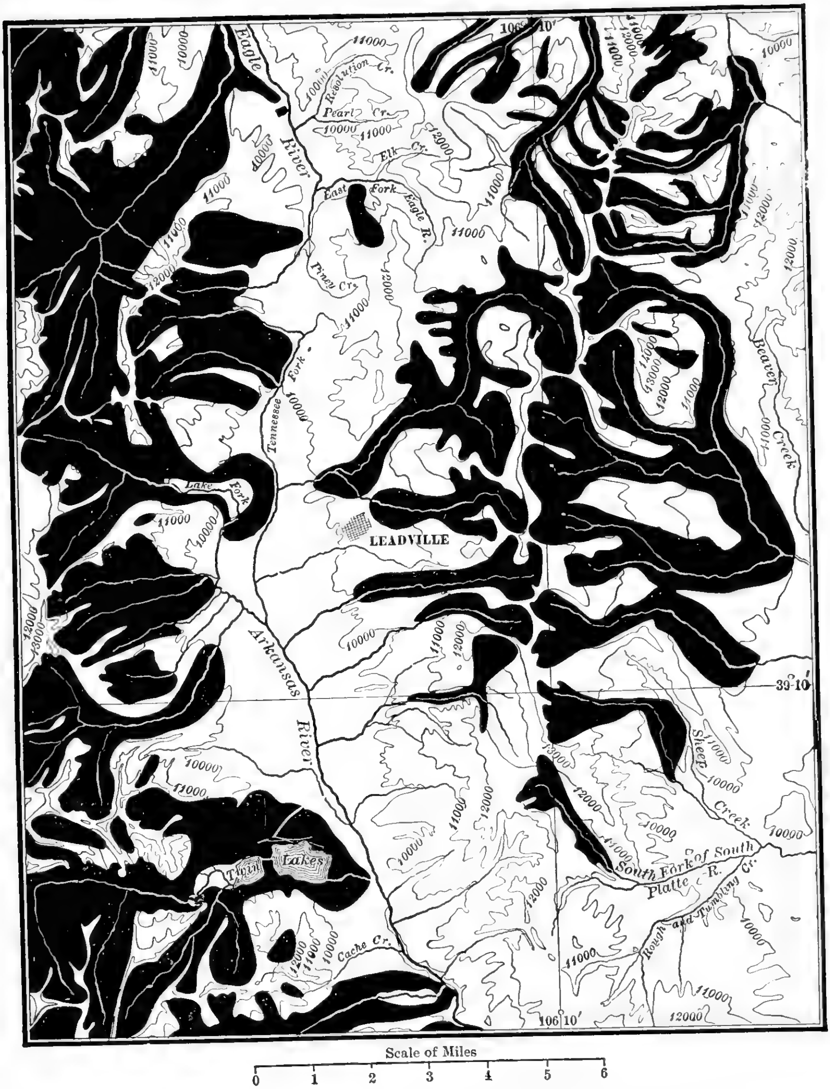

Fig. 125. — Extent of the former glacier systems in parts of the Park (east) and the Sawatch (west) ranges of Colorado, Leadville quadrangle. (After Capps, U. S. Geol. Surv.)

level." It has a rather symmetrical outline, and its pointed summits vary but little in either form or height.[1] On the east is the valley of the upper Arkansas; on the west is the valley of the Gunnison. Like the neighboring ranges on the north and east it is a great anticlinal uplift whose central axis is composed of crystalline rocks from which sedimentary formations dip away at various angles. This type of structure is, however, complicated on the southwestern flank of the range by volcanic flows which wrap about the Sawatch crystallines, as the Cachetopa Hills — a portion of the great igneous field of the San Juan region. Because of this and other structural irregularities, the range is not so simple as the Park and Colorado ranges, and is still more irregular in the southeastern extension of this mountain axis known as the Sangre de Cristo Mountains.

The higher portions of the Sawatch Range have been glaciated in common with the other high ranges of Colorado. Glacial cirques or headwater amphitheaters were developed and peaks trimmed to sharp, sometimes pyramidal outlines.

> La Plata peak in the Sawatch Range has been glaciated to such an extent that it now stands as a sharp peak between the encroaching heads of three glacial channels. Its steep slopes merge into the steep slopes of the glacial cirques that occur northwest, southwest, and east of the peak. The forms of the mountain are all sharp in contrast to the rounded forms of the unglaciated lower portions of the adjacent mountains. Mount Elbert may be cited as a type of peak in which the glacial cirques have not encroached so far and where the summit of the mountain still retains a massive dome-like outline such as La Plata Mountain had before the erosion on its flanks had been carried so far.[2]

SANGRE DE CRISTO RANGE

The Sangre de Cristo Mountains, Fig. 117, rise abruptly on the east from Wet Mountain Valley and Huerfano Park, among the larger parks of Colorado, and on the west from the San Luis Valley. They are from 12,000 to 14,000 feet high with from 3000 to 5000 feet relative altitude. The range follows an almost straight line for 40 miles and presents a very imposing sight, the dark color of the rock bringing out its relief to advantage. Its average width is not much over 10 or 12 miles, which is small compared with its length and altitude. The range extends southward to Sangre de Cristo Pass, and beyond this point the axis of elevation extends to and beyond the New Mexico boundary to Santa Fe, where it ends in a number of minor ranges.

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[1] Hayden Surveys, 1874, p. 54.

[2] W. M. Davis, Glacial Erosion in the Sawatch Range, Col., Appalachia, vol. 10, 1899, p. 403.

North of Poncha Pass the Sangre de Cristo Range is a true sierra. The Sierra Blanca group of peaks, for example, have a serrate and jagged crest line; their precipitous front rises abruptly from the flat San Luis plain to heights of more than a mile, thus giving the range a bold and majestic appearance.[1]

The Sangre de Cristo Range is a great and somewhat complex anticline. In general the axis of the range consists of intrusive granite flanked on both sides by conglomerate chiefly and also by sandstone, shale, and limestone. Faulting has locally caused the sedimentary formations to abut squarely against the basal granite.[2] In places the faults trend at an angle with the main axis of the anticlinal uplift, a structure that causes the topographic condition of offsets that diversify the mountain border.[3] Local variety is given the border relief by dikes of igneous rock which traverse the flanking sedimentaries. The streams have cut deep gorges in the upturned sandstones and limestones; steep bluffs occur along the valley sides and only an occasional patch of flat land occurs on the valley floors.[4]

WESTERN BORDER RANGES

The eastern and central divisions of the southern Rockies are characterized by the presence of granitic masses and extensive areas of metamorphic schists typically represented in the Colorado and Park ranges. But in the westernmost ranges of the district vast quantities of volcanic material have been extruded, which have in many notable instances profoundly modified the topography. The San Juan, La Plata, Needle, and Elk mountains may be taken as typical illustrations. They are so rugged and access to them is so difficult that permanent settlements have been formed in very few places. There are few trails, and at great distances from each other are scattered prospectors' cabins, now commonly deserted.[5]

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[1] C. E. Siebenthal, Geology and Water Resources of the San Luis Valley, Col., Water-Supply Paper U. S. Geol. Surv. No. 240, 1910, pp. 34-35.

[2] Idem.

[3] For structural features see J. J. Stevenson, The Geology of a Portion of Colorado, U. S. Geog. Surveys West of the 100th Meridian (Wheeler Surveys), vol. 3, 1875, pp. 490 et seq.

[4] F. M. Endlich, U. S. Geol. and Geog. Surv. of Col., and Adj. Terr. (Hayden Surveys), 1873, pp. 323 ff.

[5] So little known is the region that during the survey of the Needle Mountains quadrangle, in 1900, a large number of peaks and other prominent features were given names for the first time.

SAN JUAN MOUNTAINS

The term "San Juan region," Fig. 117, is generally applied to a large tract of mountainous country in southwestern Colorado and an adjacent zone of undefined lower country bordering it on the west and south. The greater part of the district is a deeply scored or dissected plateau drained on the north by branches of the Gunnison, on the west by branches of the Dolores and San Miguel, on the south by the San Juan, and on the east by the Rio Grande; the eastern part consists of high tablelands that represent old plateau surfaces; the San Juan Mountains proper extend from the great plateau region of Colorado and Utah on the west to San Luis Park on the east and from the canyon of the Gunnison on the north to the rolling plateaus of New Mexico on the south. They have a length of 80 miles east and west and a north-south width of nearly 40 miles, their summits forming a great group rather than a range. The elevations of the highest peaks exceed 14,000 feet, and hundreds of peaks exceed 13,000 feet. Some of the valleys in the heart of the mountains have been cut down 9000 feet or more, and the configuration, especially on the west, is extremely rugged and presents an almost infinite variety of slopes. Several of the small groups of high peaks in the border zone have special names, such as Needle Mountains on the south, La Plata and Rico mountains on the southwest, and San Miguel Mountains on the west. The geologic structure and to a certain extent the topographic character of the bordering groups are sufficiently unlike the San Juan Mountains to constitute them subordinate topographic divisions.

The southwestern border of the San Juan Mountains is marked by bluffs with vertical faces where the great upland crowned by mountains descends to the Navajo, San Juan, Piedra, and adjacent stream courses, Fig. 117. When viewed from this direction the upland appears as a rugged range, but at the general summit level its true character as a great plateau crowned by isolated summits becomes apparent. The relatively unbroken character of the surface over a considerable number of summit areas prevents thorough drainage, and swamps abound above timber line.

A special feature of the San Juan region remarkably developed in the San Juan Mountains and in many places in the Needle Mountains is the large number of landslides determined by the alternation of soft shale and beds of limestone or sandstone. They consist of great blocks of rock tilted at various angles, with fine material collected in the intervening spaces, and have very uneven surfaces without regular drainage systems. Stagnant pools and morasses alternate with deep trenches. The slides occur at the heads of the ravines and on the sides of the steep ridges separating the smaller valleys.[1]

The landslides of the Telluride and Rico districts of the San Juan region are supposed to have been caused in part by earthquake shocks on such a prodigious scale that the sliding and fracturing of solid rocks occurred. Possibly also the melting of supporting ice masses after they had deepened the valleys and steepened the valley slopes may have added to the effect of the structural conditions.[2] Earthquake shocks have occurred in recent years in the Telluride and Red Mountain districts within the landslide area, and fresh fractures have also been observed in the Red Mountain mines.[3] In the Telluride region the rocks involved in the landslides have been those of the volcanic series which rest upon soft Cretaceous shales.[4]

Fig. 126.—Landslide surface below Red Mountain, near Silverton, Colorado.

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[1] Ernest Howe, Landslides in the San Juan Mountains, Colorado, Prof. Paper U. S. Geol. Surv. No. 67, 1909.

[2] Cross and Howe, Silverton Folio, Col. U. S. Geol. Surv. No. 120, 1905, p. 25, col. 1.

[3] H. C. Lay, Trans. Amer. Inst. Mining Engineers, vol. 31, 1902, pp. 558–567.

[4] F. L. Ransome, A Report on the Economic Geology of the Silverton Quadrangle, Col., Bull. U. S. Geol. Surv. No. 182, 1901, pp. 27–28, et al.

RAINFALL AND VEGETATION

The San Juan Mountains are surrounded by arid country, but they themselves have an abundant precipitation, the higher peaks and basins being seldom entirely free from snow. The abundant water supply supports a heavy forest growth in many localities upon the western and northern slopes. The upper timber line lies between 11,500 and 12,000 feet, and as a consequence large areas in the lofty interior of the San Juan Mountains are without tree growth, although a low alpine flora is found in favored situations. Spruce and aspen cover the higher slopes, and below them white pine, scrub oak, piñon pine, and cedar are found. On the great volcanic plateau of the San Juan region the precipitation is less and supports only an herbaceous vegetation. Prominent yet low cone-shaped peaks present a more desolate appearance and are sometimes so strewn with rock fragments as not to support plants of any sort. High plateaus of volcanic rock appear in places with a grassy vegetation so different from the forests on the older sedimentary and igneous rock to the east and locally in the deep canyons of the volcanic area, as to form in a certain sense a guide to the geologist.[1]

LA PLATA MOUNTAINS

The La Plata Mountains are located between the well-watered, well-forested San Juan Mountains and the arid mesa, plateau, and canyon country that extends into Utah, Arizona, and New Mexico. The La Plata Mountains are a dissected dome and their drainage systems have a radial arrangement. Many of the peaks rise a thousand feet or more above timber line and are characteristically rugged.[2] On the west the slopes descend rather steeply 4000 or 5000 feet to the rolling plain known as the Dolores Plateau, deeply dissected by a number of deep canyons, Fig. 78. The simple character of the La Plata Mountains is complicated on the western and northwestern sides by intruded igneous rocks which occur in soft shales overlying sandstone, the intrusive rock having prevented the uniform erosion of the shales. On the southwest the dip of the slope of the sandstone is uninterrupted between 8000 and 10,000 feet, and the descent in this quarter is regular and broad. The intrusive rock is for the most part porphyry, and the masses are large enough to cause peaks or ridges which appear as irregularities in the

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[1] F. M. Endlich, U. S. Geol. and Geog. Surv. of Colorado (Hayden Surveys), 1873, p. 306.

[2] Cross and Spencer, La Plata Folio U. S. Geol. Surv. No. 60, 1899, p. 1.

Fig. 127. — Looking down La Plata Valley from the divide at the head of the valley. The steep slopes are characteristic. Landslide in left foreground. (La Plata Folio U. S. Geol. Surv.)

Fig. 128. — Western summits of La Plata Mountains from the divide at head of La Plata Valley. This view is panoramic with the view above. It shows the rugged summits within the eroded volcanic stocks of the mountains. Diorite Peak on left. (La Plata Folio U. S. Geol. Surv.)

general slope of the dome. The porphyries occur as sheets or small laccoliths;[1] later intrusions took place which cut the sedimentary beds and the sheets of porphyry forming stocks which constitute several of the highest peaks of the La Plata Mountains.

In connection with the formation of the dome of the La Plata Mountains a number of faults were developed but these are neither numerous nor important. The upthrust is commonly on the side near the center of the dome and has resulted in the formation of a number of steep slopes facing southward.[2]

The arid plains or plateaus rising west of the La Plata Mountains support a growth of white pine, piñon, and cedar, transitional between the barren expanses of the plateau and the forested slopes of the La Plata Mountains. In general the heaviest timber grows on the western and southern slopes since it is from those directions that the winds commonly blow. The forests extend up to 11,500 and 12,000 feet; the growth consists of spruce, fir, and aspen; above the timber line there is a scanty vegetation of alpine character.[3]

NEEDLE MOUNTAINS

The rocks composing the Needle Mountains are chiefly granite, schist, and some quartzite. Four of the summits exceed 14,000 feet in elevation and many exceed 13,000. Some of the mountains are deeply dissected and extremely bold. North of the Needle Mountains is the great curve of the Grenadier Range, which is chiefly of quartzite; on the north and east the surface is almost entirely covered by volcanic or other rocks; on the south sedimentary rocks were laid down upon a pre-Paleözoic land surface of moderate relief, now exposed (by the removal of the sedimentary cover) in the form of a southward-sloping tableland consisting of isolated mesas between deep-cut valleys. There is thus afforded a very strong contrast between the sharp peaks and needles of the Needle Mountains and the comparatively low relief of the reëxposed and ancient land surface extending southward from them.[4]

Of great topographic importance was the formation (Tertiary) of three series of volcanic accumulations: (1) a tuff which attained a thickness of 3000 feet east of Ouray (San Juan), (2) lava flows, tuffs, and agglomerates (Silverton Series), also reaching a thickness of about half

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[1] Cross and Spencer, La Plata Folio U. S. Geol. Surv. No. 60, 1899, p. 8, col. 1.

[2] Idem, p. 10, col. 3.

[3] Idem, p. 2, col. 1.

[4] Cross and Howe, Needle Mountains Folio U. S. Geol. Surv. No. 131, 1905, p. 1, cols. 2–3.

a mile in places; and (3) later thin lava flows and tuff of a third period of volcanic activity (Potosi Series). In connection with the formation of these materials there were intruded into the sedimentary rocks various dikes, sills, laccoliths, and irregular masses which are the deeper-seated equivalents of the surface volcanics.

On the flanks of the Needle Mountains dome a simple consequent drainage was developed during the doming period. The southern flanks of the dome were not covered with volcanic material and the consequent drainage developed on these slopes was not affected by volcanic action. The northern slopes of the domes, on the other hand, were affected by volcanic outpourings and the drainage greatly modified. After the last great eruptions the streams proceeded to dissect the surface deeply.

Fig. 129.—Mount Wilson group in background. Looking down Howard Creek from south of Ophir Pass.

The consequence of further uplift of the region and resulting deep dissection has been the formation of a confusing variety of slopes in intimate relation to the detailed geologic structure. Within short distances of each other one may find (1) ancient granites, (2) sedimentaries of more recent origin, (3) Tertiary conglomerates, and (4) more recent volcanic accumulations. The development of slopes upon these varied rocks has naturally been very complex and few generalizations may be applied to individual mountains or to the group as a whole.

Fig. 130.—Part of Needle Mountains, Colorado. Grenadier Range on west, White Dome in center; about the head of Vallecito Creek. These two views are panoramic with each other.

GLACIAL FEATURES

A phase of the recent dissection of the region is associated with glaciation; the conditions prevailing in the Needle Mountains during the portion of the glacial period of which the best records are left were nearly the same as those which exist in the Alps at the present time. From the positions of well-defined terminal and lateral moraines it is inferred that during the last recognized period of glaciation alpine glaciers descended the more favorably located valleys some 25 miles. The rock débris in the terminal moraines consists largely of material derived from the Needle Mountains. The higher and sharper peaks and ridges were not buried beneath ice and snow, but at lower elevations the bare rock surfaces are grooved and polished and indicate vigorous glacial action.

ELK MOUNTAINS

The principal range of the Elk Mountains lies north of the San Juan region and west of the northern end of the Sawatch Range. The mountains have great diversity of color, due to the presence of light-gray trachyte, red, maroon, and brown sandstone, etc. They are from 13,000 to 14,000 feet high, and are characterized by sharp, conical peaks and ragged, serrated ridges, pinnacles, and spires. The main range is bordered throughout a large part of its extent by broad, high, flat-topped spurs or secondary ranges.[1] It is about 40 miles long and dissected by gorges and canyons whose extreme ruggedness and picturesqueness are owing to the complicated structure, the variegated rocks, and the youthfulness of the forms themselves. Enormous amphitheaters at the heads of the bordering valleys have been cut back so far as to give the main crest a zigzag course and to make it so narrow as to be almost impassable.[2]

PARKS OF THE SOUTHERN ROCKIES

Between the two main ranges of the Rockies in Colorado is a line of basins of exceptional interest. The three northernmost, North, Middle, and South parks, are geologically a unit. Their southern continuation is not San Luis Park, as generally supposed, but Wet Mountain Valley and Huerfano Park between the front range axis on the one hand and the Sangre de Cristo axis on the other. The San Luis basin lies between the latter axis and the Sawatch Mountains. The former depression began to take shape at least as far back as the Triassic; the San Luis Valley is occupied chiefly by late Tertiary and Pleistocene sediments.[3]

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[1] H. Gannett, U. S. Geol. and Geog. Surv. of Colorado and Adj. Terr. (Hayden Surveys), 1874, p. 417.

[2] Hayden Surveys, 1874, pp. 58, 71.

[3] C. E. Siebenthal, The San Luis Valley, Colorado, Science, n. s., vol. 31, 1910, p. 745.

San Luis Park is the largest of the five main parks of Colorado. It is in many respects like the Sage Plains of the Green River Valley or the valley of the San Joaquin in California, consisting of a depression floored by young sedimentary strata and still younger alluvium; the lost rivers on the piedmont alluvial plain flanking the mountainous margin of the basin are also characteristic. Each of these parks drains to the sea by way of a stream which cuts through a deep mountain gorge on the margin of the basin. North Park is drained by the Platte, South Park by the South Platte, Middle Park by the Grand, and in the mountains enclosing San Luis Park the southward-flowing Rio Grande takes its rise. These parks are all the more striking because they lie in the midst of a very rugged mountain region. Their unique character is due primarily to broad intermont structural depressions whose low relative elevation and high outlets have made them the seat of aggradation, not dissection, while the neighboring uplifts are among the loftiest ranges in the country and have been profoundly dissected, giving rise to a rugged and, locally, even an alpine topography. With these general relations in mind we shall now note briefly the special features of each park.

NORTH PARK[1]

North Park, 7500 feet above the sea, is nearly quadrangular in shape; it is about 50 miles in extent from east to west and 30 miles across from north to south. Its surface, although somewhat rugged, is marked by broad bottoms along the streams, especially the North Platte and its tributaries. The lofty and, for a part of the year, snow-covered mountains enclosing it like a gigantic wall, are covered with a dense growth of pine, but scarcely a single tree may be found over the whole 1500 square miles of the park itself save along the stream courses. Grass is found in abundance, and the park was originally the feeding ground of thousands of antelopes. The bordering strata dip under the park, becoming nearly or quite horizontal toward its center. In this respect North Park resembles the three other major parks of Colorado in being primarily a great structural depression sufficiently free from mountainous elevations and hence sufficiently drier to form a striking contrast to the high forest-clad country about it.

MIDDLE PARK

Although Middle Park has on the whole a basin-like aspect, yet in detail this feature is often lost in the prominence of many of the ridges separating its secondary drainage lines. In this respect it is in sharp

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[1] F. V. Hayden, U. S. Geol. Surv. of the Terrs., 1867, 1868, and 1869, pp. 87–88.

contrast to both North and South parks on either hand. The basin is unique in being the easternmost region in the United States where Pacific waters take their rise; it drains westward through the Grand River to the Pacific. The borders of the basin are composed of crystalline schists and granites on the eastern, southern, and western sides, while the northern border as well as much of the floor of the basin is composed of younger sedimentaries.[1]

SOUTH PARK

South Park is about 45 miles long and about 40 miles wide at its widest portion near the southern end. Its elevation at the north is about 9500 feet, at the south about 8000 feet. Its surface is regular only by contrast with the more rugged country surrounding it. Numerous parallel ridges with northerly trend cross the park and make its surface irregular. At the southern end are many isolated buttes, most of them of volcanic origin. Portions of the park are underlain by rather flat-lying sandstone, as is the case with San Luis Park, and such portions have as a rule a more uniform surface than the rest.[2]

SAN LUIS PARK

The San Luis Valley basin owes its origin primarily to the broad, gentle, trough-like depression of its underlying sandstones. In late geologic time it probably contained a lake of considerable extent, a condition inferred from the character of the fine sediments accumulated in it.[3] The draining of the lake by the cutting down of the outlet stream, the building up of great alluvial fans, among which that of the Rio Grande is the largest, and the deposition of glacial deposits locally about its border are still later occurrences of physiographic importance.

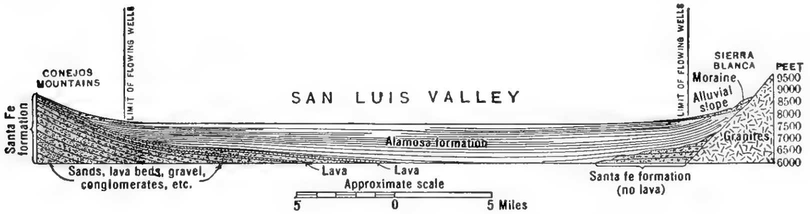

Fig. 131. — Cross section of San Luis Valley from foot of Blanca Peak to foot of Conejos Range. (Adapted from Siebenthal, U. S. Geol. Surv.)

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[1] Emmons, Cross, and Eldridge, Geology of the Denver Basin in Colorado, Mon. U. S. Geol. Surv. No. 27, 1896, p. 4.

[2] A. C. Peale, U. S. Geol. and Geog. Surv. of Col. and Adj. Terr. (Hayden Surveys), 1873, p. 212.

[3] F. M. Endlich, U. S. Geol. and Geog. Surv. of Col. and Adj. Terr. (Hayden Surveys), 1873, pp. 334, 339.

San Luis Valley appears nearly level over great areas but in fact it departs from the horizontal by important amounts. The marginal slopes descend by regular gradients to an axial depression located well toward the eastern margin of the valley; they are developed upon a series of coalescing alluvial fans and the longest and flattest slopes are those built by the largest streams; the Rio Grande has built an alluvial fan so large as to throw the axis of the valley to one side (east) of the center of the depression.[1] The eastern side of the basin is bordered by the Sangre de Cristo Range, on whose flanks a great alluvial plain has been formed whose deposits above an elevation of 9000 to 9500 feet consist of fluvio-glacial débris formed in connection with Pleistocene glaciers. Concentric terminal moraines surmount the crests of the alluvial fans and cones, Fig. 131.[2]

Fig. 132. — Looking eastward from Hunt Springs across the north end of San Luis Valley; San Luis Creek in the middle distance, Sangre de Cristo Range in the background. (Siebenthal, U. S. Geol. Surv.)

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[1] C. E. Siebenthal, Geology and Water Resources of the San Luis Valley, Col., Water-Supply Paper U. S. Geol. Surv. No. 240, 1910, p. 10.

[2] C. E. Siebenthal, Notes on Glaciation in the Sangre de Cristo Range, Colorado, Jour. Geol., vol. 15, 1907, p. 15. Idem, The San Luis Valley, Colorado, Science, n. s., vol. 31, 1910, p. 746.

Northeastward from Antonito there stretches a line of flat-topped to rounded basaltic hills which represent late flows upon the alluvial floor of the valley. They form the chief topographic break in the continuity of the basin floor. The smooth valley surface is also interrupted in a number of localities by sand dunes. The highest occur between Medano and Sand Creek and these also cover the most extensive single tract, 40 square miles. They consist of rather coarse, white, quartzite sand blown into place by the heavy southwest winds that occasionally blow for a two or three day period across the valley. Elsewhere the sand is commonly blown out of place between patches or clumps of bush and grass, leaving small hollows or basins that contain lakelets in the wet season.[1]

OTHER TYPES OF PARKS

Besides these large intermont parks there are scores of smaller ones. They have been formed in at least four main ways. (1) San Luis Park, as we have seen, is a broad structural basin drained by the Rio Grande River, and the same is true of North, South, and Middle parks. (2) In the Pikes Peak region and specifically in the south-central portion of the Pikes Peak quadrangle, is a depression known as Shaw's Park; it is formed upon sandstones, marls, and limestones in the form of a syncline whose margins have been in a number of cases downfaulted in a pronounced manner. The weathering of the softer sedimentaries has accentuated the flatness of the depression normal to the synclinal structure and thus developed a lowland 5 or 6 miles in width. A similar park has been developed under similar structural conditions immediately west of Shaw's Park and is known as Twelve Mile Park. (3) A third type of park may be seen very commonly throughout the region, a typical occurrence being Low Park, shown in the Needle Mountains topographic sheet, in the valley of the Florida River, where a broad valley lowland is formed by combined glacial erosion and the present drainage.[2] Similar valley lowlands of small extent are not uncommon at the junction of tributary and master streams and are commonly known as "parks." (4) A fourth type of park is described by Powell,[3] who calls attention to the fact that the great anticlinal folds in the Park Mountains have a north-south trend and that on the flanks of each fold there is developed a zone of maximum dip so that the rocks at the flanks of the ranges are turned abruptly down. In such cases small parks are formed by the wearing out of the softer beds, leaving

[1] C. E. Siebenthal, Geology and Water Resources of the San Luis Valley, Col., Water-Supply Paper U. S. Geol. Surv. No. 240, 1910, pp. 47–48. The detailed features of the San Luis basin are represented in Sheet 10, Atlas of Colorado, Hayden Surveys, where the course of the Rio Grande is shown as well as the course of San Luis, San Isabel, and other creeks which empty into San Luis Lake instead of having a surface channel to the Rio Grande.

[2] Pikes Peak Folio U. S. Geol. Surv. No. 7, 1894.

[3] Physiography of the United States, Nat. Geog. Soc. Monographs, 1896, pp. 88–89.

the harder strata standing as great steep walls parallel to the axes of the principal ranges. The famous Garden of the Gods near Pikes Peak is explained in this way.

TREE ZONES AND TYPES

Among the smaller parks Estes Park shows a typical zonal arrangement of the tree species of northern Colorado. There are three well-defined forest types: (1) the yellow pine type, developed typically as an open woodland which reaches from the upper foothills to an altitude of 9000 feet; it occupies the ridges and slopes of the lower part of the park, but at higher elevations occurs only in the open valleys. In the open it occurs on small rocky knolls and ridges, whence it invades the grasslands of the park floor. (2) The lodgepole pine-Douglas spruce type occurs above the yellow pine type between 8000 feet and 10,000 feet, though below the lesser altitude the growth is mixed to some extent with the yellow pine, while above the greater altitude it is mixed with Engelmann spruce. (3) The Engelmann spruce-alpine fir type constitutes the forest at timber line and usually some distance below it. Timber line is here at 10,500 feet. From 8500 to 9000 feet the grass land of Estes Park is in the form of typical mountain meadows.[1]

Among the larger parks San Luis exhibits a rather typical distribution of vegetation. On the high mountain sides flanking San Luis Valley are pine, aspen, and spruce. Lower down are piñon and cedar; in the valleys and along the streams are cottonwood and willow. Away from the streams and on the arid basin floor greasewood is the principal growth.[2]

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[1] F. E. Clements, The Life History of Lodgepole Pine Forests, Bull. U. S. Forest Service No. 79, 1910, pp. 7–8.

[2] C. E. Siebenthal, Geology and Water Resources of the San Luis Valley, Col., Water-Supply Paper U. S. Geol. Surv. No. 240, 1910, p. 26.

CHAPTER XXI

TRANS-PECOS HIGHLANDS

MOUNTAINS AND BASINS

THE Trans-Pecos region embraces an assemblage of topographic forms which individually resemble the features of adjacent provinces, the Rocky Mountain province on the north, the Arizona Highlands province on the west, and the Mexican plateau on the south, and it may therefore be regarded as a transition province. The Trans-Pecos ranges do not have that continuity which marks the main mountain ranges of the Pacific Cordillera. They exhibit a great variety of slopes produced at different geologic times and in many different ways; the province includes a mixed group of topographic forms not conveniently classified with the forms of adjoining provinces. In this respect it is unlike the other physiographic regions of the United States, each of which has a certain essential unity of structure or topography or both.

Mountains and intermontane plains of several types and of variable extent are the predominating features of the Trans-Pecos country. The latter are in part plains of degradation, in part broad constructional plains built up by detritus from the bordering mountains and called bolsons (Spanish *bolsón*, for "large purse"). The trend of the mountains and intervening basins is north-south, except near and south of the New Mexico-Texas boundary where they trend northwest-southeast. In general the elevations are distinctly lower than those of any other portion of the Pacific Cordillera in this longitude. Only two peaks rise above 8000 feet and the general elevation of the lowlands is from 3500 to 4500 feet.

While the greater number of the Trans-Pecos mountains have a fault-block origin, as a whole they are of diverse origin, structure, and topography. They exhibit many irregular forms of relief and all have sharp and rugged outlines. Few of them rise to the height of the dry timber line (6000 feet). On the summits and in the higher canyons of the Sacramento, Chisos, and Davis mountains, and a few others, this elevation is exceeded and a certain amount of timber is found. On the lower and drier mountains the vegetation consists of edible pines, a variety of junipers, and several species of maguey. The lower eleva-

Fig. 133. — Principal mountain ranges of the Trans-Pecos province, chief drainage features, and the bordering Llano Estacado on the east. (U. S. Geol. Surv.)

tion of the group as a whole is expressed in the lesser rainfall and general barrenness of the mountains in contrast to the partly timbered Rocky Mountains to the north. The highest summit is Sierra Blanca (11,880 feet) in the Sacramento range in southern New Mexico, but in general the peaks fall short of this altitude.

Mountain Types

Four types of mountains may be identified: (1) mountains of deformation, consisting of structural folds or tilted fault blocks in which the outline of the mountain is in sympathy with the structural breaks or deformations, for example the Sandia and Manzano mountains east of Albuquerque; (2) plateau mountains, consisting of nearly horizontal plateaus without important deformations. This type of mountain occurs in the form of summits or shoulders and in close proximity to

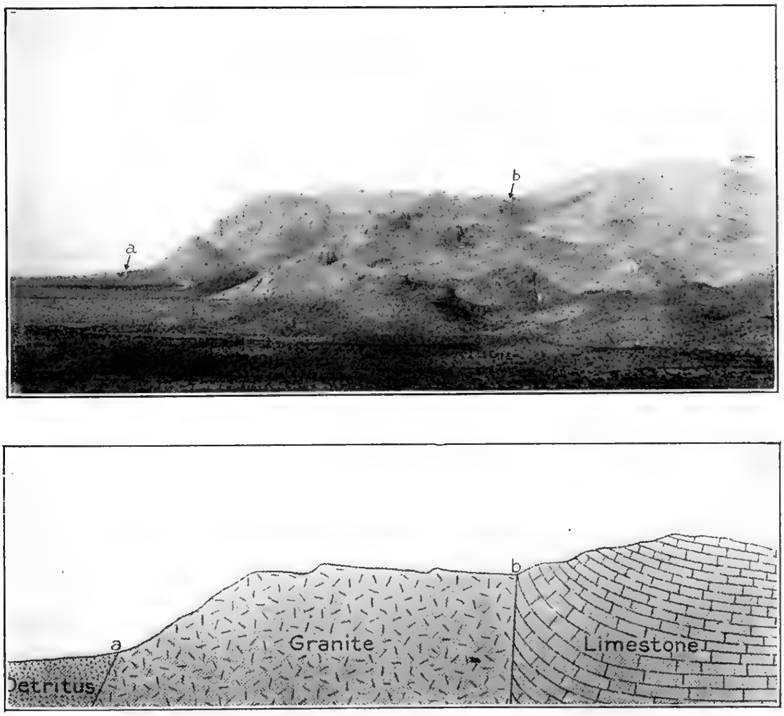

Fig. 134. — Western face of the Fra Cristobal Mountains, New Mexico. Two faults, *a* and *b*, give prominence to the mountain front. They are represented in the section below the photograph. (Lee and Girty, U. S. Geol. Surv.)

the higher relief features of the province.[1] (3) Mountains due to the upthrust of a granitic core through sedimentary rock that now forms the borders of the range, as the Black and Mimbres ranges. (4) Mountains consisting chiefly of volcanic material like San Mateo and Valles mountains and others. The members of the last-named group fall into three subtypes: (*a*) old igneous vents such as dikes and necks, (*b*) volcanic craters, and (*c*) mesas capped by sheets of lava that have protected the underlying rocks from the denudation that carried away the surrounding material.

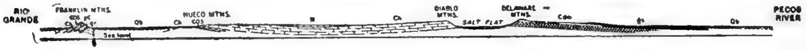

Fig. 135.— East-west section across the Trans-Pecos Highlands north of El Paso, Texas. pC, pre-Cambrian quartzite and porphyry; COS, Ch, gs, etc., paleozoic limestone, sandstone and gypsum; K, cretaceous limestone and sandstone; gr, intrusive granite; Qb, Quaternary basin deposits. Scale, 1 inch represents nearly 50 miles. (Richardson, U. S. Geol. Surv.)

The Trans-Pecos province is one of the least-known physiographic provinces in the United States and few generalizations may be made concerning details of mountain form beyond those in the preceding paragraph. It is known that the province as a whole is separated from the Rocky Mountains province at Bernal, New Mexico, by a broad level plain or plateau, and it is not until about 100 miles south of Bernal that the mountains of the Trans-Pecos begin in the Jicarillas, the northern outliers of a chain of mountains, the loftiest ranges of the province, that extends with marked continuity through New Mexico and Texas as far as the 32d parallel. The individual members of the chain are the Jicarillas on the north, and next in order from north to south are the Sierra Blanca, Sacramento, Sierra Guadalupe, Comanches, Caballos, and the Sierra de Santiago. These constitute the front ranges of the province and they give a distinctive character to the eastern edge of the highland belt in which they lie. The rocks composing these mountains are chiefly limestone and sandstone. The general structure of the eastern border ranges is an eastward-dipping monocline ending at the Rio Pecos, but there are many lateral ridges and separate peaks. On the west the mountains of the eastern border terminate in a steep scarp 1000 to 2000 feet high. The long eastern slopes correspond with the dip of the underlying strata.

West of the front ranges of the Trans-Pecos country are other ranges of the fault-block type. They occur as short sierras or groups of sierras in the form of isolated mountains or elongated chains surrounded by extensive and nearly level desert plains. They have lower altitudes

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[1] R. T. Hill, Physical Geography of the Texas Region, Folio U. S. Geol. Surv. No. 3, 1900, p. 3.

than the front ranges, and so isolated are the various members that no group name has been given them. The principal ranges are, however, arranged in two lines on either side of the Rio Grande Valley. On the east side are the Sandia, Manzano, Oscura, San Andreas, and Organ ranges; on the west are the Nacimiento, Limitar, Magdalena, Cristobal, Caballos, and Cuchillo Negro ranges. The fault scarps of these ranges are always steep and in general face inward toward the Rio Grande Valley, which is thus a great structural depression or series of elongate basins, though there are some important exceptions to this rule. They are all high and in process of vigorous dissection, and hence display a

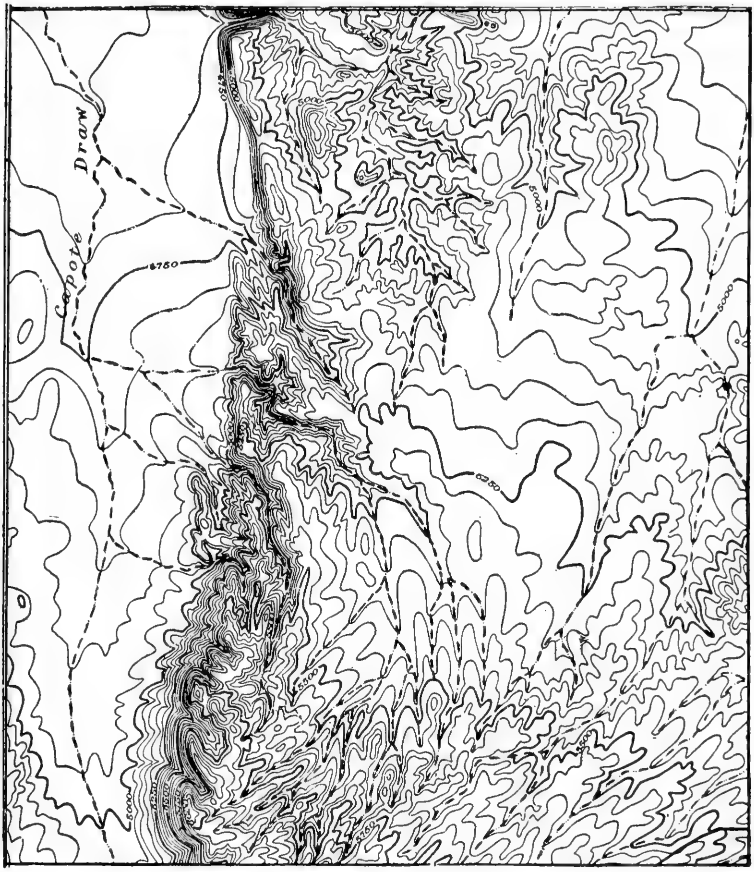

Fig. 136. — Fault-block mountain in the Trans-Pecos Highlands, Texas. (Marfa quadrangle, U. S. Geol. Surv.)

varied relief. The trend of the group is, however, definite, due to their fault-block origin, and of similar definiteness are the valleys that occur among them. Westward of these block mountains are many short independent blocks surrounded by bolson deserts and not capable of union into related chains. They rise from desert plains and in general have steeper descents on their western than on their eastern sides. They consist for the most part of fault blocks with monoclinal dips, although in places extensive folded structures also occur.

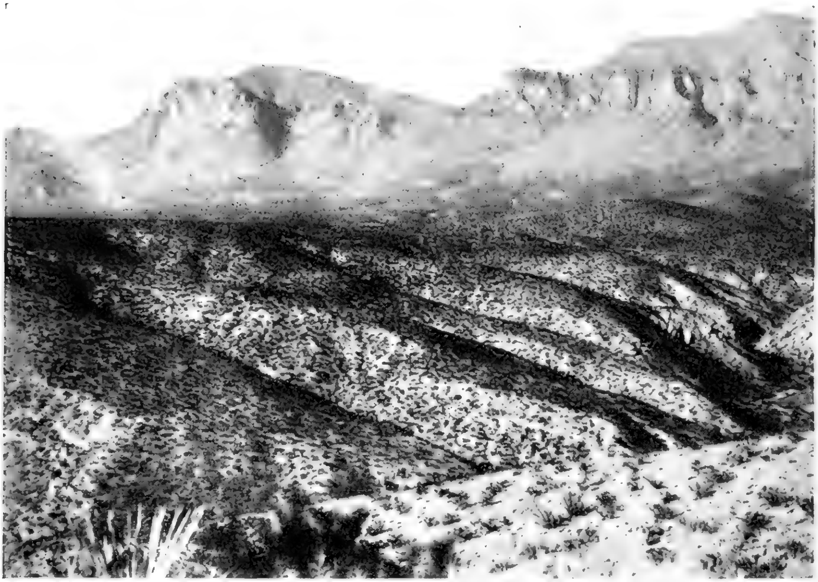

Fig. 137. — Western escarpment of the Caballos Mountains, New Mexico, and the dissected alluvial slope at their base. (Lee, U. S. Geol. Surv.)

FRANKLIN RANGE

The most detailed study of mountain form and structure in the Trans-Pecos region is by Richardson, whose structural sections of the Franklin range are shown in Fig. 138. They will serve as illustrations of a type of mountain found in the province. The Franklin range is a long, narrow, crust block resembling the mountains of the basin-range type in its general features but differing from many though not from all of them in having a more complex system of internal faults. The strata strike parallel to the trend of the range and dip westward at steep angles. On the steeper eastern face of the Franklin range are exposed the eroded edges of the strata composing the fault block, while the gentler westward slope coincides to an important degree with the dip of the underlying strata. The range is broken into several secondary blocks by normal parallel faults some of which strike with the trend of the range, but there are also several transverse fractures, and the strike of a few of the faults is a curve. Both the eastern and the western margins of the range are marked by faults; that on the western border consists of two parallel faults at the base of the range between the foothills and the main mountain mass. The greatest displacement is in the central part of the range, where a throw of 2500 feet has been determined.

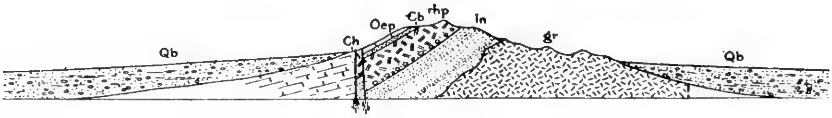

Fig. 138. — Section across Franklin Mountains, showing relation of structure to relief. In, quartzite; rhp, rhyolite porphyry; Cb, sandstone; Oep, Om, Sf, Ch, and Kcm, limestone; gr. intrusive granite; Tap, andesite porphyry; Qb, basin deposits. Scale 1 inch represents 2 miles. (Richardson, U. S. Geol. Surv.)

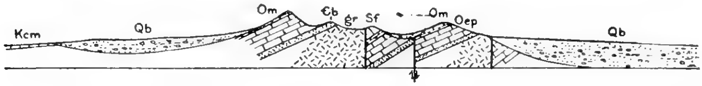

Fig. 139. — East-west section across the Franklin Mountains north of El Paso, Texas. To supplement Fig. 138. Legend and scale as in Fig. 138.

The fault at the eastern foot of the range is completely concealed by wash and its position is hypothetical. That the mountain front is the locus of a fault is suggested by the evidences of geologically late (probably Quaternary) faulting at El Paso, where displacements in alluvial deposits may be seen, and by the benches west and northwest of Fort Bliss at elevations ranging about 4000 feet. The benches are the upper portions of broken alluvial slopes which in places fringe the base of the range in an uneven eastward-facing scarp varying from 10 to 50 feet in height. In many places the bench has been destroyed by erosion along the many arroyos that descend from the adjacent mountains. The original fault along the base of the range is probably of ancient origin, for the drainage has diversified the eastern border and to a large extent obliterated that inequality of slopes that obtains in the case of a young block mountain.[1]

VOLCANIC MOUNTAINS AND PLATEAUS [2]

In addition to the mountains formed out of tilted crust blocks of sedimentary material there are many eccentric and irregular mountains of volcanic origin that rise from broad plains. Of this type are the Chisos (ghosts), Corazones (hearts), the Sierra Blanca, and the Davis mountains, among which the last-named are the most extensive. They consist of a group of volcanic necks and dissected volcanic plateaus that end

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[1] G. B. Richardson, El Paso Folio U. S. Geol. Surv. No. 166, 1909.

[2] R. T. Hill, Physical Geography of Texas, Folio U. S. Geol. Surv. No. 3, 1900.

Fig. 140. — Fisher's Peak and Raton Mesa. Shows vertical cliffs of basalt, and the flat-topped mesa rising 3000 feet above the plain in the foreground. The prominent terrace is developed on a hard flat-lying stratum (Laramie).

at the south in a great escarpment over 1000 feet in height that overlooks the continuation of a broad intermontane plain toward the south.

The mesa and cuesta types of mountains are capped in some instances with old igneous material in places 500 feet thick. The volcanic caps are remnants of former sheets of similar material that have been all but removed by denudation. Elephant Cuesta and Nine Point Mesa are illustrations of this kind of mountain. Besides these are other volcanic mountains of recent origin, cinder cones or true volcanic craters accompanied by sheets of lava which flowed from them. The craters are of interest because they are the most easterly known in the United States and the only ones lying east of the front of the Cordillera. The cinder cones have been formed since the degradation of the Mesa de Maya and Ocate plateaus, for they rise out of the newer and lower plain below the latter. The most conspicuous crater is Mount Capulin, a very symmetrical cinder cone with a vast crater at the top of it.

Within the Trans-Pecos Highlands are extensive areas of uplands with sublevel summits bordered more or less completely by pronounced escarpments. They occur as large benches that border the mountain ranges or that rise from the bolson deserts. They are either completely isolated from the mountains or project bench-like from the bases of the mountains. They are lava-capped mesas whose summit layers of hard volcanic rock have protected the more friable material underneath them; they are distinguished from the flat-topped mountains noted above only by their greater extent and lesser elevation. They are cut by deep canyons, bordered by steep escarpments, and owe their present outlines to marginal erosion. Northeastern New Mexico, Fig. 133, is therefore not a part of the Great Plains but an eroded plateau of Cretaceous rock surmounted by basaltic flows.[1]

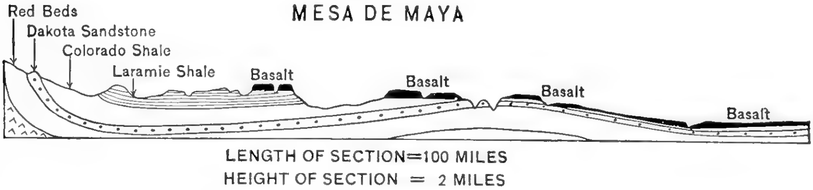

Fig. 141.— Upturned strata on the eastern border of the Rockies, the anticlinal structure of the bordering strata underneath the Mesa de Maya, and the protective influence of the basalt cover. (After Keyes.)

The three most conspicuous plateau plains of northern New Mexico are known as the Mesa de Maya, the Ocate Mesa, and the Las Vegas

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[1] R. T. Hill, Notes on the Texas-New Mexico Region, Bull. Geol. Soc. Am., vol. 13, 1892, pp. 85–100.

Mesa. The western portion of Mesa de Maya is also known as Raton Mesa or Raton Mountains. The mesa is a long dissected plateau almost due east of Trinidad, Colorado, which extends southward into New Mexico and Texas. Its border rises nearly 4800 feet above the adjacent valleys and the massive summit is composed of thick beds of old lava now dissected into remnants of a once more extensive plateau. Underneath the lava are less resistant sandstones and shales (Upper Cretaceous).

Raton Mesa is 8 miles long, 4 miles wide, and includes about 20 square miles. It has been entirely separated by erosion from a similar area to the south and from the main lava field to the east. The aggregate thickness of the basalt flows which constitute the cap rock of Raton Mesa and of the Mesa de Maya is from 250 to 300 feet about their borders, and increases to 500 feet toward the central part of the western mesa. At least 8 distinct beds of lava have been identified, which probably represent the same number of independent eruptions. The differ-

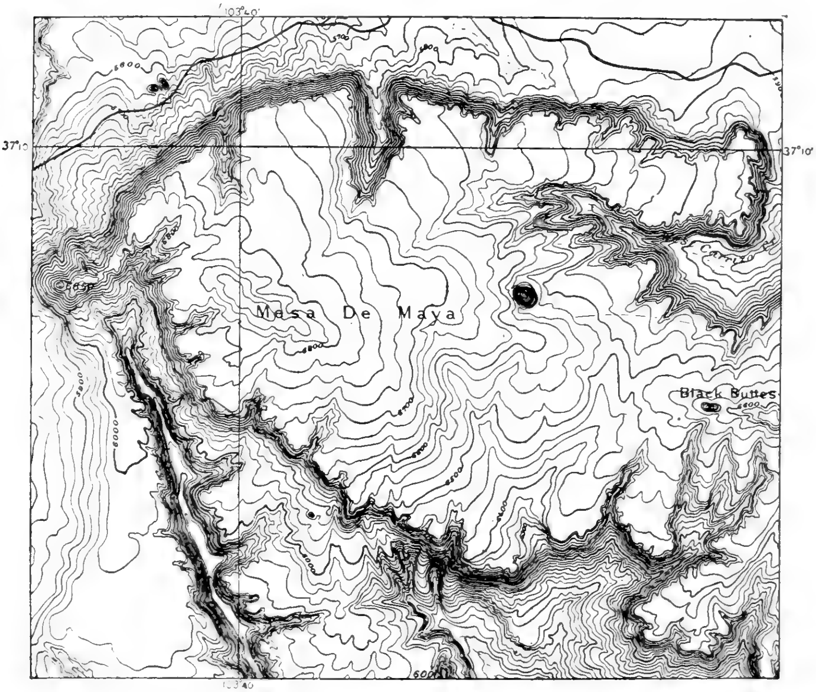

Fig. 142. — Topography of Mesa de Maya, south-central Colorado. Typical lava-capped mesa with steep bordering scarps and flattish summit. (U. S. Geol. Surv.)

ent beds are 30 or more feet in thickness, though they vary greatly from place to place.[1] Raton Mesa has a mean elevation of about 1800 feet and is bordered by an almost vertical escarpment from 200 to 300 feet high, an escarpment so sheer as to render it almost inaccessible, Fig. 141.

There is a dense growth of piñon and juniper along the base of the Raton Mesa; the small streams that head in the plateau are fringed with cottonwoods; on the steep border of the plateau, pine and spruce trees are scattered through a dense undergrowth of scrub oak, with aspen appearing locally near the base of the escarpment. The entire district up to 7500 feet affords a scanty growth of nutritious grasses well suited for sheep farming, which is one of the chief industries. The tableland on the summit of the mesa supports a growth of bunch grass.[2]

The Ocate Mesa has a cap rock of thick sandstone and it is the remnant of a lower-lying mesa that extends westward to the foothills of the Rocky Mountains between the Arkansas River in Colorado and the Cimarron River in New Mexico. The largest development of the Ocate Mesa is between the Cimarron Valley and the Mora, where from a broad platform rises Ocate crater (8900 feet). The eastern border of Ocate Mesa is an escarpment nearly 500 feet above the plain to the east, known as the Las Vegas Mesa, which extends south of Mesa de Maya to the great cliffs of the Canadian valley and east toward the Great Plains near the Texas line. The surface of Las Vegas Mesa slopes gently to the east; the western border has an average altitude of about 8600 feet. It is a vast stratum plain underlain by a chalky sandstone (Colorado formation). Many volcanic craters and dikes rise out of it to diversify and complicate its relief.

The cliffs which terminate the eastern border of Las Vegas Mesa form one of the longest and most remarkable escarpments in America. They are continuous with the cliffs of Galistes Mesa and extend in an indirect manner from the 104th meridian southwest to the 106th meridian, or nearly 300 miles. The cliffs are developed upon sandstone and overlook the deep Pecos Valley.

DRAINAGE FEATURES

A detailed map of New Mexico and western Texas, Fig. 142, displays many features characteristic of surface drainage in arid lands. A large number of enclosed basins of structural origin occur, and these are in the main floored with loose sediments derived from the surrounding mountains. About the margins of the basins are long talus slopes, huge bowlder and alluvial fans, and dry arroyos. The basins are without

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[1] R. C. Hills, Elmoro Folio, U. S. Geol. Surv. No. 58, 1899, p. 3, col. 2.

[2] Idem, p. 1, col. 1.

surface streams of any extent, a few watercourses entering them from surrounding highlands, but the porous nature of the soil, the high rate of evaporation, and the low rainfall, cause the streams to disappear before they have traveled far from the margins of the basins. The annual rainfall is in some places less than 10 inches, over the greater part of the region it does not exceed 15 inches, and everywhere it is chiefly in the form of summer thunder showers of short duration and limited extent.

All of the basins or bolsons, as they are sometimes called, are characterized by "lost rivers,"— streams that disappear about the borders of the basins. The floors of some of the basins are occupied by salt marshes or temporary lakes. In the largest basins, those between the Sierra Madre and Guadalupe mountains, the salt deposits are of great extent and have been used for hundreds of years by the Mexican population as one source of a salt supply. Around the margins of some of the bolsons are benches consisting of fan-shaped heaps of land waste derived from the mountains and deposited by torrential streams.

The word "bolson" is of Spanish origin and according to Hill it designates structural valleys between mountains or plateau plains which have been partially filled with débris from adjacent eminences.[1] Bolson originally meant a constructional plain bordered by mountains or plateau escarpments that supplied the material with which the bolson is floored; the term did not cover the bordering mountains, though the definition implied that the bordering mountains are features normally associated with the plain, and that a bolson plain was part of an interior basin.[2] In short, a bolson plain is the floor of an interior basin with such variations in its expression as are naturally associated with variations in climate, disposition of waste, size of basin, length of existence, etc.

The basin floors are characteristically flat and in broad view are somewhat similar in appearance to the plateau plains just described. They are, however, to be distinguished from the plateau plains by the fact that they are, at least in part, surfaces of aggradation, while the plateau plains are on the whole either destructional surfaces or surfaces that have been at least partly preserved from destruction by a cap of resistant lava.

Longitudinal Basins

The basins of the Trans-Pecos region occur in four longitudinal belts in sympathy with the belted arrangement of the intervening mountains, Fig. 133. The easternmost lies along the eastern fronts of the Guadalupe and Santiago ranges. The second belt lies between these ranges and the Sierra Diablo and Cornudas mountains. The third line of basins lies between the Sacramento and Sierra Blanca mountains on the east and the Sierra Oscura and San Andreas ranges on the west.

[1] R. T. Hill, The Physical Geography of the Texas Region, Folio U. S. Geol. Surv. No. 3, 1900.

[2] W. G. Tight, Am. Geol., vol. 36, 1905, pp. 271–284.

The fourth line lies between the last-named mountains and the Sierra de los Caballos on the borders of the Rio Grande.

Among these four longitudinal basins the Hueco basin, Fig. 133, is the largest. It lies partly in New Mexico, partly in Texas, is about 200 miles long, about 25 miles wide, and stands about 4000 feet above the sea. The mountains that border and enclose it are 2000 to 5000 feet higher. A few miles north of the New Mexico-Texas boundary the basin is crossed from west to east by a low divide. The southern half is drained by the Rio Grande; the northern half is a closed basin with salt marshes and unusually interesting dunes of white gypsiferous sands, a district known as the Tularosa Desert. In the vicinity of El Paso the Hueco basin is a structural basin or trough deeply filled with detritus. The streams wither at the foot of the mountains, and the mouths of the mountain arroyos are marked by huge detrital cones and fans that spread radially outward and finally coalesce with the wash from the intervening slopes.

JORNADO DEL MUERTO

The most noted basin of the Rio Grande Valley is the Jornado del Muerto Bolson. Its name means "the journey of death" and was given to it in pioneer days because of the great difficulty then involved in crossing its dry, barren, and inhospitable wastes.

The Jornado basin lies in south-central New Mexico. It extends north and south a distance of more than 200 miles, and is from 30 to 40 miles wide. It is a flat-bottomed basin except along the Rio Grande where the river has cut a valley 400 feet below the general level. Its margins are upturned steeply on all sides to heights of 2000 and 3000 feet above the general level. In the central part of the basin are a number of shallow depressions which hold storm waters that sometimes linger as lakes for several months, seldom through the year. At various points the even surface of the basin floor is broken by low hills of volcanic origin, among which may be mentioned the Doña Ana Hills, San Diego Mountains, and Cerro Roblero in the southern part of the basin. All of the volcanic cones are of recent origin and some of them have perfectly preserved craters. From some of the cones basalt flows have extended out over the surrounding plain, the one south of San Marcial covering more than 100 square miles.

It has been shown recently[1] that certain interior basins of the Trans-Pecos country, among them the Jornado del Muerto, instead of being structural valleys deeply floored by mountain waste, have a rock surface developed on the beveled edges of the strata, representing a total

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[1] C. R. Keyes, Rock Floor of Intermont Plains of the Arid Regions, Bull. Geol. Soc. Am., vol. 19, 1908, pp. 63–92.

thickness of thousands of feet, and that for the most part the rock floors of these plains are covered by a thin veneer of detritus only instead of the thick alluvium usually ascribed to them. Rarely does the thickness of the detrital mantle exceed 100 feet. The general slope of the Jornado del Muerto plain for example is only 2° or 3°, while the dips of the strata are in many cases as high as 30° in the same direction, and even vertical. On the beveled edges of these steeply inclined beds alluvium and also broad sheets of basaltic lavas have been laid down.

BASINS OF THE RIO GRANDE VALLEY

Among the most important basins of the Trans-Pecos country are those drained by the Rio Grande. This river from the San Luis Valley in southern Colorado to the point where it cuts the easternmost mountains of the province (long. 103° W.) flows almost continuously through a series of old structural basins connected by canyons that increase in length and depth toward the southeast. The present course of the Rio Grande is owing in part to the basin feature and in part to volcanic action, and the activities of the river itself.

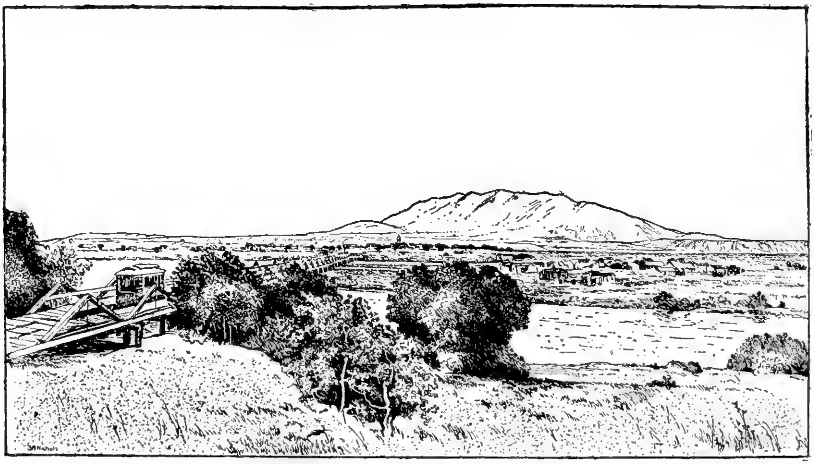

Fig. 143. — Valley of Rio Grande, El Paso, Texas, showing passage of the river from the Mesilla Valley to the Hueco basin across the southern end of the Franklin range. Note the terraced margins of the dissected basins. (Hill, U. S. Geol. Surv.)

Long after the partial filling of the broad structural troughs of the region there was an early period of valley cutting which was followed by a second period of valley filling, probably on account of changed topographic and climatic conditions. Near the close of the second period of aggradation great sheets of basalt were extruded. During this time the stream courses were in many instances violently changed and the Rio Grande, which formerly ran southward through the Jornado del Muerto basin into the interior basins of northern Mexico, was diverted into Engle and Las Palomas valleys, which are much narrower than the first-named basins. At the same time topographic changes due to volcanic action farther south probably forced the Rio Grande eastward to its present course south of the Franklin range at Hill Pass and southeastward to the Gulf. The volcanic eruptions and changes of river courses were followed by a second period of erosion in which were formed the present narrow elongated valleys that stand at an elevation several hundred feet lower than the basins in which they were cut. A last phase of river activity is expressed in the form of silt accumulations on the floors of the flood plains, a filling with a maximum depth of 85 feet in the El Paso canyon. The river is carrying an immense quantity of silt to-day; on the average it transports about 14,580 acre feet of mud a year.[1]

The flood plain of the Rio Grande is cut well below the level of the Jornado del Muerto and is known in part as the Mesilla Valley. This division is about 45 miles long and 5 miles wide. Along the valley margins terraces of notable extent and height have been formed. Some of them are of structural origin; their upper surfaces correspond with the dip of the rock in many instances, and rock outcrops along their valleyward margin. At a lower level are alluvial terraces representing complexities in the down-cutting of the Rio Grande since gaining its present course across the basins.

The Rio Grande is a storm-water stream subject to great and sudden floods. The rainfall occurs principally in the form of violent showers or cloud-bursts which fill the dry stream beds with turbulent floods of short duration. When such floods occur simultaneously at many points they are likely to cause destructive floods on the valley floor where the fertile irrigable lands are located and where most of the population and the principal towns are to be found.

Climate, Soil, and Vegetation

The rainfall of New Mexico varies from 20 to 25 inches in the mountains, as above Las Vegas and Cloudcroft, to about 15 inches on the Great Plains to the east in the vicinity of Roswell and Carlsbad, so that the Pecos River, forming the eastern boundary of the Trans-Pecos Highlands, receives practically no tributaries from the east. The effects of the small rainfall of lower elevations are reënforced by the porous nature of the soil, upon which there is no extensive surface drainage; the water also drains rapidly away underground in many places through fissured limestone rock.[2] At El Paso the mean annual precipitation is 9.85 inches, ranging between a maximum of 18.30 inches in 1884 and a minimum of 2.22 inches in 1891. The average humidity is 38.8 %, ranging between 23.2 % in May and 47.3 % in January.[3] The mean annual precipitation throughout western Texas is about 12 inches. It falls mainly in the summer months in the form of brief showers and is variable and uncertain.

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[1] W. T. Lee, Water-Supply Paper U. S. Geol. Surv. No. 188, 1907, pp. 20–24.

[2] Freeman, Lamb, and Bolster, Surface Water Supply of the United States, 1907–08, pt. 8, Western Gulf of Mexico, Water-Supply Paper U. S. Geol. Surv. No. 248, 1910, p. 114.

[3] G. B. Richardson, El Paso Folio U. S. Geol. Surv. No. 166, 1909, p. 2.

In the lower Pecos Valley irrigation has reached a very high stage of development.[1] Thousands of acres are under cultivation, beginning a short distance above Roswell and continuing into Texas; below this fertile belt but little irrigation is carried on because the seepage water contains a large amount of alkali, which renders it unfit for irrigation purposes.

The floors of the arid basins in the Trans-Pecos region generally consist of fine detrital material and support a growth of stunted shrubs and grasses, such as mesquite, greasewood, and cactus. Along the river bottoms are cottonwoods and an undergrowth of shrubs. The coarser talus slopes are covered with a growth of yucca, cactus, and other desert flora and a scattered scrubby growth of oak, cedar, and juniper. These forms are gnarled and stunted at lower elevations, but in higher situations they become increasingly more exuberant in growth.[2] Upon the slopes and summits of the highest mountains, the Chisos, Davis, Capitan, and Sacramento ranges, a thrifty tree growth of pine and fir is found; upon the lower mountains the tree growth becomes more scattered and upon the lowest ranges no true forests appear. The Black range bears a good growth of pine upon its upper slopes; the Magdalena range and San Mateo Mountains have poorer growths of

Fig. 144. — North end of San Mateo Mountains, Trans-Pecos Highlands, New Mexico. Shows characteristic tree-covered slopes. Mountains composed of rhyolite flows and tuffs. (Gordon, U. S. Geol. Surv.)

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[1] G. B. Richardson, El Paso Folio U. S. Geol. Surv. No. 166, 1909, p. 115.

[2] C. E. Dutton, 6th Ann. Rept. U. S. Geol. Surv., 1885, p. 125.

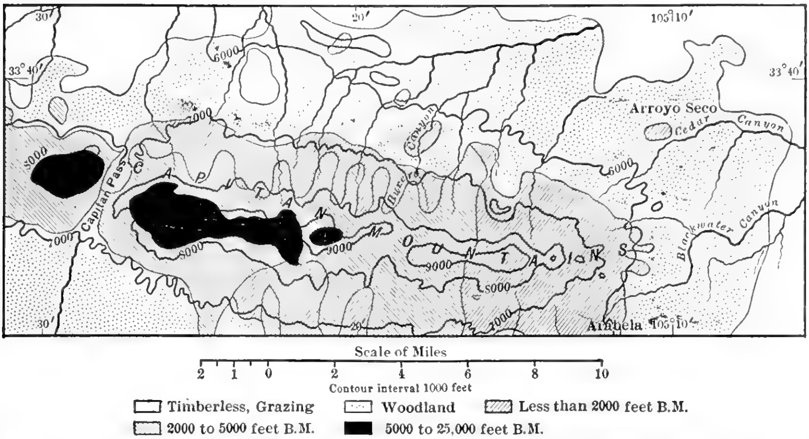

Fig. 145A. — Timber belts, Capitan Mountains, New Mexico. Note (1) the manner in which the timber belts follow the waterways, (2) the increase in growth with increase of elevation, and (3) the island-like outlines of the densest growths. (Adapted from U. S. Geol. Surv.)

pine interspersed with cedar and juniper, though in the better-favored situations good stands are found.[1]

The ranges of the species of trees occurring in the Trans-Pecos region vary as to rainfall, soil, and slope exposure. The lowest and best growth is found on the northern cooler and moister slopes and wherever the best soils have been developed. Except on the broader summits the soil has little humus for the undergrowth is scattered and light, oxidation of decaying vegetation is rapid and fairly complete, and erosion is in general active. There is a notable banding of the various species of forest trees, though the ranges of the different species overlap, as shown in Fig. 145B, which illustrates distributions in the Lincoln Forest Reserve of New Mexico (Capitan and Sierra Blanca ranges). The highest, or subalpine zone is found in this district between 9000 and 11,000 feet. Engelmann spruce is the principal tree of this zone with subordinate amounts of white fir, red fir, Mexican white pine, and aspen, generally in groves. The yellow pine zone between 6400 and 9000 feet includes, beside the dominant yellow pine, red fir, white fir, Mexican white pine, and oak. Between 5000 and 6400 feet is the woodland zone in which the principal species are piñon, juniper, cedar, scrub oak, and, along the streams, ash, box elder, and walnut.

The Trans-Pecos forests seldom form dense stands; open scattered forest growth is the prevailing type. Since the forests grow only at the higher elevations, they are in relatively inaccessible situations, for the settlements are found in the valleys. The principal value of the forests

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[1] Lindgren, Groton, and Gordon, The Ore Deposits of New Mexico, Prof. Paper U. S. Geol. Surv. No. 68, 1910, p. 217.

is in relation to water conservation. Many small perpetual streams are limited to the forested zone; only a few advance even two or three miles into the bordering deserts. Forage grasses form a ground cover of great extent both in the parks of the forested zone and below the 7000 foot level where the forest ends. In the more accessible situations these have been irreparably damaged by overgrazing, for with the destruction of the grasses deep and extensive erosion has taken place and rich pastures have been laid waste.[1]

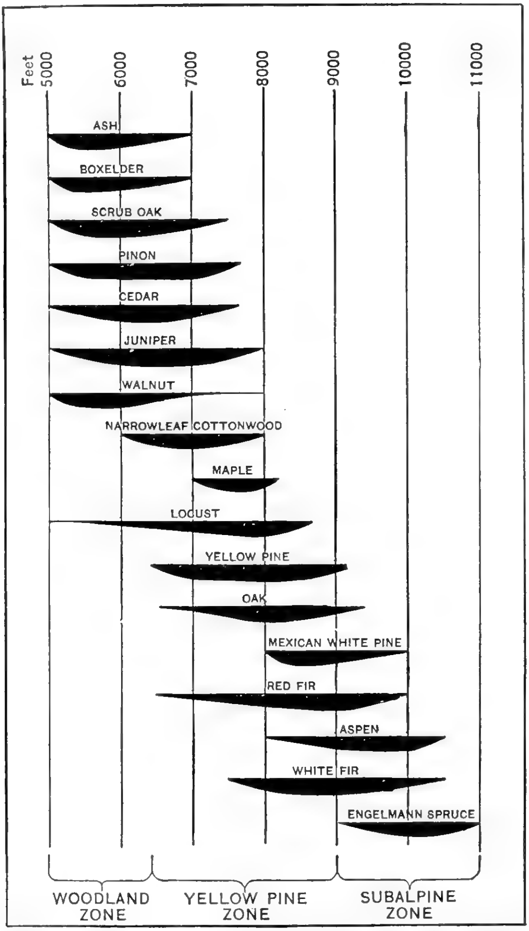

Fig. 145B. —Range and development of tree species in Lincoln National Forest, Trans-Pecos province. (U. S. Geol. Surv.)

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[1] Plummer and Gowsell, Forest Conditions in the Lincoln Forest Reserve, New Mexico, Prof. Paper U. S. Geol. Surv. No. 33, 1904, pp. 10, 11, 18.

CHAPTER XXII

GREAT PLAINS

Topography and Structure

The Great Plains province slopes eastward from the foot of the Rocky Mountains to the valley of the Mississippi, where it merges into the Prairie Plains on the north and the Coastal Plains on the south. The Great Plains appear as wide areas of relatively flat tabular surfaces crossed by broad shallow valleys drained by scores of eastward-flowing streams tributary to the Mississippi. Certain portions, as in central Montana, are drained by streams sunk in narrow canyons several hundred feet deep. The general expanse of smooth surface is also broken in some places by buttes, mesas, domal uplifts, extended escarpments, and local areas of "badlands." In some districts extensive areas are covered with sand hills, as in northwestern Nebraska, where is found a typical area of this character several thousand square miles in extent.

As a whole, the province descends toward the east about 10 feet per mile and from altitudes of about 6000 feet on the west to about 1000 feet on the east, though the elevations and the general regional slope have considerable variation from place to place. An important illustration of variation in altitude is Pine Ridge, an irregular escarpment which extends from the northern end of the Laramie Mountains in Wyoming eastward to the northwestern corner of Nebraska and the southern part of South Dakota. It marks the northern boundary of the higher portions of the Great Plains, and from it cliffs and steep slopes descend northward 1000 feet into the basin of the Cheyenne River. North of the Cheyenne River the divides are much lower and the surface as a whole does not attain the level of the High Plains to the south.

The plains topography is developed on a great mass of (1) rather soft deposits — sands, clays, and loams — spread out in the form of thin and extensive beds that slope gently eastward and (2) gently inclined and more indurated stratified rock varying from limestone and gypsum through shale and sandstone to conglomerate. The material of the first class is found chiefly in that subdivision of the Great Plains called the High Plains which extend from the southern margin of the badlands to the parallel of 32° south in central-western Texas, and east and west extends between the 100th and 104th meridians. The hard rock elsewhere underlying the Great Plains is for the most part thinly cloaked with rock waste, and its topography is in large part responsive to structure save (*a*) where the effects of base-leveling are still topographically expressed or (*b*) where glaciation has modified the surface or (*c*) where local alluviation has concealed an earlier structural surface. The two classes of material forming the Great Plains were derived mainly from the west and deposited in stratified condition upon flood plains and lake floors and in part on the sea floor. The region has suffered broad uplift and depression a number of times in its geologic history, but these deformations have been regional in character and have not deformed the sedimentary series in a complex manner except in local instances.[1]

Fig. 146. — Geologic map of the Texas regions, showing the relations of the Great Plains formations to those of the surrounding provinces. 1, Older granite; 2, Paleozoic and Mesozoic; 3, Cambrian-Silurian; 4, Carboniferous; 5, Permian; 6, Jurassic; 7, Lower Cretaceous; 8, Upper Cretaceous; 9, Nonmarine Tertiary; 10, Marine Eocene; 11, Coast Neocene; 12, Later igneous. (Hill, U. S. Geol. Surv.)

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[1] Darton and Salisbury, Cloud Peak-Fort McKinney Folio U. S. Geol. Surv. No. 142, 1906, p. 2, col. 1.

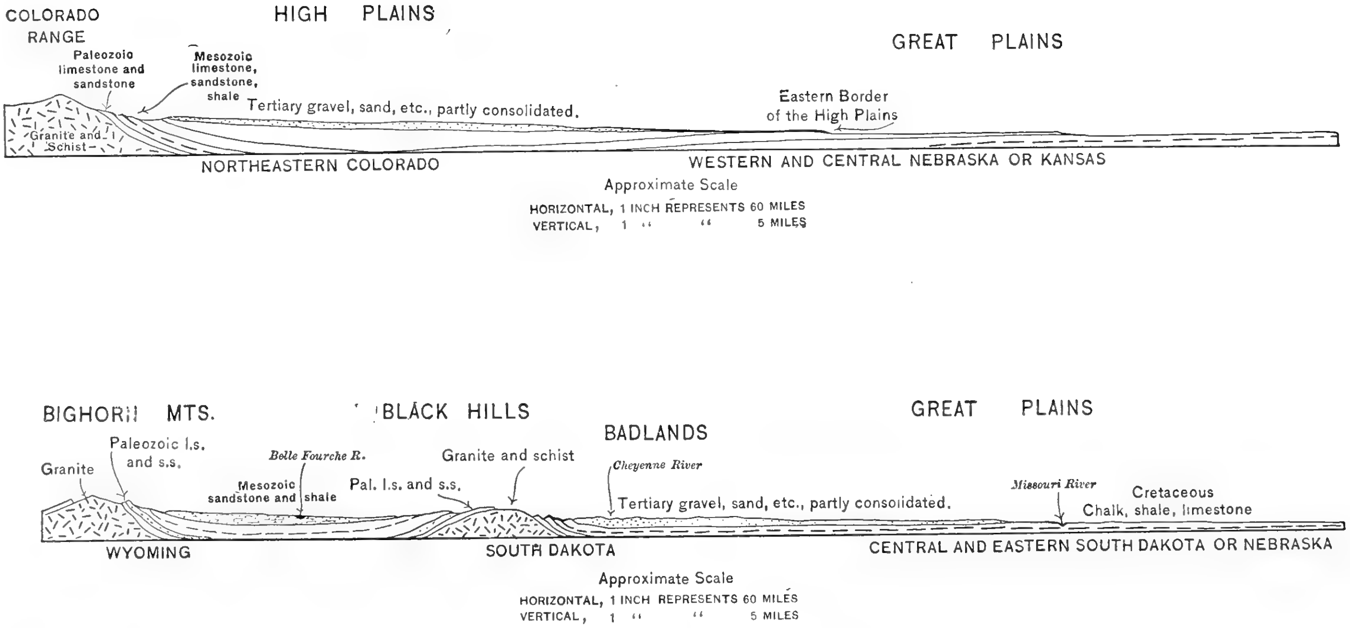

Fig. 147.—Topographic and structural sections across the Great Plains. Both are semi-diagrammatic. The upper section extends from west to east, the lower from northwest to southeast.

Although the strata of the plains lie sensibly flat within short distances, the structure of the hard rock, as shown in Fig. 147, has the general character of a great geosyncline which rises on approach to the eastern border of the Rocky Mountains, where the steeply inclined, eastward-dipping strata appear in the form of hogback ridges, fringing the front ranges of the Rockies. This regional westward dip of the Great Plains strata is distinctly characteristic; but the general structure is modified in places by structural deformations of a certain degree of importance. In southeastern Colorado, for example, there is an arch in the form of an anticline which extends southeastward from the Greenhorn and Wet Mountain ranges and passes under the Mesa de Maya, Fig. 141. Again, the continuity of the monocline of the foothills on the western border of the Great Plains, formed upon the upturned edge of the Plains strata, is broken by a number of small offsets, a series of three occurring at Greeley, Colorado, Fig. 117.[1]

Over the larger portion of the Great Plains the westward-dipping strata end in long, low, ragged, eastward-facing escarpments; the topography thus has a "stair step" composition; the escarpments stand out as conspicuous risers and the broad, flat, inter-escarpment areas represent the treads. Of such origin are the Flint Hills, the Dakota Sandstone Hills, and the gypsum hills of Kansas and Nebraska; and similar examples occur in many other places. These features are most prominently developed where the hard strata (sandstones) are thick and the soft strata (shales) thin. Where the reverse is true the escarpments may be so low as scarcely to be identifiable and the inter-escarpment tracts dissected by a maze of branching systemless streams. For example, the Pierre shale occupies many thousand square miles of country adjoining the Black Hills and gives rise to a monotonous landscape of rounded hills thickly covered with grass instead of the more common tabular relief bordered by escarpments.[2] The Great Plains of Texas are developed largely upon an extensive limestone stratum (Edwards) which is completely surrounded by escarpments of erosion. In the Llano Estacado, which is the southern end of the High Plains subdivision, the surface is for the most part capped by alluvium from the mountains.[3]

[1] N. H. Darton, Geology and Underground Water Resources, Central Great Plains, Prof. Paper U. S. Geol. Surv. No. 32, 1905, pp. 74–75.

[2] Idem, pp. 22–23.

[3] R. T. Hill, Physical Geography of the Texas Region, Folio U. S. Geol. Surv. No. 3, 1900, pp. 6–7.

Stream Types

Two types of streams cross the Great Plains, (1) streams whose headwaters are in the mountains and (2) streams whose headwaters are on the plains. Those streams whose headwaters are in the mountains are supplied with water more or less regularly either through rain or snow or both. In addition, their headwaters often drain glacial lakes and these tend to regulate the flow. The result of the somewhat regular water supply is that although the streams may become very low and even dry up occasionally, they are for the most part through-flowing the entire year. This result appears the more striking when it is known that their plains tributaries are intermittent and feeble and that the master streams suffer heavy losses by evaporation in crossing the semi-arid plains country.

A stream of this type is the Arkansas River, whose headwaters are in the Sangre de Cristo, Culebra, and Sawatch mountains, in each of which there are summits exceeding 14,000 feet in altitude. The precipitation along the crests of these high ranges is mainly in the form of snow and amounts to 20 or 30 inches of rain each year. From the foothills of the mountains to Arkansas City the rainfall ranges from 12 to 35 inches; it is 25 to 35 inches in the last 100 miles below Hutchison. Natural storage in the Arkansas basin is limited to a few mountain lakes of glacial origin. The streams are subject to two floods per year — the annual spring floods caused by the melting of the mountain snows, and the summer floods due to cloud-bursts in the foothills and plains regions.[1]

The Missouri River resembles the Arkansas in that its upper tributaries drain a forested region, while the main stream flows through a country almost wholly devoid of forests. The precipitation in the mountainous portion of the basin is mainly in the form of snow, but a great part of the area lies within the arid and the semi-arid regions, and it is probable that the mean annual precipitation throughout the entire basin is less than 20 inches. The river notably decreases in volume by evaporation in crossing the dry plains, though it never disappears, as is the case with many neighboring streams whose headwaters do not reach into the mountains.[2]

In contrast to the Arkansas and the Missouri is the Red River, whose sources are on the plains of northern Texas. The flow of this river is

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[1] Freeman, Lamb, and Bolster, Surface Water Supply of the United States, 1907–08, pt. 7, Lower Mississippi Basin, Water-Supply Paper U. S. Geol. Surv. No. 247, 1910, pp. 29–31.

[2] Follansbee and Stewart, Surface Water Supply of the United States, 1907–08, pt. 4, Missouri River Basin, Water-Supply Paper U. S. Geol. Surv. No. 246, 1910, p. 30.

very uncertain, the run-off consisting chiefly of flood water from heavy rains. The flow ceases entirely in the late summer and fall of ordinary dry years. The drainage area consists of semi-arid plains varied by small areas of sand hills. If the summer is dry, the flow of the river ceases altogether, although water sufficient for stock always remains standing in pools. During long-continued or unusually heavy rains, or directly after such rains, the river becomes wide and deep, its bottom lands are flooded, and considerable damage is often done to livestock, railroads, and plantations.[1]

Those streams that descend the eastern slopes of the uplands south of the Canadian River and near the New Mexico-Texas boundary line are of an extreme type and die out just eastward of the boundary line. Their waters are absorbed in the surface material or gathered in the form of temporary lakes. It is not until the central portion of the Panhandle region of Texas is reached that the drainage is through-flowing and reaches the Gulf of Mexico by way of the Red River and other streams.

Regional Illustrations

NORTHERN GREAT PLAINS

Many features of the northern part of the Great Plains in the United States owe their origin and character either to base-leveling or to glacial accumulation or both.[2] Westward from the valley of Red River of the North and the prairies of the Lake Winnipeg region is a plains country which rises gradually northwestward to the foot of the Rockies. The chief ascent of this plain west of the basin of Lakes Manitoba, Winnipeg, and Winnipegosis is over an abrupt escarpment developed upon Cretaceous strata that form the eastern border of the continuation of the Great Plains in Canada. The escarpment is from 200 to 1000 feet high, and its sections are named in order from south to north, Coteau des Prairies, the Pembina, Riding and Duck mountains and the Pasquia Hills or Mountains. West of these hills and so-called mountains the broad expanse of plains is broken here and there by valleys and irregularly dissected tracts, but in general the surface appears to be very moderately rolling, rising 4 or 5 feet to the mile to a height of 4000 feet at the foot of the Rocky Mountains in Montana and Alberta.

At the beginning of Tertiary time this region became a land surface

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[1] Follansbee and Stewart, Surface Water Supply of the United States, 1907–08, pt. 4, Missouri River Basin, Water-Supply Paper U. S. Geol. Surv. No. 246, 1910, p. 85.

[2] W. Upham, Tertiary and Early Quaternary Base-leveling in Minnesota, Manitoba, and Northwestward, (Abstract) Geol. Soc. Am., vol. 6, pp. 17–20. See also the American Geologist, vol. 14, 1894, pp. 235–246.

and has remained a land surface down to the present. During this long period (Tertiary) the great tract of country was base-leveled except for isolated residuals, here and there, consisting of remnants of horizontal Cretaceous strata elsewhere eroded. Turtle Mountain on the northern edge of North Dakota and the southern edge of Manitoba is an illustration of such a residual. It is about 40 miles long, about two-thirds as wide, and has an altitude of 200 to 800 feet above the surrounding country. It consists of nearly horizontally bedded shales and lignites capped by 50 to 75 feet of glacial drift.[1] West of Turtle Mountain the depth of the Tertiary base-leveling was greater and attained a tremendous value on the plains of Montana; in the Highwood and the Crazy Mountains districts the country was planed down 3000 to 5000 feet. These mountains owe their superior elevation to the great resistance of their rocks as compared with the strata wrapping about them; they now stand as embossed forms rising conspicuously above the general expanse of the monotonous plains.[2] The greater denudation of the western portion of the Great Plains was due to greater initial uplift; it appears to have been raised 1000 to 5000 feet.

The Tertiary topographic cycle of erosion was closed by a great uplift, after which vigorous stream erosion set in. In the eastern part of the Great Plains region erosion was carried to the point of partial base-leveling and the development of wide flat valleys. The Red River developed a broad plain more than 200 miles in extent from south to north and from 200 to 500 feet below the general level of the country. In Manitoba the Cretaceous beds were eroded down to the underlying Archæan and Paleozoic rocks over a large area and the eastern marginal escarpment formed. The depth of post-Tertiary erosion is indicated by the White Hills west of Lakes Winnipegosis and Manitoba, a long line of escarpments. During the period in which this escarpment was forming in Manitoba and in which its tributaries were deeply incised the plains of Montana were partly dissected by the deeply intrenched streams.

These plains now present one of the best illustrations of an uplifted base-leveled surface to be found in the country. The surface bevels the strata of the region regardless of changing dip and hardness, consequently neither the structure of the rock nor alluviation can be appealed to in explanation of the general topographic uniformity. The

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[1] W. Upham, Tertiary and Early Quaternary Base-leveling in Minnesota, Manitoba, and Northwestward, (Abstract) Geol. Soc. Am., vol. 6, pp. 17–20. See also the American Geologist, vol. 14, 1894, pp. 235–246.

[2] W. M. Davis, The United States in Mill's International Geography, 1900, p. 756.

interstream spaces are rather flat and give no indication of the marked depth and steep walls of the intrenched streams which are practically invisible until one is almost at the canyon brink. The narrow valley of the Missouri is from 300 to 600 feet below the general level of the plains, and that of the Yellowstone and many others have been cut to comparable levels.

GLACIAL FEATURES

The map, Fig. 148, shows how small a portion of the Great Plains has been glaciated. Besides glacial features similar to those of the northern part of the Prairie Plains may be noted the two terminal moraines which cover the country north of the Little Rocky Mountains. The surface is a rolling plain with rounded flat-topped ridges and broad and low intervening hollows. The larger drift is chiefly Laurentian, but the bulk of the material is made up of quartzite drift from the Rocky Mountains, and consists of well-rounded pebbles and small quartzite bowlders of different colors.[1]

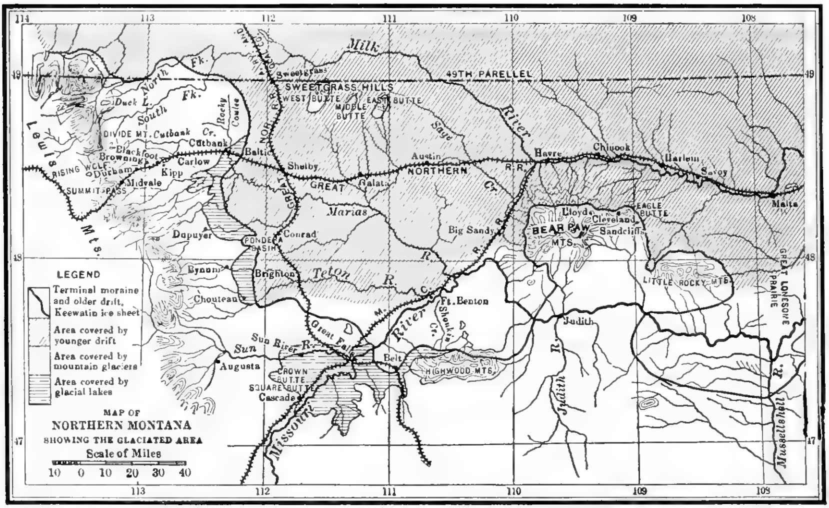

Fig. 148. — Note the large proglacial lake west of the Highwood Mountains, caused by the glacial damming of the Missouri River. Its discharge across the northern border of the Highwood Mountains formed Shonkin Sag, a temporary outlet. (After Calhoun, U. S. Geol. Surv.)

The Keewatin ice sheet extends southward into the northern Great Plains as far as the Highwood, Bear Paw, and Little Rocky Mountains. These elevations stopped its southward progress locally, while on the

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[1] Weed and Pirsson, Geology of the Little Rocky Mountains, Jour. Geol., vol. 4, 1896, p. 402.

plains between it moved somewhat farther south in great lobes, Fig. 148. The Sweetgrass Hills, almost on the international boundary line (long. 111° W.), were completely surrounded by the ice, above which they projected 2000 feet as great nunataks. Terminal moraines therefore completely encircle the hills, while the higher mountains farther south and east are but partly encircled by moraines. The position of these moraines along mountain slopes and on north-south lines makes it possible to establish the fact that the slope of the ice surface was from 30 to 50 feet per mile. A similar basis is afforded by the disposition of the moraines formed on the margins of lobes that extended up many of the valleys of the region, the divides between (150 feet high) remaining uncovered — with a similar result.

Terminal moraines fringe the border of the drift-covered country in places only. Elsewhere there is no well-defined terminal ridge, only a broad low rise usually too slight to be noticeable. The terminal moraines are monotonously rough and their hollows contain large numbers of smaller lakes and ponds. In places the moraines are bowldery ridges, in others they are broad belts of till of variable composition. Near the edge of the glaciated tract the drift is thin, though locally it is from 50 to 200 feet thick.

The drainage of the glaciated northern portion of the Great Plains is toward the northeast and east, and ice invasion was therefore bound to block the streams either temporarily by the ice or more permanently by moraines or both. The lakes are of two classes. Those of the first class were in a few instances of great extent, and their floors are noted for the scattered bowlders rafted into position by detached ice blocks. The name Great Falls Lake has been given to one such temporary water body, formed by the ponding of the upper Missouri between the southward-facing ice sheet and the northward-facing slopes of the Highwood Mountains. Its outlet along the northern mountain flanks at 3900 feet cut a broad channel nearly a mile wide and 500 feet deep, known as Shonkin Sag. It is one of the most striking topographic features in the region, since it is entirely independent of rock structure and crosses the present drainage lines at right angles.

After the disappearance of the ice the terminal moraines continued for some time to act as barriers to the drainage, but outlets were soon cut down and the nearly bowlderless clays of the lake floors exposed. Most of the existing lakes of the region occur in the hollows of the morainic belts and are individually of small extent.

Glacial features of considerable topographic prominence are also found upon the northwestern border of the Great Plains of the United

States west of the limit of continental glaciation where valley glaciers from the front ranges of the Rockies deployed, building terminal and lateral moraines and supplying material for local alluviation (p. 312). The glaciers extended as individual tongues of ice down the main valleys, but 14 of them united in groups along the base of the mountains to form piedmont glaciers of great size which extended out over the plains from 30 to 35 miles. In other cases the ice extended only part way down the valleys, deposited valley moraines, and caused the formation of related features such as lakes, outwash plains, and valley trains.

The piedmont glaciers and the continental ice sheet overrode common ground in two localities — the headwaters of the Marias and St. Mary's rivers — though these ice bodies were not contemporaneous. The valley glaciers had retreated before the continental ice sheet reached its greatest extension, since the deposits of the latter ice body overlie those of the former. The terminal moraines of the piedmont glaciers are of great size, some of them attaining heights of 200 feet and breadths of a mile or more.[1]

BADLANDS OF THE BLACK HILLS REGION

Among the badland areas of the Great Plains the largest and most important is in South Dakota and Nebraska on the southern, southwestern, and southeastern borders of the Black Hills. The portion of the badlands showing the greatest topographic complexity lies near the southeastern border of the Black Hills between the White and Cheyenne rivers and is known as the Big Badlands. It is continuous with a second badlands area which extends eastward, southward, and westward along the upper White River forming the high Pine Ridge escarpment that extends through western Nebraska and into Wyoming. Outside the limits of the main badlands area are many remnants of the strata that formerly extended over the region. They now occur as mesas or tables which stand at various heights up to three hundred feet or more above the adjacent basin or valleys. Some of them are of large size and those east of the Cheyenne River have been given individual names by the settlers who occupy them, as Sheep Mountain Table, White River Table, Kuba Table, etc. The badlands were at first thought to be quite uninhabitable, the name itself being derived from the French name "Mauvaises Terres" applied by the early hunters and trappers. The phrase is meant to signify a country difficult to cross, chiefly because

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[1] F. H. H. Calhoun, The Montana Lobe of the Keewatin Ice Sheet, Prof. Paper U. S. Geol. Surv. No. 50, 1906.

of the rugged surface and the general lack of water. Later exploration and development have shown that much the greater portion of the area within the badlands is level and fertile and covered with abundant grass; and that water may be obtained, especially on the higher tables, by sinking shallow wells in the surface mantle of gravel. As a whole the region has considerable agricultural and grazing importance.

The chief factors controlling the development of the badlands topography have been the great extent of slightly consolidated, fine-grained strata lying at a considerable altitude above the sea in a region of low rainfall and sparse vegetation. The scarcity of deep-rooted vegetation enables the soft material to be rather easily eroded. While short grasses are abundant over large areas they do not have deep root penetration and do not form a sufficiently continuous cover to prevent cutting. There is a small amount of vegetation of a higher order, but it is even less effective than the grass in preventing the formation of gullies. A few gnarled cedars occur on the highest points and bushes of various kinds occur in the valley floors in favorable places, but they offer little obstruction to the development of the gulches and canyons which diversify the scarped margins of the area.

Fig. 149. — Details of Badlands in Brule clay at foot of Scotts Bluff, Nebraska. (U. S. Geol. Surv.)

It is also noteworthy that the rainfall is more or less concentrated into heavy showers of short duration and these act most vigorously in denuding the surface, forming channels, and transporting accumulated rock waste. The clays which compose a large part of the badlands expand greatly when wet and contract when dry (p. 415), so that their surfaces tend constantly to break up and form an easily eroded mass of material. Frost action tends toward the same effect, with the result that the clay is constantly being loosened in the dry as well as in the wet season, and is thus prepared for rapid erosion when rain falls.

The topographic complexity of the badlands is explained chiefly by the unequal resistance to erosion on the part of alternating beds. Individual layers vary horizontally as well, and the softer portions are worn back into the form of gulches and alcoves while the harder portions remain projecting as spurs or headlands. A hard layer tends to persist longer than a soft layer above or below it, thus forming typical scarp and terrace topography. In many cases the hard layer is undercut to such an extent as to develop a precipice. Joints are developed here and there in the clays and these tend to accelerate erosion along vertical planes with the result that cave-like excavations are formed at the heads of vertical walled gulches. Many beds contain large numbers of concretional masses whose resistance is greater than that of the surrounding material, thus tending to the production of a surface whose irregularities reflect the irregularities of the concretions.

Among the important topographic elements of the badlands are the alluvial fans which cling to the base of every pillar, mound, or table, and have a large total extent. Their surfaces have low gradients and they represent the lag of transportation behind disintegration. Most of the streams of the badlands area are intermittent. They have a continuous flow for a short time after the rainy season but their sources rapidly fail, and soon nothing is left in their channels but bars and banks of sand and silt, and a few trifling pools of water, either so strongly alkaline as to be of little value, or so turbid as to have the consistency of mud. Only two streams have a continuous flow, Cheyenne River and White River; but their flow varies greatly in volume, being high in the rainy season, when their tributaries are full, and very low in the dry season, when their tributaries fail. Many streams, especially the streams of medium size, flow in box-like trenches, the material of their banks standing up in bluff-like form as about the border of the area.[1]

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[1] For a summary description of the badlands of South Dakota, illustrated by well-selected photographs, see The Badland Formations of the Black Hills Region, C. C. O'Harra, Bull. S. D. School of Mines No. 9, 1910.

HIGH PLAINS

The map, Plate IV, indicates the extent of the High Plains, the most important subdivision of the Great Plains province. The interior topographic and drainage features of the High Plains are typically represented in the Llano Estacado (Staked Plains) of Texas, the surface of which appears extremely flat to the eye, though it actually slopes eastward at the rate of 8 or 10 feet to the mile. Only gentle depressions occur here and there — the products of underground solution and of unequal wind erosion. Local storm floods tend to level these irregularities by filling the hollows and eroding the surrounding surface.[1]

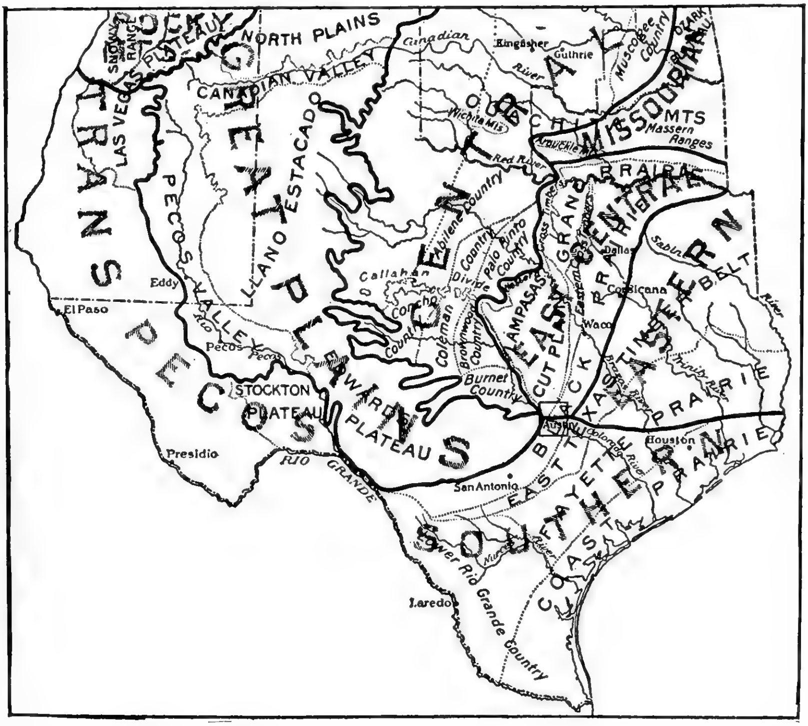

Fig. 150. — Physiographic subdivisions of Texas and eastern New Mexico. (Hill, U. S. Geol. Surv.)

The High Plains strata were laid down as a series of great compound alluvial fans or a piedmont alluvial plain at the eastern base of the Rocky Mountains. The eroded bedrock floor upon which the materials were deposited and the eroded condition of the materials themselves

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[1] R. T. Hill, Physical Geography of the Texas Region, Folio U. S. Geol. Surv. No. 3, 1900, p. 6, col. 3.

imply a succession of changes in the character of the stream action from degradation to aggradation and back again to degradation. These changes harmonize with the conception of climatic changes of known occurrence, the dry Tertiary (aggradation) being succeeded by the wet Pleistocene (degradation), which was in turn succeeded by the dry Present in which the streams are aggrading their valley floors.[1] It is also conceivable that cutting power may have been gained or at least increased (1) by broad uplift on the west which would increase the

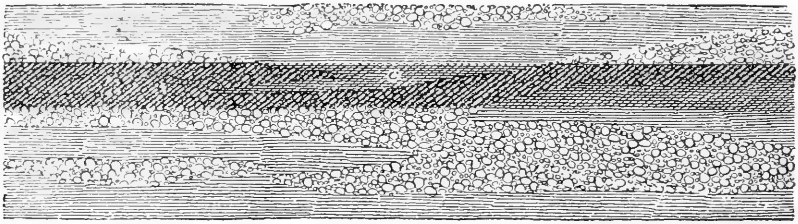

Fig. 151. — Ideal structure of the Tertiary deposits of the High Plains. The dark band indicates the position of a partly consolidated portion of the section known as a mortar bed. (Gould, U. S. Geol. Surv.)

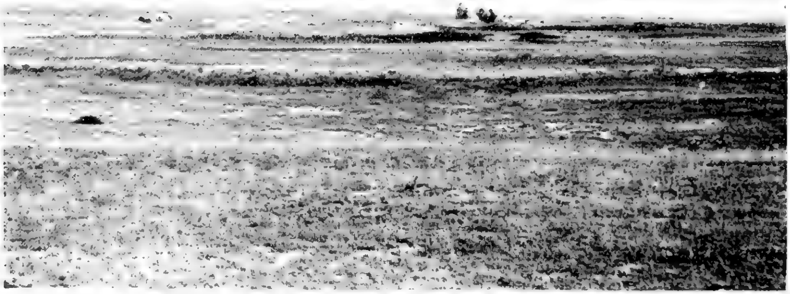

Fig. 152. — Typical view of the High Plains of western Kansas. (Gilbert, U. S. Geol. Surv.)

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[1] W. D. Johnson, The High Plains, 20th and 21st Ann. Repts. U. S. Geol. Surv., 1898–1899, 1899–1900.

stream gradients and (2) by a cooling of the climate so as to reduce the evaporation.

The greater part of the Tertiary deposits of the High Plains consists of clay, sandstone, and conglomerate, with clay largely predominating. The materials are usually arranged in a heterogeneous manner, as shown in Fig. 151, a characteristic dependent upon their origin as coarse channel or finer flood-plain deposits.[1] A large part of the deposits is composed of smooth rounded white or yellow quartz grains locally cemented by lime into coarse rough sandstones, but more commonly unconsolidated and in places blown by the winds into dunes. In many instances the sand is mingled with small pebbles and clay cemented with lime, forming the so-called "mortar beds." The pebbles vary greatly in size, shape, and color, and generally occur in more or less lenticular cross-bedded layers, some of which are at least 50 feet thick. In many places they are mixed with fine sand and locally are scattered through the clay formations.

> The clays are generally white, but locally buff and pink in color. In places the lime cements the clay into irregular and grotesque forms, which, being harder than the surrounding formations, are left standing in relief by erosion and form picturesque elements in the local scenery.[2]

The average thickness of the Tertiary deposits in eastern Colorado and western Kansas is 200 to 300 feet, but increases to nearly 1000 feet in portions of western Nebraska and southwestern Wyoming. Originally the entire region was probably covered with late Cretaceous deposits that extended far up the flanks of the Rocky Mountains, the Bighorn Mountains, and the Black Hills, a conclusion indicated by the occurrence of outliers of these deposits at high altitudes, the intervening portions having been extensively stripped off.[3]

PHYSICAL DEVELOPMENT

After the great Rocky Mountain System on the west had been outlined and during late Tertiary time there was a long period in which streams of moderate gradient drained across the central portion of the Great Plains. Locally, extensive lakes were formed, but the larger part of the deposits (Oligocene) of that time consists of coarse sandstones, sands, etc., deposited on river flood plains and aggrading stream channels. Aggradation took place chiefly in Oligocene time, and the area of Oligocene deposits, Plate V, extends across the eastern part of

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[1] C. N. Gould, Geology and Water Resources of the Panhandle, Texas, Water-Supply Paper U. S. Geol. Surv. No. 191, p. 33.

[2] Idem, p. 32.

[3] N. H. Darton, Geology and Underground Water Resources of the Central Great Plains, Prof. Paper U. S. Geol. Surv. No. 32, 1905, pp. 169–170.

Colorado and Wyoming, western Nebraska and South Dakota, and probably northward into Canada. The streams of this time shifted their courses from side to side and laid down a sheet of débris in the form of low-grade and confluent alluvial fans of vast extent and with a thickness in places of 1000 feet. The period of deposition ceased with the Miocene, and uplift and erosion followed which removed large portions of the accumulated material. During this period of deposition (Oligocene) in the northern part of the High Plains the southern part was probably a region of erosion, but with the uplift and erosion of the northern High Plains (at the close of the Miocene) the southern portion became a region of deposition and the streams began depositing thin mantles of late Pliocene sands in southern Colorado, southern Nebraska, Kansas, and still more southerly localities.[1]

It is important to recognize that these changing conditions of late Tertiary deposition and erosion first in the north and then in the south were determined by differential uplift. The uplifted region suffered erosion, the depressed region suffered deposition. It is equally important to recognize the fact that these occurrences took place in the Tertiary under more or less stable climatic conditions and before the advent of the glacial ice. We have in these conditions clear evidence of broad differential uplifts and depressions which produce alternating conditions of aggradation and degradation over large areas during the Tertiary period, and which were, so far as we may judge, wholly unrelated to climatic influence except the general influence of aridity to leeward of the high Rocky Mountain Cordillera. The broad changes of later date are, however, undoubtedly to be associated with climatic change, though the exact locality in which erosion or deposition was strongest was probably determined by crustal movement. During the early Pleistocene uplift of the land there also occurred an increased precipitation which resulted in widespread degradation of the preceding deposits; the Tertiary deposits were entirely removed in the eastern portion of the area and widely and deeply trenched in the western portion.[2] There was deep erosion about the Black Hills dome, and the High Plains, whatever their extent in that direction, were largely removed and their northern edge left as at present in the great escarpment of Pine Ridge facing the Black Hills uplift. The streams of Pleistocene time also cut deeply and removed widely the high plains of Nebraska, Colorado, Kansas, and Texas, though wide areas of tabular surfaces are still exposed.[3]

Descriptions of various portions of the High Plains vary greatly with reference to the present character of the stream work. It is frequently asserted that the High Plains are a region of denudation, although as frequently one finds the rivers described as building up the bottoms of their valleys. This contradiction is only apparent. The greater portion of the High Plains and many portions of the Great Plains are being denuded by the ramifying headwater streams, and the

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[1] N. H. Darton, Geology and Underground Water Resources of the Central Great Plains, Prof. Paper U. S. Geol. Surv. No. 32, 1905, pp. 185–186.

[2] W. D. Johnson, The High Plains and their Utilization, 21st and 22nd Ann. Rept. U. S. Geol. Surv., pt. 4, 1899–1900, 1900–1901.

[3] N. H. Darton, Geology and Underground Water Resources of the Central Great Plains, Prof. Paper U. S. Geol. Surv. No. 32, 1905, pp. 186–188.

detritus is being carried down to the valley bottoms, where it accumulates in the form of broad valley flats or flood plains which to a large extent control the curves of the rivers, as along the valley of the Platte. Such aggradation is a normal result of the return to the drier conditions prevailing both now and in the Tertiary. The process will continue until a gradient is established which will allow the streams to carry all their waste to the sea. Dissection by the streams of Pleistocene time caused such a degree of valley cutting that the present aggradation on the floors of the valleys is small compared with the degradation that preceded it. Consequently the tributaries of all the master streams of the High Plains region join valleys far below the general level. The tributary streams are therefore eroding the surface actively, and they drain by far the larger portion of the High Plains. Active erosion has stopped completely and active aggradation taken its place on almost all the larger valley floors.

BORDER TOPOGRAPHY

In some localities the erosion of the border of the High Plains has given rise to the formation of "holes" with local badland topography. A typical instance is Goshen Hole on the border of Wyoming and Nebraska. The formations which outcrop in this area consist largely of clays and sandstones. The clay (Brule) is easily eroded in such manner as to keep the sandstone (Arikaree) covering it in constant retreat as a nearly vertical wall about the edges of the Hole, a process greatly hastened by the issuance of ground water at the line of contact of the two formations. The escarpment separates the dissected lowland of the floor of the hole from the upland or general undissected surface of the High Plains. It is best defined upon the western side of Goshen Hole, owing to the absence of streams upon this portion, though the escarpment is here in constant retreat as the result of the sapping action of the ground water at the heads of the minor streams to which it gives rise. Upon the lowland constituting the floor of the hole are small mesas and tablelands, remnants of the upland that once occupied the region and that has since been worn away. Wherever the relations of drainage and geologic formations are such as not to bring the streams below the soft strata or where the upper strata are soft and the lower strata hard, either a lowland has not been formed or, if formed, its borders are not so well defined as in those cases where the softer members underlie the harder and the drainage has been developed distinctly below the level of the soft formations.

The eastern border of the High Plains in Texas and Oklahoma is in most places a distinct scarp 200 to 500 feet above the eroded plains on the east, though ordinarily the descent is more gradual and takes place in a belt 5 or 6 miles wide — a belt with distinct topographic features in high contrast to the flatter plains to east and west.[1] This escarpment is locally known as "The Breaks," Fig. 155. It occurs along the valley margins, passing in broad eastward-looping curves from one drainage system to another, and is characterized by badland erosion forms, short ridges, steep talus slopes, isolated buttes and peaks, and an intricate system of narrow V-shaped valleys that sometimes develop into impassable canyons, Fig. 154. It is a region very difficult to trav-

Fig. 153. — Jail Rock with the valley of North Platte in the distance, looking east. The capping stratum is sandstone (Gering) while the slopes are of clay (Brule). Typical border topography of a portion of the High Plains. (Darton, U. S. Geol. Surv.)

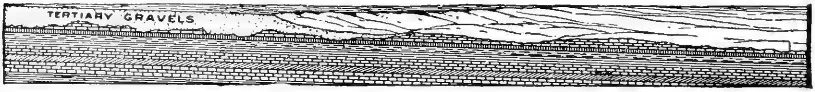

Fig. 154. — Eastern erosion escarpment of the High Plains of Texas, Oklahoma, and Kansas. The eroded bed-rock surface has been covered with Tertiary deposits and later reëxposed in part. (Johnson, U. S. Geol. Surv.)

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[1] C. N. Gould, Geology and Water Resources of the Eastern Portion of the Panhandle of Texas, Water-Supply Paper U. S. Geol. Surv. No. 154, 1906, p. 9.

erse, and can be crossed with a wagon only at infrequent intervals and by specially selected routes. The marginal escarpment is most typical along the Canadian River and in Palo Dura Canyon in Armstrong County, Texas.

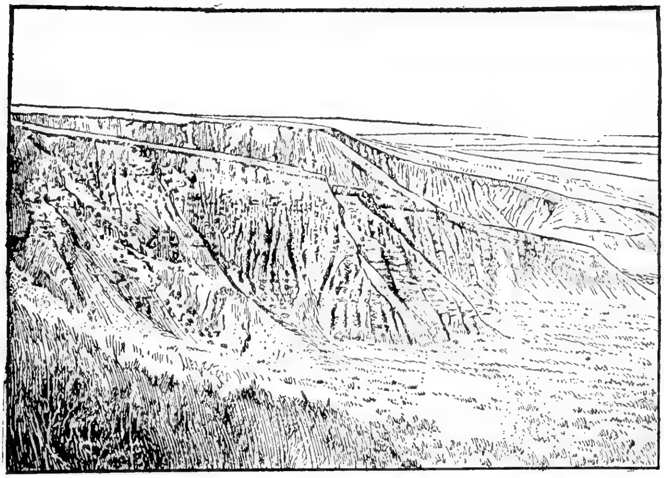

Fig. 155. — Details of form, eastern border of the High Plains, Texas. The scarp is known as "The Breaks of the Plains." (Hill, U. S. Geol. Surv.)

The eroded plains east of "The Breaks" have suffered such extensive dissection that the Tertiary and Pleistocene deposits have been entirely removed from their surface and the streams are actively dissecting the underlying Red Beds. The region is a rolling plain into which the streams are cutting rather deep steep-sided valleys, and outlining hills generally of conical shape but often elongated and attaining heights of 200 to 800 feet or more. These hills are capped by resistant ledges of sandstone, gypsum, or dolomite that have resisted the erosion which swept away the softer clays and shales above them.[1]

SAND HILLS AND LAKES

The sand hills of the Panhandle region of Texas range in size from small mounds to ridges 30 or 40 feet high. They are oval, crescentic, or elongated in shape and extend in various directions. They are interspersed with broad, shallow, basin-like depressions from 1 to 10 acres in extent, probably representing great "blow-outs" or wind-eroded hollows. In a few localities there are migratory dunes, as on the west

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[1] C. N. Gould, Geology and Water Resources of the Eastern Portion of the Panhandle of Texas, Water-Supply Paper U. S. Geol. Surv. No. 154, 1906, pp. 9–10.

side of the Canadian River in Roberts County. The dune sands are derived from sandstone ridges chiefly, but also in part from river sand.

The rainfall on an important part of the southern High Plains is collected into shallow saucer-shaped depressions known as "lakes" or playa lakes, scattered irregularly about. The depressions vary in size from a diameter of a few feet and a depth of a foot or two to lakes several hundred rods in diameter and from 20 to 40 feet below the general level. Some of these depressions are more than a square mile in area. Many lakes in the depressions are perennial and afford an abundant supply of water for stock. Others are ephemeral, that is, they are filled during a period of rain, but soon dry up; and still others contain water only at long intervals. Before wells were constructed and in the early settlement of the country the lakes were often in intimate relation to the location and welfare of settlers, for they constituted practically the only water supply. Wagon trains in crossing the Llano Estacado camped beside them, and they were centers to which cattle were driven until comparatively recent times.[1]

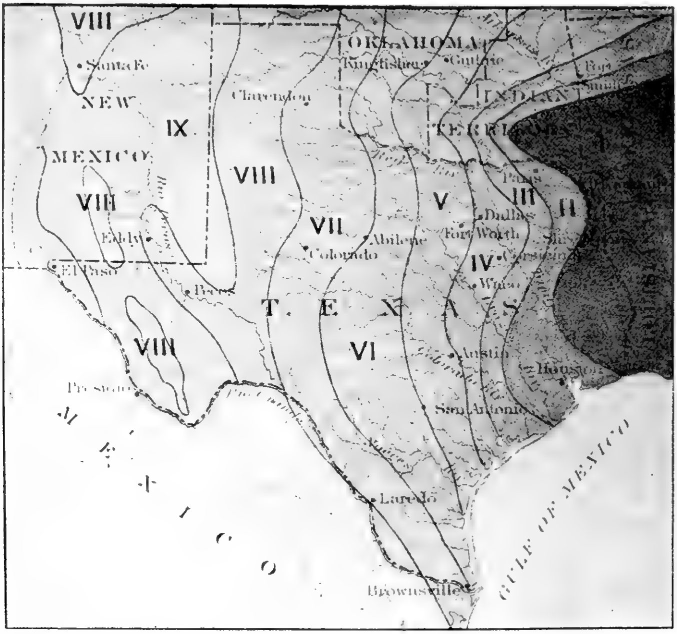

Fig. 156. — Precipitation in the Texas Region. I, over 50 inches; II, over 45; III, over 40; IV, over 35; V, over 30; VI, over 25; VII, over 20; VIII, over 15; IX, over 10. (Hill, U. S. Geol. Surv.)

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[1] C. N. Gould, Geology and Water Resources of the Panhandle, Texas, Water-Supply Paper U. S. Geol. Surv. No. 191, 1907, p. 50.

The sand-hill country is not limited to the High Plains but is found (1) in many cases with limited development along the valley floors where sands deposited in the stream channels during high water become available to the winds during the low-water stages, as along the Arkansas, and (2) over the outcrop of unconsolidated material. The largest tract lies in Nebraska[1] and was developed upon the outcrop of a sandy unconsolidated formation which the present sand cover largely conceals. The thickness of the sand cover is rarely over 100 feet and generally much less. The total area of the tract is about 18,000 square miles. A peculiar feature of this great area is the relative absence of streams, except such as are supplied from outside sources. In spite of the small surface drainage there is considerable spring flow and seepage along the main river valleys. Most of the rainfall is absorbed by the loose dry sands and percolates downward, to be added to the ground water, which is surprisingly large in amount and is in general of good quality. The large amount of ground water is reflected in the numerous lakes scattered through the sand-hill country. Since the lake surfaces represent the surface of the ground water the lake levels rise and fall in response to the variable rainfall just as does the ground water. In times of light rainfall they are smaller and shallower; in times of heavy rainfall they are deeper and broader. Some of them disappear in extremely dry seasons; others are so permanent that their waters are stocked with fish. They are of great importance as a source of stock water, since the bunch-grass of the sand hills gives the area high value in respect of grazing, the chief industry of the region.

Vegetation

Bunch-grass is the characteristic vegetal growth of the High Plains. Its growth is extended by roots and more rarely by seeds. The dryness and coarseness of the surface soil and its wind-swept condition render reproduction by seed very difficult. The result is not a turf so dense that the ground is not visible but a series of tufts or bunches separated by large and small bare spaces.[2]

It is the general conclusion of students of the plains streams that floods are growing in volume and frequency, a state of things that is thought to be related largely to the breaking up of the protective grass cover by over-pasturage in the headwater regions. A grass cover has almost as great influence in checking run-off and favoring absorption

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[1] G. E. Condra, Geography of Nebraska, 1906, pp. 85–94.

[2] Report upon Geographical and Geological Explorations and Surveys West of the 100th Meridian (Wheeler Surveys), Geology, vol. 3, 1875, p. 606.

by the soil as a timber cover, and this relation is of such importance throughout the Great Plains region as to make it a point of great interest to the forester interested in general conservation, for the combination of grass-land and timber is thoroughly practical.

In the middle courses of the Great Plains streams and on numerous tributaries in the mountains there is a protective timber covering. In a similar way a timber growth is found on the borders of the escarpments. and its maintenance is a matter of the liveliest concern to every one in any way related to the régime of the streams. The amount of washed soil running off in the floods that follow cloud-bursts in the Great Plains is enormous, especially where trees are absent and the grass covering thin; the maximum extent of grass and forest cover ought therefore to be maintained. This is seen especially in the lignitic belt of Texas, which is a rough broken country with sandy soils. But for the shortleaf and post-oak forests which cover them the soils would be washed in quantities from the steeper slopes. Annual plants with a superficial root system can not flourish in such soils without abundant rainfall. More than that, soils in these positions have little capacity

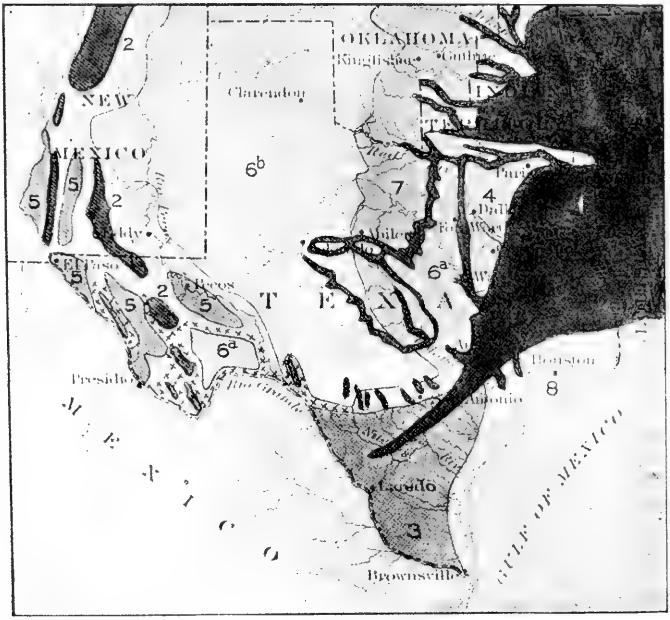

Fig. 157. — Vegetation of the Texas regions. 1, Atlantic forest belt; 2, Rocky Mountain forest; 3, Chaparral; 4, Black Prairie; 5, bolson desert flora; 6a, Grand Prairie; 6b. Great Plains; 7, transitional, with plains, prairie, and Atlantic flora; 8, coast prairies; XXX, yucca belts. (Hill, U. S. Geol. Surv.)

for retaining moisture, and forest growths are slow in beginning. The hills bordering the Edwards Plateau would become arid and worthless if they were stripped of their forest cover. The inch-deep soil débris would be rapidly washed away and the restoration of the forest become impossible.

The Great Plains contain but little timber, though the supply is in many cases sufficient for local and limited use. In the Camp Clarke district of Nebraska the ridge extending west from Redington Gap bears scattered pine trees of moderate size, and there are also a few Rocky Mountain pines (*Pinus ponderosa*) on the slopes ascending to the high table at the southern margin of the district. The largest are from 1 to 2 feet in diameter. A moderate number of young pines begin growth in favorable situations on the ridges, though few of them attain maturity. The zone of cottonwoods is characteristic of most western streams, though it is absent along North Platte River, where only a few small trees and bushes are found. The principal deciduous growths are found in ravines; they include cottonwood, box elder, wild plum, and a few other varieties.[1]

The Great Plains include much of the central treeless region of the United States where forest planting has been a part of the progress in agriculture, so that the areas of most extensive agricultural development are also those where greatest tree planting has taken place. Approximately 840,000 acres have been planted in the central treeless region, but the best conditions can be obtained only by planting about 14,000,000 acres in all. Although forest planting had been in a period of decline in this region, it has recently revived. It has been demonstrated that about 5% of the prairie region should be forest covered, and farther west, in the Great Plains proper, 3% could profitably be devoted to tree growing. South Dakota has planted about 122,000 acres; Nebraska, about 192,000 acres; Kansas, 175,000 acres; Oklahoma, 21,000 acres; Texas, 13,000 acres. The chief purpose of such tree planting has been for shelter, for post production, for protection from the hot winds of summer and the blizzards of winter, and to a limited extent for fuel.[2]

A point of great interest in connection with the limited tree growth of the central plains is the possibility of an earlier and more extensive timber cover which may be restored by proper effort. If the rainfall was more abundant for a time during and after the retreat of the ice, it follows that timber may have grown upon areas now too dry to support it. The

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[1] N. H. Darton, Camp Clarke Folio U. S. Geol. Surv. No. 87, 1903, p. 1.

[2] Yearbook Dept. Agri., 1909, pp. 340–342.

thought is the more plausible when we recognize the great length of time involved in the disappearance of the ice sheet, long enough, we may suppose, for considerable progress to have been made in natural reforestation. The conclusion appears to be supported by the finding of remnants of old pine forests in geologically recent deposits in the valley of the Niobrara, 50 miles southeast of existing forests of pine. It has been concluded that these forests formerly extended down near the mouth of the Niobrara.[1] Likewise in the sand-hill country of Nebraska the stumps of cedars and pines — trees now confined almost wholly to the river bluffs — are found some distance away from the rivers, thus suggesting former more extensive tree growth.[2]

The fundamental condition governing the treelessness of the Plains and the Prairies is the deficiency of rainfall in spite of the fact that the larger portion of the rainfall of the central plains region occurs in the summer or growing months, Fig. 22. Beyond the Mississippi the rainfall shades off rapidly; in sympathy with this increasing dryness is the gradual thinning out of the forest and its final disappearance. In the transition belt it is obvious that secondary forces will hold the balance of power. Among these undoubtedly the most important are the fineness of the soil, forest fires started by the Indians and by lightning, the prolonged droughts of exceptionally dry years, the high rate of evaporation of soil water, and the low humidity.

The importance of the fineness of the soil has been strongly urged,[3] since almost all forms of vegetation require an aerated soil, and this is true especially of all but a small number of forest trees. Prairie soils are notably fine and compact, especially in their natural state, and this tends to keep rainfall near the surface for a longer time than in the case of coarse soils, hence a larger part of the rainfall is reëvaporated. The deeper-lying tree roots are thus deprived of a large part of the rainfall, besides being deprived by grass roots of such rainfall as is left available to plants. Prairie and forest fires are of frequent occurrence, and before the coming of the whites were often started by Indians either in sheer ignorance, carelessness, and wantonness, or for purposes of war and the chase. The number of thunderstorms that develop on the plains during the summer months is excessive. Lightning starts a fire in the dry half-withered grass and this spreads with great rapidity and is often not extinguished by the ensuing rain, which may be very light. Indeed

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[1] S. Aughey, U. S. Geol. and Geog. Surv. of Col. and Adj. Terr. (Hayden Surveys), 1874, p. 266.

[2] G. E. Condra, Geography of Nebraska, 1906, p. 93.

[3] J. D. Whitney, Plain, Prairie, and Forest, Am. Nat., vol. 10, 1876, pp. 577-588 and 656-667.

many summer thunderstorms are not accompanied by rain and fires burn unchecked. That this was formerly an important natural agent is shown by the extension of the natural forest upon prairie land in the Edwards Plateau of Texas.[1] Settlement has stopped the periodic burning of the grasses, which were harmed by fires much less than were the shrubs, the vanguard of the timber vegetation. The over-pasturing of the ranges of this region has prevented the grass from forming a continuous sod, thus throwing further influence in the direction of the timber growth. In recent years the results have been marked. The shrubs have come in rapidly, trees have grown in their wake, and there is now in progress a gradual but extensive transition from grass to woody growth.

The prolonged droughts of exceptionally dry years are effective in preventing the germination of the seeds of forest trees and in harming tender seedlings. At least three-fourths of the rain that sinks into the ground never gets beyond the surface layer of two feet,[2] while the increasing distance to the ground water with increasing aridity is well known. When these naturally hard conditions are enforced in exceptionally dry years the roots of seedlings and mature trees are confronted with grave difficulties in their search for a water supply. The water in the surface layer is soon evaporated in large part or left in the form of a film surrounding the soil grains where it ceases to be supplied by capillarity and gravitational flow to the root zone of forest trees. Evaporation is hastened by the high summer temperatures of the plains and the continued sunshine and the rather steady and often high winds.

It should not be forgotten in the analysis of the problem that the underlying condition is regional dryness. Were the rainfall heavy, or even moderately heavy, a forest cover would undoubtedly exist in the plains country. Besides this factor the others appear secondary, yet the sum total of the secondary forces definitely restricts the forest. (1) There are far windier situations on forested mountain slopes that one may find on the plains, (2) forest fires do not eliminate trees from many relatively dry regions, (3) heavy clay lands bear luxuriant forests where rainfall and temperature conditions are normal. But when the conditions of rainfall are critical the balance of power is held by otherwise feeble influences.

That the cause is not wholly climatic is reasonably inferred from the success with which tree planting has been conducted in the treeless

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[1] W. L. Bray, The Timber of the Edwards Plateau of Texas, Bull. Bur. For. No. 49, 1904, pp. 14-15.

[2] F. H. King, Productivity of Soils, Science, n. s., vol. 33, 1911, p. 616.

settled portions of the western country where windbreaks, snowbreaks, thrifty groves in city parks, etc., testify to the possibilities of at least a restricted reforestation. Even the sand dunes of Nebraska appear to be reclaimable, as shown by the at least temporary success that has attended the afforestation efforts of the government. The whole plains country cannot be afforested since the greater part of it is too dry, but a large part will support a limited forest cover and the Prairie Plains can be made to grow trees almost everywhere, where now the growth is limited, at least toward the western border, to the valley floors and borders, and to tracts of porous soil with a good water supply.

CHAPTER XXIII

MINOR PLATEAUS, MOUNTAIN GROUPS, AND RANGES OF THE PLAINS COUNTRY

Edwards Plateau

The combined Edwards Plateau and Llano Estacado (the portion of the High Plains that lies in western Texas) is the most extensive relief feature of the non-mountainous part of Texas, with an area of about

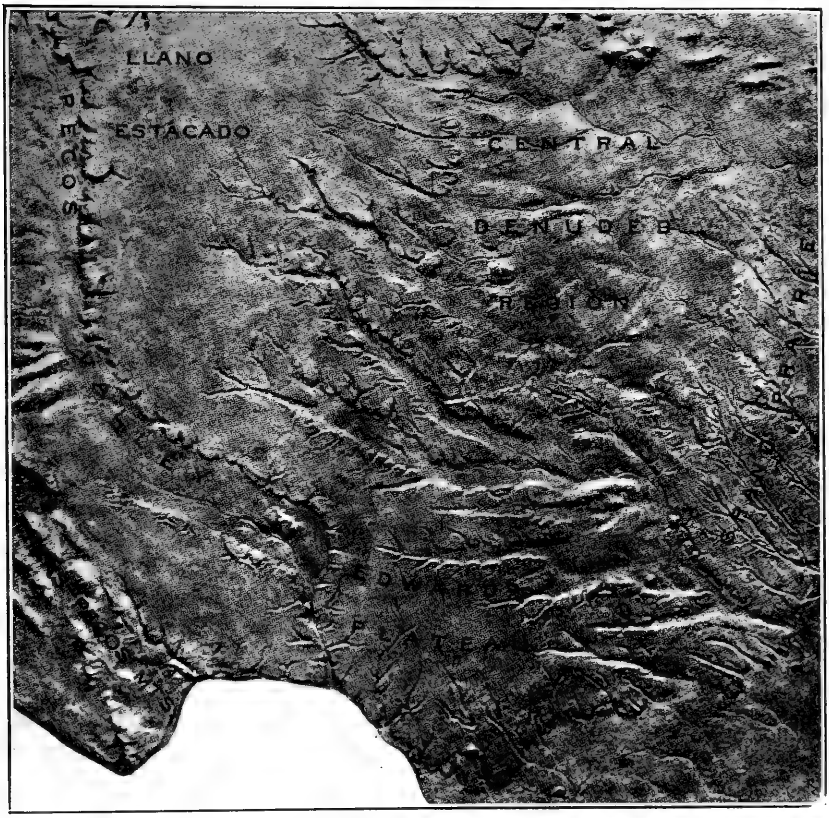

Fig. 158. — Llano Estacado, Edwards Plateau, and adjacent territory. The central denuded region was once covered with the Edwards limestone now exposed about the border as a frayed escarpment of erosion. (Hill, U. S. Geol. Surv.)

60,000 square miles. The two merge into each other and no sharp line can be drawn between them. They are surrounded on all sides by pronounced escarpments. The eastern margin is an escarpment of headwater erosion, the southern margin is the dissected Balcones fault scarp, and the western and northern margins descend steeply to the drainage grooves of the Pecos and the Canadian respectively.

While the Edwards Plateau continues the High Plains of western Texas or the Llano Estacado southward, it presents structural conditions wholly different from those found in the High Plains and, except for the general plain-like character of much of the surface, is quite different in its topographic character. It should be regarded as a subdivision of the Great Plains province and not as a portion of the High Plains. The surface of the Edwards Plateau is capped by the Edwards limestone, the most conspicuous and extensive sedimentary formation in Texas (and a large part of Mexico) inland from the coastal plain. The Edwards limestone is also important topographically, for its harder strata resist erosion to a greater degree than associated formations, and it is on this account the chief structural factor in the formation of the scarps, mesas, and buttes of the Grand Prairie, Edwards Plateau, and large portions of the limestone mountains of Mexico.[1]

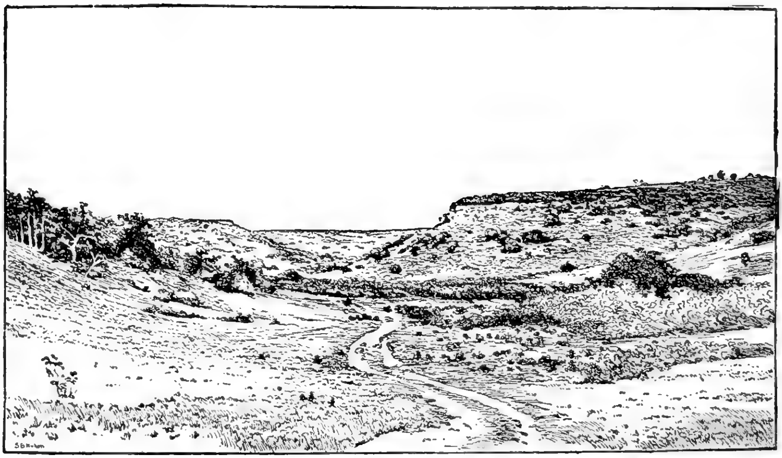

Fig. 159.—Summits of the Lampasas Plain, Texas. (Hill, U. S. Geol. Surv.)

The wide, flat, upper surface of the Edwards Plateau is terminated on the borders of the province by a pronounced descent, a ragged scarp due to the dissection of the draining streams whose irregular interlocking headwaters have cut up the border into innumerable circular mesas

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[1] Hill and Vaughan, Nueces Folio U. S. Geol. Surv. No. 424, 1898, p. 3.

and buttes. The descent from the level plateau to the canyons is over a cornice layer of hard rock that weathers into a nearly horizontal vertical bluff. At intermediate levels on the walls of canyons and valleys cliff makers occur; the intervening spaces between cliff makers consist of more easily weathered beds that yield a sloping talus. Fig. 155 represents typical features in the eastern border of the plateau.

The drainage of the plateau summit except in the case of the largest streams is of the intermittent variety, and in places even some of the larger streams disappear for a short distance. This is due partly to evaporation, which is especially strong under the cloudless skies of western Texas, but in larger degree to absorption in the waste-filled valley floors or in the fissured limestone. The smaller streams have been called streams of gravel rather than streams of water, so clogged do their valley floors appear. The streams draining the border of the plateau have a very much more regular flow than might be expected because of the large number of springs which are fed by fissures and underground channels into which the absorbed water is directed.

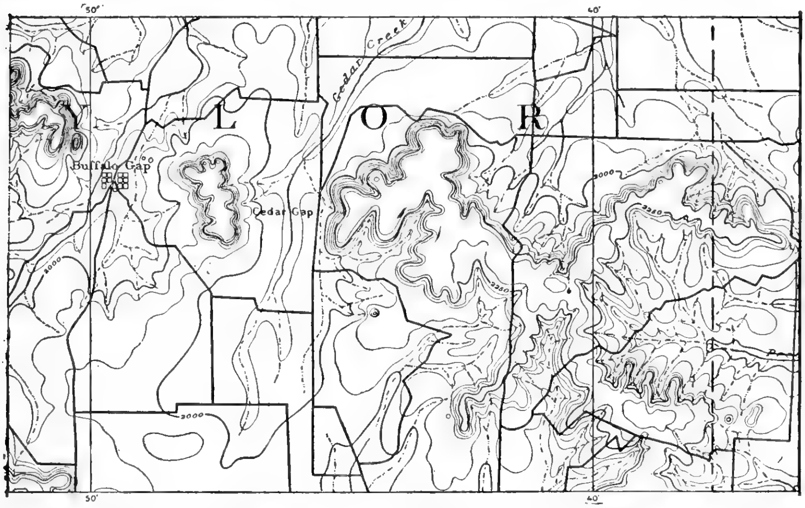

Fig. 160. — Summits of the Callahan Divide on the Great Plains of Texas (Central Province of Fig. 158). (U. S. Geol. Surv.)

A subdivision of the Edwards Plateau is the Stockton Plateau west of the Pecos and east of the front ranges of the Trans-Pecos region. The southern border of the Stockton Plateau is tilted and faulted into low monoclinal blocks, while the scarps of the northern border overlook the Toyah basin.

Formerly the Edwards Plateau extended farther eastward, a condition shown by the erosion remnants now occurring as outliers beyond the eastern border of the plateau. These remnants consist of circular flat-topped hills and groups of hills on the interfluves. The summits of the outliers are all of the same geologic formation as the adjacent plateau and are in vertical alignment with the normal coastward slope.[1] The altitude of these outlying mesas is about 500 feet above the principal stream courses and about 250 feet above the surrounding plains. They form less than 10% of the total area, although they are widely distributed. The principal group occurs on the 31st parallel on the divide between the Brazos and the Colorado and is known under the collective name of the Callahan Divide. As a group these remnants represent a former broad topographic level that once extended from the mountains of the west to the eastern border of the Grand Prairie of Texas, p. 493. During and since the Tertiary this old level was largely destroyed in the central region of Texas and two opposing escarpments formed — the eastern border of the Edwards Plateau and the western border of the Grand Prairie — which are retreating from each other at the present time. Although the Balcones escarpment is commonly referred to as a fault scarp it should be noted that a portion of the descent is to be attributed to the increased steepness of dip along the front of a monoclinal fold which has been still further accentuated by erosion, Fig. 162.

The northeastern extension of the Edwards Plateau forms a third subdivision of the province. Its surface is structural in origin, as indicated by the large number of flat-topped remnantal summits which dominate the tract. They are developed most extensively on the divides between the drainage lines and in places have sufficient height to be called mountains. In general the plateau remnants are bordered by bare white limestone cliffs above and by gentler waste slopes below. The flat summits consist of weathered limestone in places without soil, in other places bearing a thin but rich soil cover. The largest continuous area of these remnants is called the Lampasas Plain which extends for 115 miles from the Colorado in Travis County to the northeast corner of Comanche County, Fig. 160. As shown in Fig. 161, there is an intimate relation between the topography and the geology on the one hand and the vegetation on the other. From the scrub oak and post oak growths of the summit with its thin soils one passes in downward succession over the nearly soilless cliffs with a growth of shin oak to the deeper soils of the sandy formations with their good forests of black jack and post oak.[2]

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[1] R. T. Hill, The Physical Geography of the Texas Region, Folio U. S. Geol. Surv. No. 3, 1900, p. 6, col. 4.

[2] R. T. Hill, Geography and Geology of the Black and Grand Prairies, Texas, 21st Ann. Rept. U. S. Geol. Surv., p. 7, 1899–1900, p. 77 et seq.

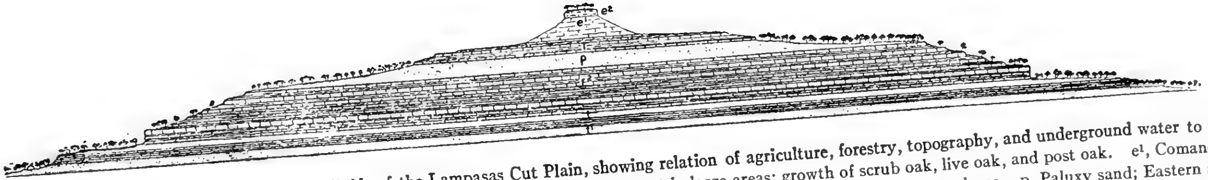

Fig. 161. — **Diagrammatic representation of a divide of the Lampasas Cut Plain, showing relation of agriculture, forestry, topography, and underground water to the geology.** e², Caprina limestone; summit divide of Lampasas Cut Plain; soilless except in large areas; growth of scrub oak, live oak, and post oak. e¹, Comanche Peak limestone; chalky, soilless slopes; growth of shin oak. f, Walnut formation, Walnut Prairie; rich, fertile land in many places. p, Paluxy sand; Eastern and Western Cross Timbers, forested with post oak and black jack; fair cotton and good fruit land; water-bearing. r², Barren limestone slopes with growth of juniper, live oak, and sumac; occasional fertile soils from interbedded marly layers; water-bearing. t², Trinity sands; Western Cross Timbers; same forest growth as p. r¹, small prairie spots; good soil. t¹, Trinity sands; Western Cross Timbers; same forest growth as p. (Hill, U. S. Geol. Surv.)

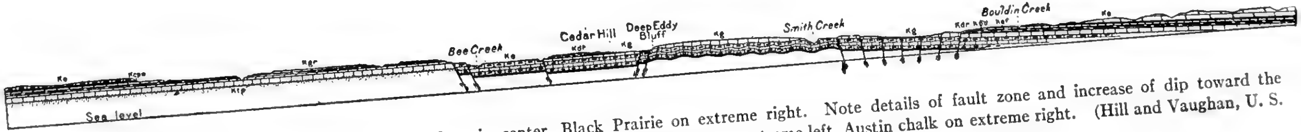

Fig. 162. — Edwards Plateau on left, Balcones Fault Zone in center, Black Prairie on extreme right. Note details of fault zone and increase of dip toward the east (right). Horizontal and vertical scales, 5000 feet to the inch. Edwards limestone on extreme left, Austin chalk on extreme right. (Hill and Vaughan, U. S. Geol. Surv.)

PHYSIOGRAPHIC DEVELOPMENT

The main mass of the Edwards Plateau was elevated into permanent dry land at the close of the Cretaceous period. During the Eocene period there was extensive erosion and the upper Cretaceous formations (3000 feet) were swept away. Near the close of the Eocene, folding and faulting took place and the Balcones fault scarp that limits the plateau on the south was outlined. During the Miocene the plateau was still further stripped and the Edwards limestone that now forms the surface of the plateau was exposed. Active erosion has continued from the early Pleistocene down to the present day. At the time of its appearance above sea level at the close of the Cretaceous the Edwards Plateau region probably had topographic features similar to those exhibited to-day. The strong differences between the alternating strata resulted in wide stripping wherever the upper surface of a harder stratum of wide extent was exposed.

SOIL COVER

The soils of the Edwards Plateau are residual and consist in large part of chert nodules that have resisted solution and ordinary wear much better than the soluble limestone. With these are found impurities common to limestone everywhere and even a certain proportion of the calcareous element. Upon the higher levels where flattish summits prevail the soils are good, but along the stream courses they are usually rough and stony.

VEGETATION

The most important topographic elements of the Edwards Plateau from the standpoint of vegetation are (1) the flat-topped summits of the plateau on the divides, (2) the "breaks" or scarps and related slopes of its ragged canyoned border, known locally as "the mountains," and (3) the streamways and their tributaries. The ragged escarpment which borders the plateau rises from 400 to 1000 feet above the coastal plain, and it is chiefly on this border that rainfall occurs.[1]

The Edwards limestone has a high absorptive capacity because of its low dip and the extensive system of fissures and caverns developed in it. These structures operate also to convey a large part of the water to the deeper strata, from which it discharges as spring water on the valley

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[1] W. L. Bray, The Timber of the Edwards Plateau of Texas: its Relation to Climate, Water Supply, and Soil, Bull. U. S. Bur. For. No. 49, 1904, p. 9.

margins. The border region of the plateau is so deeply dissected that were the water not detained by a vegetal covering it would flow off after a heavy rainfall before it had time to enter the limestone, and the streams would have such volume and velocity as to cause swift and destructive floods.

The Edwards Plateau is not covered with continuous forests even in the most favorable situations. The timber is much interrupted by open grassy uplands. Tongues of luxuriant forest follow the stream-ways into the center of the limestone region and in the deeper, well-watered, sheltered canyons the trees attain large dimensions. The forest is in the form of a thick-canopied, shady cover protecting many shade-loving shrubs. This floral community is altogether unlike that found in the adjacent country. It is distinctly like the Atlantic type, from which it is separated by miles of treeless country. The chief representatives are the American elm, sycamore, pecan, cottonwood, walnut, black cherry, etc., and in some places cypress with a diameter of 5 feet or more and a corre-

Fig. 163. — Escarpment timber of the Edwards Plateau. Conral River near its source. (U. S. Bur. of For.)

sponding height. The timbered belt is confined rather strictly to the deeply eroded portions of the plateau, gradually giving way to prairie on the level uplands toward the west and to grassy plains toward the east. There is a gradual dwarfing and thinning out of the heavy timber as one passes from the generally heavy growth of the watered canyons to the stunted forests of the hills and bluffs and the still scantier tree growth of the loose stony slopes. Finally there remain only scattered chaparral and the vegetation of the low Sotol Country, Fig. 157, whose principal representatives are sotol, cactus, yucca, and agave.

The hill and bluff forest occurs on the "breaks" of the Colorado along the escarpment front from Austin westward and on the Guadalupe, the Pedronalles, and the Freio. It also extends northward upon the breaks of the Grand Prairie and the jagged hills of the granite country. The timber of this type varies in density with local conditions. On lower flats where deep black soil occurs there is a heavy mixed growth of cedar, live oak, elm, hackberry, mountain oak, shin oak, etc., and the type is extended to the side gorges and draws leading from the main stream-ways. Ten miles northwest of Austin on the Colorado are some timber-capped buttes, and similar occurrences are found in a few other localities. On the unstable talus slopes, where the natural shortage of water is emphasized by the excessive porosity of the loose débris, no timber covering is found except a scattered growth of mountain cedar.[1] Juniper and laurel occur along the vertical slopes of the scarps and sometimes encircle the hills with bands of evergreen. On the floors of the drier valleys are tongue-like extensions of the chaparral flora of the Rio Grande Valley. They are characterized by thorny deciduous trees, mostly acacias, with an undergrowth of Mexican nopal. Thick-skinned yucca, ixtle, and cacti are also found as true desert flora on the bare limestone of the numerous buttes about the borders of the plateau.

On the broken limestone areas are the "oak shinneries," marked by a predominating growth of oak or dwarf shin oak. These are simply dense thickets, scarcely more than tall shrubbery, as on the divides between the Colorado and the San Gabriel drainage country in Burnett County, where much of the growth is so dense as to make it impossible to ride through on horseback. Though it has no value as timber it is a soil retainer of great value. Mixed with this growth is a certain amount of live oak, mountain oak, plum, sumach, holly, and a number of climbers.[2]

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[1] W. L. Bray, The Timber of the Edwards Plateau of Texas: its Relation to Climate, Water Supply, and Soil, Bull. U. S. Bur. For. No. 49, 1904, pp. 15–17.

[2] Idem, pp. 17, 18.

Among the most valuable assets of the Edwards Plateau region are the cedar brakes conspicuous on the white arid hills of crumbly limestone where the cedar is the dominant and practically the only species. It also grows in mixture with other species, attaining its largest growth in the mixed forests of the lower uplands, where the water supply and soil conditions are better. The most extensive bodies of cedar are those of the Colorado River brakes from Austin to the San Saba country.[1] The cedar brakes are dry and as likely to burn as a prairie of tall grass. Evidences of ancient or recent fires are found almost everywhere.

Many of the trees of the Edwards Plateau region are peculiar products of their environment.

> "The eastern red cedar here becomes the mountain cedar; black walnut is represented by the Mexican walnut, whose nuts are tiny balls scarcely half an inch in diameter. Texas oak becomes mountain oak. The common live oak becomes a new form in its mountain habitat. The common persimmon is represented by the Mexican persimmon, whose fruit is a dark blue-black; Canadian redbud is here also a characteristic 'Judas-tree,' but of a different species. The same is true in the case of the buckeye, mulberry, hackberry, and still others."[2]

The type of vegetation in the Edwards Plateau is undergoing a transition from grass to woody growth. The mesquite is capturing the open pastures, and the scrub oak occupying uplands that were formerly open prairies. The transition is due to a number of causes. The ridges have been over-pastured and the balance of power thus thrown to the shrubs which are the vanguard of a timber covering. Twenty-five years ago the prairie held sway over large areas where now one finds scrub oak on every side. A great deal of the "shinnery country" undoubtedly represents a recent gain in timber on the prairie divides; from the edge of the brush each year new sprouts or seedlings are pushed out a few feet farther, and the new growths soon offer shelter for others. These scattered vanguards were formerly killed by the prairie fires and the timber growth held in check; but with the spread of settlements prairie fires have been reduced and a means of holding its position withdrawn from the grass covering.

One of the most striking aspects of this encroachment of the timber upon the prairie land has been the spread of mesquite over the cattle country. Pastures have often been covered with a thicket as close as that of scrub oak, in which, however, the mesquite forms an open orchard-like growth with which are finally associated various species of chaparral and very commonly the prickly pear and the Opuntia. The final result of the spreading of mesquite is a heavy covering of vege-

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[1] W. L. Bray, The Timber of the Edwards Plateau of Texas: its Relation to Climate, Water Supply, and Soil, Bull. U. S. Bur. For. No. 49, 1904, p. 19.

[2] Idem, p. 15.

tation which serves as a protector of water supply and soil, although the original grassy growth would be of far greater value to man.[1]

Some of the interrelations of forests, water supply, temperature, and soils are peculiarly interesting. The forest covering furnishes shelter to the ground beneath from the sun's rays and prevents intense heating of the rocks and soils. A reduction of temperature is also afforded by the constant transpiration of water vapor from the leafage of the forest. A far more important effect, however, is the influence of the forest upon the soils. The foliage breaks the force of the rain and compels it to run harmlessly down the trunk or to drip slowly through the leaves. The direct impact of the falling raindrops upon the soil is thus prevented, erosion greatly diminished, and the absorption of the rain water promoted. Tending to the same result is the organic material of the forest floor, which holds back the fallen water until it has had time to soak into the soil. Thus gullying is prevented and frequent and destructive floods reduced in number and violence. These results are beneficial not only to the inhabitant of the region but also to those whose welfare is in any degree bound up with the régime of the streams. The rice planter on the coast is just as eager as the ranchman of the plains to have a constant and large flow of water, and the ranchman of the hills wishes his soils preserved and the soil moisture retained. For these purposes a forest cover, especially in a semi-arid region like the Edwards Plateau, is a vital necessity.[2]

BLACK HILLS

The Black Hills of southwestern South Dakota and adjacent portions of Nebraska and Wyoming rise several thousand feet above the surface of the surrounding plains. They have, by reason of their elevation, an abundant rainfall and as a result are well wooded, have many streams, and are in effect an oasis in a semi-arid region. They are

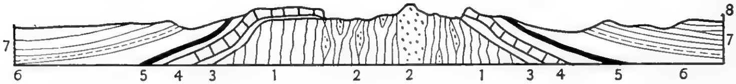

Fig. 164. — Ideal east-west section across the Black Hills. Vertical scale six times the horizontal. 1, slates and schists; 2, granite; 3, sandstone (Potsdam); 4, limestone (Carb.); 5, sandstone (Trias.); 6, shales (Jura); 7, shales (Cret.); 8, shales (Tertiary). (After Newton.)

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[1] W. L. Bray, The Timber of the Edwards Plateau of Texas: its Relation to Climate, Water Supply, and Soil, Bull. U. S. Bur. For. No. 49, 1904, pp. 23, 24.

[2] Idem, pp. 26, 27, 29.

carved from a dome-shaped uplift of the earth's crust; the uplift has been sufficient to cause vigorous erosion, so that the upper layers once forming the top of the dome, and corresponding in age and character with the strata on the surface of the plains, have been removed by erosion, and the sedimentary rocks now exposed on some of the mountain summits of the Black Hills are older than those forming the surface of the Great Plains. The length of the Black Hills dome is about 100 miles, the width 50 miles. The chief features are (1) a central area of high ridges culminating in Harney Peak (7216 feet). This central area is composed of intrusive crystalline schists and granite of several varieties. (2) About the central crystalline area occur various concentric rings of sedimentary rock separated by well-developed valleys; the innermost mass of sedimentary rock occurs in the form of a limestone plateau with an infacing escarpment, Fig. 164.

Fig. 165. — Western slope of Black Hills southeast of Newcastle, Wyoming looking southeast. Steep-dipping beds are limestone, which spread out in a plateau at foot of slope. (Darton, U. S. Geol. Surv.)

The limestone plateau slopes outward and extends around the Black

Hills. Near its base there is a low ridge of limestone with a steep infacing escarpment from 40 to 50 feet high. The escarpments and slopes are sharply notched here and there by canyons which form characteristic "gates." Between this limestone plateau and the hogback ridge which constitutes the outer rim of the Hills is a depression, the Red Valley, which extends continuously about the uplift. The Red Valley is in many places two miles wide, though it is much narrower where the strata dip more steeply. It is one of the most conspicuous features of the region and is called the Red Valley on account of the red color of its soil. The outer hogback rim presents a steep face toward the Red Valley, above which it rises several hundred feet; on the outer side it slopes more or less steeply down to the plains that encircle the hills. It is crossed by numerous gaps and canyons which divide it into subordinate ridges of various lengths.

The Black Hills dome was first developed either in early Tertiary or in late Cretaceous time, but the first uplift was to a moderate height. After this first uplift the larger topographic outlines of the region were established, the dome truncated, and its largest encircling valley excavated in part to its present depth. Later deposits (Oligocene) were laid down by streams and in local lakes, and these deposits extend far up the flanks of the Black Hills, as at Lead and Bear Lodge mountains, respectively. After the deposition of these beds the Black Hills dome was raised several hundred feet higher and more extensively eroded, an erosion that has continued through Quaternary time and is in progress to-day.[1]

SOILS AND FORESTS

The soils of the Black Hills region are closely related to the underlying rocks and are of residual origin except on the valley floors and in a few cases where eolian action has taken place. On the limestone plateaus calcareous material forms the greater part of the rock. The soluble portions have been removed and the insoluble portions of clay and sand have collected as a soil mantle which varies in thickness with the character of the limestone, being thin where the limestone is pure, and thick where it contains many impurities. The amount of soil in a given region depends also on the rate of erosion. On many slopes erosion removes the soil as soon as it is formed, leaving bare rock

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[1] Darton notes the occurrence of outliers of Tertiary (Oligocene and Miocene) deposits high up on the slopes of the Black Hills (N. H. Darton, Geology and Underground Water of South Dakota, Water-Supply Paper U. S. Geol. Surv. No. 227, 1909, pp. 26–27).

surfaces; on others the surface is flat, erosion is not active, and the soil has accumulated to considerable depth.

In the central core of crystalline schists and granites the rocks have been decomposed most by the dehydration of portions of their feldspar, with the result that the derived soil is usually a mixture of clay, quartz grains, mica, and other materials. The shales yield a sandy soil where they are sandy and a clayey soil where they themselves have been formed of relatively pure clay. In many cases the geologic formations alternate in short distances; there are corresponding abrupt transitions in the character of the soil in narrow parallel zones. Lack of sympathy between soils and underlying rock may be seen in the river bottoms, in sand dunes, in areas of high river gravels, and on slopes where soil derived by slope wash are mingled with or covered by soils derived in place.

The Black Hills forest in general terminates abruptly at the broad valley known as the "Race Track," which lies between the main mass of the uplift and the lines of ridges which encircle the hills. The higher portions of the encircling ridges are also clothed with forest. Sometimes the growth in the latter case is good, sometimes it is in the form of a narrow summit fringe of trees. The main portion of the Black Hills forest includes about 2000 square miles of densely timbered territory. In many places the continuity of the forest is broken by parks and mountain prairies, and large tracts have been destroyed by forest fires which have swept the Black Hills periodically for years if not for centuries.

The yellow pine is the only species of commercial importance; the others are either too small or have too specialized a use to have any great value. A few small bodies of spruce occur, and aspen has come in on some of the burned tracts. The best-quality pine is found in the side ravines and canyon bottoms, where soil and water supply are most favorable and where protection is afforded by the topography. On the steep slopes the soil is stony and thin, the drainage excessive, and the trees shorter and smaller. The forests on the north slopes are in general better than those on the south slopes because of (1) better protection from fire and (2) greater water supply on account of lessened insolation.[1] In general the limestone soils are more fertile than those derived from other kinds of rock and bear the most vigorous growths of trees.

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[1] H. S. Graves, Black Hills Forest Reserve, 19th Ann. Rept. U. S. Geol. Surv., pt. 5, 1897–98, pp. 72–75.

Outlying Domes

On the northern border of the Black Hills the Great Plains are diversified by a number of picturesque elevations that are unique topographic features besides affording illustrations of a very peculiar type of structure. Each hill owes its existence to the injection from below of a column of molten rock into stratified beds. They are not to be considered as volcanic necks, which they in some respects resemble, for the injected rock did not reach the surface so as to form either coulees or cinder cones. Named in general order from east to west

Fig. 166. — Devil's Tower from the north. The steep laccolithic mass is phonolite; the gentler slopes about it are developed on shales and sandstones. (Darton, U. S. Geol. Surv.)

the principal hills are Bear Butte, Custer Peak, Terry Peak, Black Butte, Crow Peak, in South Dakota, and the Inyan Kara, the Sun Dance Hills, Warren Peaks, Mato Tepee or the Devil's Tower, and the Little Missouri Buttes in Wyoming.

As a group these hills display variety in the degree of erosion and hence in the degree of preservation of the original structures. In some cases the dome of stratified beds covering the injected rock is still unbroken and the plutonic rock concealed; elsewhere erosion has exposed the plutonic core, while in some erosion has progressed to the point where the central core stands forth as a tower of columnar rock (phonolite) several hundred feet in height. The first type is illustrated by Little Sun Dance dome, which has very regular outlines, is about a mile in diameter, and deeply scored by erosion but not sufficiently eroded to expose the core of igneous rock that presumably lies underneath.[1]

The eroded type is illustrated by Mato Tepee, in which the arch of sedimentary rock has been entirely removed, exposing a column of injected rock. The tower stands on the west bank of the Belle Fourche River, quite by itself, and rises to a height of 626 feet above the platform on which it stands. The shaft of this magnificent natural column is composed of cluster prisms which extend from base to summit without cross divisions, each prism being a uniform unbroken column more than 500 feet high. Since the plateau on which Mato Tepee stands is itself about 500 feet above the river, it is clear that the minimum amount of erosion that must have taken place to expose the column is somewhat over 1000 feet. It was probably much over this amount, for none of the material of the Butte was extruded at the surface. There is good reason for believing that the amount of erosion in the region is but little under three-fourths of a mile, a conclusion which means that this great tower must have been buried under at least a half mile of sedimentary rock.

LITTLE BELT, HIGHWOOD, AND LITTLE ROCKY MOUNTAINS

In central Montana, just east of the front ranges of the Rocky Mountains, are a number of isolated mountain groups with structural and topographic qualities totally different from those of the northern Rockies. On the east they break the continuity of the Great Plains of Montana and are prominent topographic features long before the traveler sights the Rocky Mountains. Lying east of or on the eastern border of the main Cordillera and in a region of deficient rainfall, their own sum-

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[1] I. C. Russell, Igneous Intrusions in the Neighborhood of the Black Hills of Dakota, Jour. Geol., vol. 4, 1896, pp. 23–43.

mits rise to such heights, 5000 to 9000 feet, as to induce a greater rainfall than occurs on the surrounding plains, and they are therefore clothed with forests. Among these mountain groups are the Little Belt, Highwood, Little Rocky Mountains, and others.

Little Belt Mountains

The Little Belt Mountains are an elevated and eroded plateau, as shown on the accompanying topographic map, Fig 167. They are about 60 miles wide from east to west and 40 miles from north to south on the west side, and taper to a sharp point at Judith Gap on the east, so that the group is roughly triangular in shape. Individual peaks along the northeastern border of the group rise above the general level and form an uneven crest line visible from the open plains. As compared with the well-defined ranges of the Rockies the Little Belt group is relatively low and wide and composed of many spurs radiating from a central point.[1] The border of the mountains on the west is defined by the deep canyon of Smith River, beyond which the country has gentler relief.

On the summit of the Little Belt arch the rocks are gently inclined or horizontal, but on the flanks or shoulders of the arch the rock dips steeply away from the uplift. The intrusions which arched the beds are laccolithic in character. Since the development of its structural features the range has suffered extensive denudation. Erosion has laid bare the larger laccoliths and worn down the general level differentially; the harder igneous rocks have been left in relief to form the higher summits, while the softer sedimentary rocks have been eroded, although the members of each group have been eroded at very different rates owing to differences in degree of resistance. On account of deficient height the Little Belt Mountains did not support local ice sheets during the glacial period, nor were they covered by the continental ice sheet during the time of its maximum southward extension.[2]

Throughout the greater part of the Little Belt region a plateau-like topography prevails; broad flat summits are characteristic. The average elevation is 7600 feet, though the summit level from which the spurs radiate is 8000 feet high. The highest summit of the group is not at the center but along the northeastern border, where Big Baldy reaches an altitude of 9000 feet. The Little Belt Mountains are

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[1] W. H. Weed, The Geology of the Little Belt Mountains, Mont., 20th Ann. Rept. U. S. Geol. Surv., pt. 3, 1898–1899, p. 273.

[2] Idem, p. 277.

Fig. 167.—Topographic map of the Little Belt Mountains. (U. S. Geol. Surv.)

bounded by relatively soft rocks to whose deep erosion the prominence of the mountains is chiefly due.

The relation of the detailed topographic features to the rock character is so intimate that it is impossible to distinguish the one feature without distinguishing the other. Summit plateaus are bordered by steep escarpments with towering limestone cliffs along the stream gorges. Only the highest peaks along the northeastern border and the steep limestone gorges lend picturesqueness to the scenery. In the center of the mountain area where the beds are horizontal or only gently inclined, secondary structural plateaus are commonly found. Upon some of these the rock is so resistant as to determine broad ridges which in some cases are emphasized by differences in soil and vegetation, as is the case in Belt Park and other timberless parks near Neihart, which have been developed on quartzite and which are in contrast with the wooded and soil-covered slopes above and below. There are no broad valleys within the mountains; for the most part the streams flow in deep trenches or narrow canyons in the harder limestone and in less narrow valleys in the shale belts.[1]

CLIMATE, SOIL, AND VEGETATION

Both rainfall and snowfall are relatively abundant in the Little Belt Mountains. Intermittent streams which flow only in wet weather or at times of melting snow are common. These are especially characteristic in limestone areas where the waters are absorbed by the porous and fissured rock and in those regions where the catchment areas are small. As a consequence of the greater precipitation due to the greater height of the Little Belt Mountains over the surrounding plains they are in general forest-clad, their dark slopes being in strong contrast to the arid treeless plains about them. Lodgepole pine is the prevailing species; in some places it forms forests with individual trees 10 to 40 inches in diameter, but usually it is much smaller. On the plateau summits the white pine is found, and spruce and fir grow along the wet stream bottoms and on moist and cold northern exposures.

There is a very intimate relation between the character of the tree growth and the nature of the slope exposure. On southward-facing slopes, which are relatively dry because of the greater insolation, the growth is sparse and open, and interrupted by grassy parks; on northward-facing slopes thick and dark forests occur. The growth varies somewhat also with the character of the rock and the physical nature

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[1] W. H. Weed, Geology of the Little Belt Mountains, Mont., 20th Ann. Rept. U. S. Geol. Surv., pt. 3, 1898–99, p. 275.

of the derived soil. The shales produce but little soil and support scanty vegetation; they usually underlie the park regions. The sandstones and the igneous rocks are covered with land waste and are generally densely wooded.

HIGHWOOD MOUNTAINS

The Highwood Mountains are a prominent member of the group of elevations that break the continuity of the northern Great Plains. They lie in the great bend of the Missouri in central Montana about 20 miles north of the Belt Mountains, and about 50 miles southwest of the Bearpaw Mountains, Fig. 148. About them stretch the smooth monotonous plains above which they rise about 4000 feet to summit elevations of 7600 feet. The Highwoods are a group of old and now much eroded volcanoes which broke through the once flat-lying Cretaceous strata of the plains. The mountains are composed chiefly of volcanic flows and breccias and a number of stocks or central cores, the remnants of former more lofty cones. The outer foothills are low and rounded; toward the center the country becomes more rugged. The descent to the plains is abrupt on the south; the chief feature of the northern slopes is an old glacial spillway known as Shonkin Sag whose origin is explained on p. 416. The drainage is in the main radial and consequent upon the original slopes of the volcanoes. The streams are rather constant in flow in the mountains but become sluggish and alkaline on the plains, some of them drying up in summer to such an extent that water remains only in pools in the deepest portions of the stream channels. The outer foothills and valley openings have been occupied by ranchmen who also utilize the water for limited irrigation. Extensive pastures are found on the higher slopes, though these give way to true forests of small pines on the northern exposures. In many places there are dense thickets of lodgepole pine. The name "Highwoods" undoubtedly had its origin in the forest growth of the northern slopes.[1]

LITTLE ROCKY MOUNTAINS

The Little Rocky Mountains lie about 200 miles east of the Rocky Mountain Cordillera and between the Missouri and the Milk about 60 miles south of the 49th parallel. They rise from 2000 to 3000 feet above the treeless plains of central Montana, forming a conspicuous topographic feature in a plains region that is generally without

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[1] L. V. Pirsson, Petrography and Geology of the Igneous Rocks of the Highwood Mountains, Montana, Bull. U. S. Geol. Surv. No. 237, 1905, pp. 1–22.

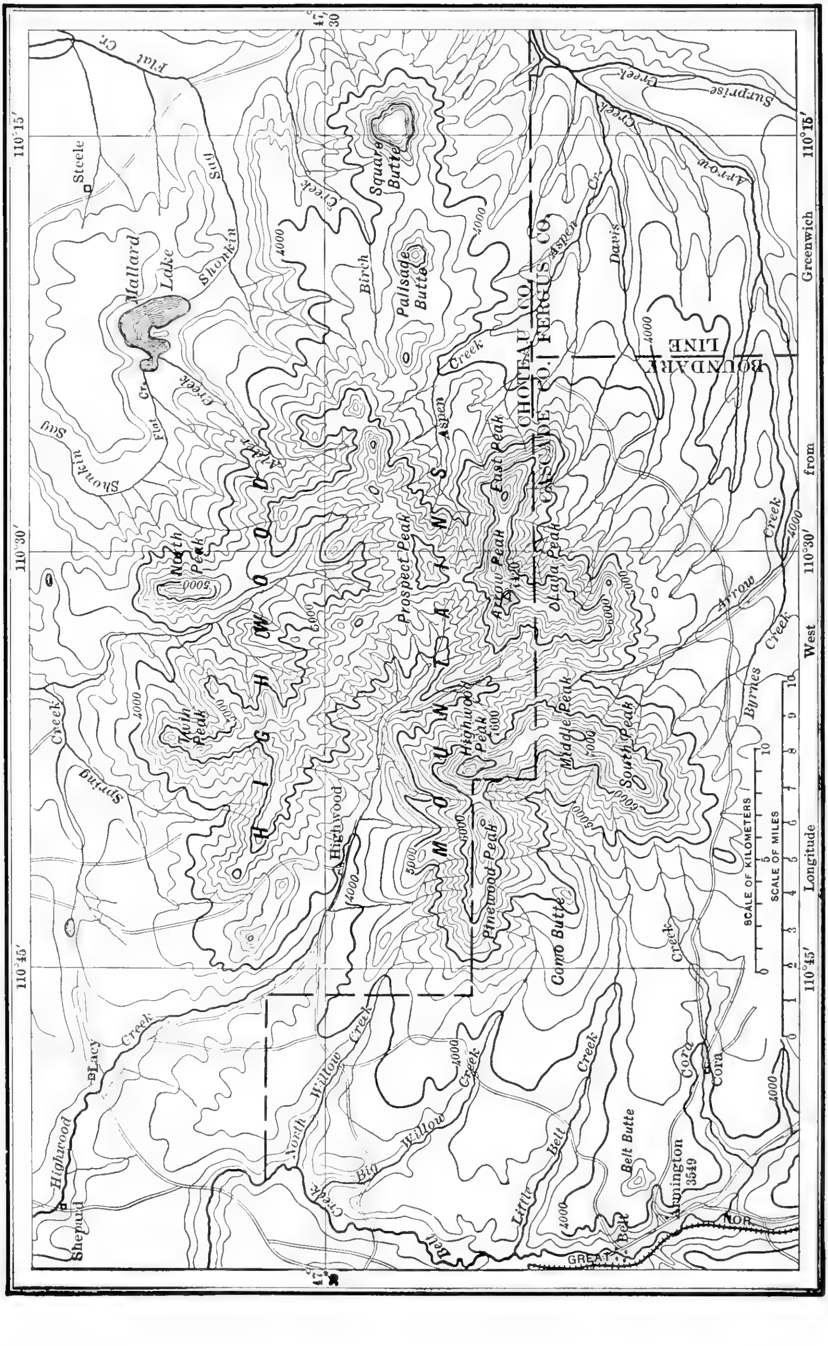

Fig. 168. — Topographic map of the Highwood Mountains, Montana. Contour interval, 200 feet. (Bull. 237, U. S. Geol. Surv.)

prominent landmarks. Their topographic prominence led the Indians to call them "Eah hea Wwetan," or the "Island Mountains."

The Little Rocky Mountains have an undulating crest without sharp peaks. The highest summit is more than 6500 feet above the sea, though only about half that height above the surrounding plains. The scenery is attractive but not grand, for the mountain summits are generally rounded, without that boldness that is the striking feature of most alpine scenery; and to this softness of outline is added the softening effect of a thick growth of small pines, which covers almost all of the summits. Perhaps the most picturesque aspects of the mountains are developed about their borders, where heavily bedded limestones (Carboniferous) are cut by deep narrow canyons variegated by a vegetation that stands in pleasing contrast to the dry plains. The limestones form a white wall encircling the mountains, and stream and cliff erosion has cut the thoroughly jointed beds into huge white scarps visible from points 50 miles away. Within the mountains the streams flow in deep V-shaped gorges.

These mountains are formed upon a single dome-shaped uplift having a central core of crystalline schists overlain and marginally wrapped about by limestones (Paleozoic) and softer beds (Mesozoic).[1] Hard and soft layers encircle and overlap the mountains and are crossed one after the other by streams consequent upon the original slopes of the uplift. Subsequent streams have developed along the strike of the softer beds and usually join the consequents where the valleys of the latter are broadest. The central core of crystalline schist is exposed in the headwater gorges of all the larger streams and in the deep-cut side slopes of the main crest. The gorges have heavily timbered slopes; the prevailing type of timber is the lodgepole pine, from 3 to 20 feet high. It is characteristic of the granite to have a covering of young pines; pines are found also upon the débris slopes, while the limestones and schist areas are covered by the big-leaf pine, which forms groves alternating with open parks.[2]

OZARK PROVINCE

The approximate limits of the Ozark region are the Missouri and Osage rivers on the north, the Arkansas on the south, the Neosho on the west, and the Black River on the east; the Shawnee Hills of southern

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[1] Weed and Pirsson, Geology of the Little Rocky Mountains, Jour. Geol., vol. 4, 1896, pp. 399–428.

[2] Idem, p. 410.

Illinois, a continuation of the Ozark plateau, extend eastward to Shawneetown on the Ohio River.

The Ozark region may be described as a broad, relatively flat-topped dome somewhat extensively dissected and consisting of three subdivisions, the Salem Platform, the Springfield Structural Plain, and the Boston Mountains. The Springfield Plain inclines at a low angle toward the west in Missouri and toward the southwest in Arkansas, a slope which corresponds with the dip of the underlying formation. It is deeply dissected by the large streams which flow through it in narrow valleys; the interfluves are large tracts of broad flat structural surfaces from which younger formations have been eroded. The Boston Mountains are capped by thin layers of sandstone and shale, the more resistant sandstone governing the physical features of the mountains. The rocks dip in the main to the south at an angle slightly greater than the general southward slope of the surface. From hilltops on the Springfield Plain the Boston Mountains appear as a bold, even escarpment with a level crest, but on closer examination the escarpment is seen to have many finger-like extensions to the north

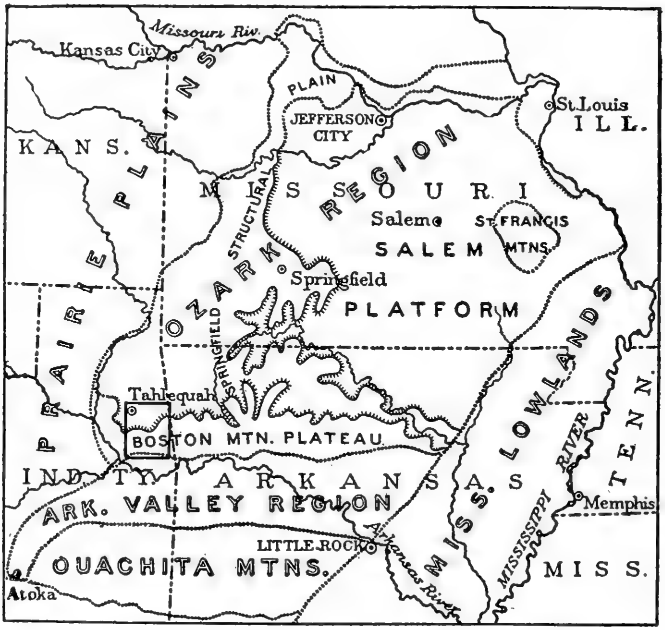

Fig. 169. — Subdivisions of the Ozark region and relations to surrounding provinces. (Taff, U. S. Geol. Surv.)

in the form of ridges and foothills. Toward the west the Boston Mountains decline in elevation and in ruggedness as the sandstone beds become thinner and more shaly in that direction.

The Boston Mountains on the southern border of the Ozark province owe their dominating height in part to the excessive erosion of the region north of them and in part to differential uplift.[1] The result of erosion

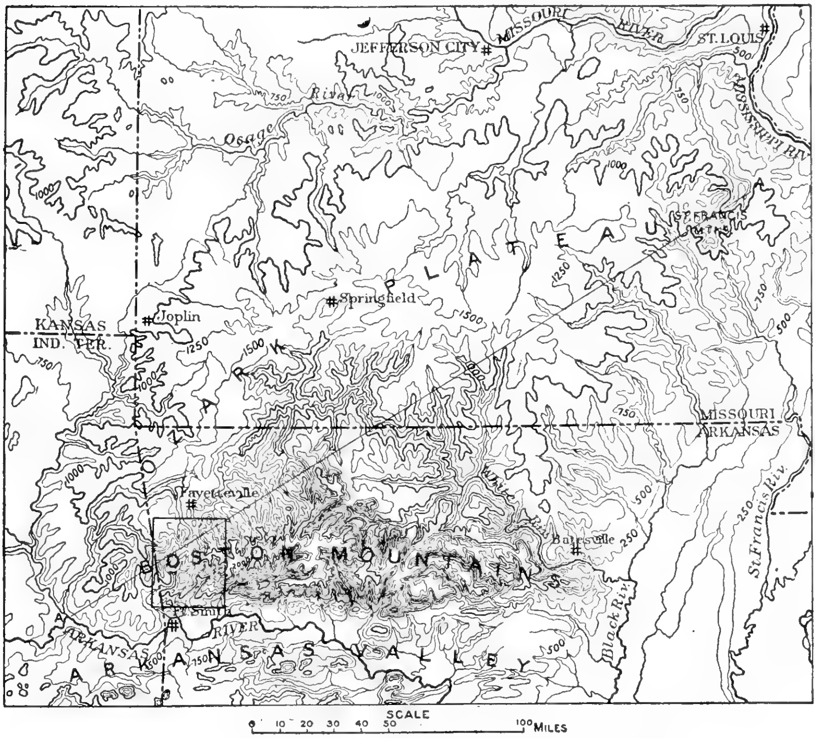

Fig. 170. — Topography of the Ozark region. (Purdue, U. S. Geol. Surv.)

was to reduce a large part of the Ozark region in Missouri and Arkansas to a comparatively low altitude, leaving the Boston Mountains as residuals and their front as a rather bold escarpment. The former greater extent of the Boston Mountains is indicated by remnantal outliers standing several hundred feet above the general level of the area about them. In contrast to the northern part of the Ozark region, which is a low flat dome with only local faulting and minor undulations, the

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[1] A. H. Purdue, Winslow Folio U. S. Geol. Surv. No. 154, p. 5, col. 4.

Boston Mountains have a monoclinal structure and a correspondingly steeper border topography.

The topographic forms of the Ozark region are those characteristic of early maturity in a region of nearly flat-bedded rocks of varying hardness in which the dip of the rock and the slope of the surface are in many places coincident. The entire northern slope of the uplift is a succession of broad flat plateaus separated by more or less ragged escarpments which mark the margins of the harder formations. Forward from the escarpments there are scattered outliers, the fragments of more extensive layers separated from the escarpments by circumerosion. The greatest dissection of the region is on the south and east, the least on the north. On the south and especially at the eastern end of the Boston Mountains the topography is rougher and the plateau character is all but lost. On the north the streams run commonly through broad and rather shallow valleys between which lie extensive areas of relatively undissected plateau. The drainage is in the main radial and consequent, the stream directions corresponding with the restored slopes of the structural dome, but a certain amount of subsequent stream development has also taken place where tributaries have excavated valleys along the outcrop of the softer formations.

Fig. 171. — Topographic and structural section across the Ozark region along line A–A in Fig. 170. Shows the crystalline rocks of the St. Francis Mountains, the limestones of the Ozark Plateau, and the shales, sandstones, and limestones of the Boston Mountains.

Seen from commanding points the surface of the Ozark region presents the appearance of an almost unbroken plateau due in part to the flatness of the structure but also and in larger part to peneplanation that once brought diverse structures to a common level which the vigorous erosion of the region since uplift has not yet wholly destroyed.

The two main subdivisions of the Ozark Plateau, the Salem upland and the Springfield Plain, are separated by the Burlington escarpment, which runs in a general north-south direction.[1] The escarpment is formed upon the border of a limestone layer (Mississippian) which constitutes the surface rock of the western part of the plateau. East of the escarpment, outliers of the limestone occur in the form of small residual areas between which are dissected plains bearing chert accumulations derived from the weathering and erosion of the limestone

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[1] C. F. Marbut, Physical Features of Missouri, Missouri Geol. Surv., vol. 10, 1896, pp. 11–110.

that once extended over the entire region. The streams of the Salem upland flow in narrow valleys some of which are 250 feet or more deep. The degree of dissection is in some places so great that the former extensive plain is not easily recognizable, though large interstream tracts still preserve their plain-like character.

The Springfield upland on the other hand is largely a structural plain developed on the surface of the Mississippian limestone. Near the eastern border of the upland the streams flow in shallow trough-like valleys which deepen westward as the streams cross low anticlines and domes. Those that drain the upland eastward have deep valleys where they cross the edge of the Mississippian limestone, which they have dissected to a ragged fringe.

SOILS AND TREE GROWTH

The soil of the Salem upland is cherty to a high degree, the chert having been derived from the overlying limestone. On weathering, the chert breaks into angular blocks and, because of its greater durability, forms a surface layer of débris. The finer soil particles produced by the weathering of the limestone are carried downward to the base of the weathered zone and are therefore at too great a depth to be accessible to agriculture, though they are of first importance to the forests, which seem to thrive in spite of the surface accumulations of loose stones. The most luxuriant forest is formed upon soils derived from the light-blue limestone and blue shales of the Morrow formation (Carboniferous). Walnut, locust, and other types found naturally only on fertile soils occur on this formation in spite of the fact that it outcrops usually on steep slopes. In general it may be said that in spite of the rather poor soils of the entire region, due to the cherty residual products resulting from the erosion of the limestone and also to the considerable dissection which the region is undergoing to-day, the surface is rather well occupied by forests, since it is too stony and steep to serve for other purposes and since the finer soil is washed down to too great a depth below the surface to be available for the ordinary plants of agriculture.

Arkansas Valley

South of the Boston Mountains is the Arkansas Valley district, which is structurally much more complex than the Ozark region, although standing at a lower elevation. The underlying strata have been thrown into overlapping folds which have been beveled off by erosion so completely as to form a local peneplain approximately 800 feet above the sea. It is surmounted, however, by residual peaks and ridges of small area and from 1700 to 2500 feet above sea level. Since the formation of the Arkansas Valley peneplain, uplift has occurred and the soft shaly beds have been worn away, leaving the inclined sandstones as low, narrow, and sharp-crested ridges whose summits are generally horizontal, a condition indicating the former elevation and topographic character of the area.

Ouachita Mountains

The Ouachita Mountains lie south of the Arkansas Valley and extend from Little Rock, Arkansas, westward into eastern Oklahoma. The range is 200 miles long and nowhere rises more than a few thousand feet above the surrounding valleys and plains. The topographic forms of the range are developed upon an Appalachian type of structure, p. 585. Near the center of the range, long wide folds are developed upon massive sandstone; on the borders of the uplift are shorter and more complex folds developed upon shales and limestones as well as sandstones.[1] The regular development of hills or ridges and valleys is a striking feature of the group as contrasted with the irregularities of the igneous knobs and ridges of the Wichita Mountains of western Oklahoma. The regularity of the topographic details is absent in many places along the border, however, where faults with vertical displacements of several thousand feet have combined with the overturning of the folds to make the relief more irregular both in general plan and in detail.

Arbuckle Mountains

The Arbuckle Mountains form a triangular area approximately 30 miles on each side with a westward extension. The western part of the Arbuckle Mountains has an elevation of about 1300 feet or 1400 feet above the plains on either side. The mountains were uplifted (late Carboniferous) and base-leveled in common with the great Appalachian province east of the Mississippi. Upon the base-leveled surface, then an almost flat plain, Cretaceous deposits were laid down. Later uplift caused the removal of the Cretaceous strata over large areas, but the superior hardness of the underlying rock has resulted in its preservation in the form of a low plateau in the central part of the mountain group, while the bordering strata have been eroded to a lower level. The minor topographic details of the Arbuckle Mountains are due chiefly to the varying resistances of the rock formations. The lime-

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[1] J. A. Taff, Structural Features of the Ouachita Mountain Range in Indian Territory, Science, n. s., vol. 11, 1900, pp. 187–188.

stones in general are hard and form level-topped and narrow ridges with crests approximating the general plane of the regional uplift. Intervening soft cherts and shales are found in the wooded valleys that separate the ridges. In the more elevated part of the uplift erosion by swift streams has etched the border of the plateau into a frill of deep gulches.

Fig. 172. — Mixed hardwoods, etc., in typical relation to topography, Arbuckle Mountains, Oklahoma. On the dry limestone formations forests are absent, except along the lower and moister valley slopes and the valley floors. (Reeds, Oklahoma Geol. Surv.)

A second and lower plain (probably Tertiary) occurs in the Wichita-Arbuckle region and descends approximately with the grade of the rivers. This plain merges into the Tertiary deposits of the coast on the one hand, and on the other hand stretches westward into Oklahoma and northward across Indian Territory. It is preserved through eastern and southeastern Oklahoma in innumerable ridges and hills, occurring at elevations approximating 1800 feet. A third erosion surface has been identified in the plains surrounding the Arbuckle Mountains; the larger streams have cut wide and flat valleys 200 feet below the general level of the Tertiary peneplain. This erosion surface is, however, much more fragmentary than either of the two surfaces just described. It is found bordering the Ouachita Mountains in the form of wide flat valleys developed upon the softer rocks.[1]

Scrub Oak, Red Cedar, and Red Bud are the common trees on the mountain slopes, while red and white elm, Bois d'Arc or Osage orange,

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[1] J. A. Taff, Preliminary Report on the Geology of the Arbuckle and Wichita Mountains in Indian Territory and Oklahoma, Prof. Paper U. S. Geol. Surv. No. 31, 1904, pp. 15–17.

hickory, pecan, hackberry, honey locust, river plum, papaw, mulberry, sycamore, willow, and cottonwood grow in the creek valleys and on the flood plains of the rivers like the Washita. There is also a striking increase in the timber growth (1) on the weaker formations (Sylvan and Simpson) which weather to lower levels, and (2) on those formations (Woodford and Reagan) which contain appreciable amounts of phosphate and iron. The chert, shale, and sandstone strata, together with the granite and porphyry of the East and West Timbered Hills, are all covered with timber. In the narrow creek valleys and canyons, which have been developed on limestones (Arbuckle, Viola, and Hunton), trees appear on the alluvial deposits and near slopes, but rarely on the upland surface, Fig. 172. The rainfall is notably heavier in the mountains than on the adjacent plains. Where the slopes are cleared for cultivation the soil washes so badly that the clearings are soon abandoned. While the clearings are not abundant, yet in the aggregate they include an important and always a conspicuous part of the total area.[1]

Wichita Mountains

The Wichita Mountains are the westernmost of the three mountain groups of the southern Great Plains. They are composed of igneous rock, chiefly granite, and have been eroded into peaks varying in height from a few hundred feet to 1500 feet above the surrounding plains.

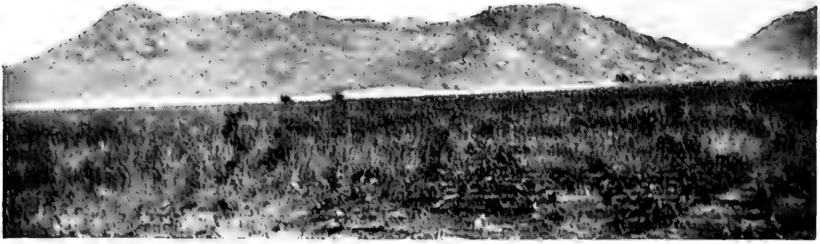

Fig. 173. — Border topography, Wichita Mountains, Oklahoma. (Gould, Oklahoma Geol. Surv.)

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[1] The data for this paragraph have been supplied by Prof. C. A. Reeds of Bryn Mawr College and Prof. C. N. Gould of the University of Oklahoma.

The main range is about 30 miles long and 12 miles wide. West of it are a number of scattered smaller ranges and peaks, such as Mount Tepee, Quartz Mountain, and Headwater Mountain. North and east is a 30-mile parallel range of hills composed chiefly of hard massive limestone, and the same limestone on the south and east occurs in the form of small rounded knobs. The limestone hills represent remnants of a series of rocks which once extended as a dome over the igneous rocks but which have since been deeply eroded. Between the granite and limestone ridges on the borders of the uplift are softer "Red Beds," shale and sandstone with local deposits of conglomerate, and these have been eroded to form valley lowlands whose extent corresponds to the outcrop of the less resistant strata.[1]

Mounts Scott and Baker are the highest mountains in the group and, like the numerous other peaks in the region, they have steep, rugged, bowlder-strewn slopes. Although the relative altitudes of peaks, ridges, and valleys are small, the mountains have a distinctly rugged appearance, with sharp outlines and narrow passes. There are more than 250 detached areas of igneous rocks in the Wichita Mountains group, and these are expressed topographically in the form of a main mountain mass 150 square miles in extent and a large number of neighboring isolated sharp knobs which rise like islands above the smooth plains about them. The whole group forms an archipelago of granite mountains and peaks rising rather abruptly from the sea-like plains developed upon softer rock.[2]

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[1] C. N. Gould, Geology and Water Resources of Oklahoma, Water-Supply Paper U. S. Geol. Surv. No. 148, 1905, p. 15; J. A. Taff, Prof. Paper U. S. Geol. Surv. No. 31, 1904.

[2] J. A. Taff, Preliminary Report on the Geology of the Arbuckle and Wichita Mountains in Indian Territory and Oklahoma, Prof. Paper U. S. Geol. Surv. No. 31, 1904, pp. 54, 77.

CHAPTER XXIV

PRAIRIE PLAINS

Extent and Characteristics

Between the great Laurentian area of Canada on the north and the Ozark-Appalachian provinces on the south and extending east and west from the Great Plains to the Appalachian Plateaus is a broad expanse of moderately rolling country known as the Prairies or Prairie Plains. The province includes the greater part of the Middle West, but it is not confined to that section of the country. Its western portions are thinly timbered, the forest growth shading off to scattered groves of timber in lower and wetter localities or to the valley floors and the stream margins. Its eastern, better-watered portions are covered with a denser arboreal growth, though clearings are so extensive as to leave but insignificant patches of the primeval forest, and everywhere the timber is confined chiefly to wood-lots of limited and generally decreasing extent. The timber of the southern two-thirds of the Prairie Plains is prevailingly hardwood; on the north is a belt of coniferous forest which fills the gap between the northern edge of the hardwoods and the spruce forest belt of Canada.

Although the Prairie Plains support a dense agricultural population and supply a disproportionately large part of the corn, wheat, oats, etc., of the country, they do not have an exceptionally favorable rainfall. It is certain that the agricultural products are far below the possibilities of the soil were a heavier and better distributed rainfall to occur. There is good reason for believing that were the surface less flat, the absorption of rain water less pronounced, the original forest would have been much more restricted.

The Prairie Plains belong to the vast central plains region between the Atlantic and the Pacific Cordillera and present from commanding points a number of characteristic views. In many places the province has the appearance of a limitless expanse of grove-dotted, gently undulating country, here and there trenched by rivers and surmounted by low hills; or it stretches away as far as the eye can see without either of these relief features — a grass-covered, farm-dotted, smoothly contoured prairie. North of the Missouri and Ohio rivers it is glaciated. Morainic belts cross it in looped pattern, and between them are notably flat till plains.

In that portion covered by glacial ice in the last (Wisconsin) glacial invasion, lakes, ponds, and undrained hollows in great numbers are scattered freely about, stream courses are disorganized, falls and rapids abound and alternate with swampy depressions often of considerable extent. The southern portion of the glaciated tract and a part of the unglaciated area beyond are covered to a variable degree by loess deposits, — fine, light, wind- and stream-deposited detritus of great importance in relation to both run-off and soil fertility. East of the Mississippi the Prairie Plains grade southward into the Appalachian Plateaus; west of that river and south of the limit of glaciation they have a distinctive quality unlike any other portion of the province. In the Osage Prairie of eastern Kansas, and specifically about Independence, they have the appearance of an ancient surface of erosion. Here broad valleys separated by low divides are characteristic features; none of the irregularities of glacial topography or drainage is found; in fact there is so little relief that water storage by dam construction is impracticable on account of the breadth of the valleys and their gentle gradients.

Fig. 174. — Typical view of the Prairie Plains in the Great Lake region. Woodland tract in left background.

THE PENEPLAIN OF THE PRAIRIES

The most general topographic feature of the Prairie Plains is the Tertiary peneplain now standing at various elevations above its former level. It may be traced from central Texas northward through Oklahoma and Kansas into Wisconsin, Indiana, and southern Michigan. While it is now a dissected and therefore a discontinuous surface its former character and wide extent may reasonably be inferred because large tracts are still in an excellent state of preservation. It is fair to assume that the Tertiary peneplain of the region was far more extensive than its visible remnants, now for the most part in process of dissection. The Tertiary peneplain appears to have been much more extensive in the upper Mississippi basin than was the corresponding plain in the Appalachian tract; the latter was limited largely to the belts of softer rock or to the larger streams.

The uplifted peneplain was dissected to various stages of maturity before the Pleistocene period, so that by the beginning of that period pronounced valleys had been formed: in some places the valleys were narrow and the intervening divides wide, while in other places the valleys were widely opened and the divides reduced to narrow ridges. The slopes of many valleys were steep and covered with a thin veneer of decayed rock, and almost the whole of the now glaciated country had a somewhat more rugged appearance than at present.

The surface of the peneplain was not everywhere affected in the same way after its development. In some cases it was uplifted and broad valleys opened at lower levels, in other cases there appears to have been no uplift, in still others uplift appears to have been progressive and no opportunity given for the formation of a peneplain. Even without peneplanation the surface would nowhere have great relief, for this is distinctly a region of low-lying and nearly flat strata. The depth of erosion conditioned by the rainfall, the elevation, and the character of the rock would be a measure of the relief, unlike many mountain regions where the relief in the earliest stages of an erosion cycle is commonly related directly to original structural irregularities.

A description of a few typical occurrences will serve to show the general development of the peneplain of the prairies and its present condition. An ancient topographic level has been clearly determined in southwestern Wisconsin (Driftless Area). Fragments of the plain slope gently southward across the outcropping edges of shales, dolomites, and sandstones. In spite of the strong variations in resistance to erosion which these beveled strata display the plain truncates them with striking uniformity. It is therefore not a structural plain but a plain of erosion. It is typically developed about Lancaster, Wisconsin, where it stands about 1100 feet above the sea. Since its formation it has been broadly uplifted and extensively dissected. The main valley bottoms lie several hundred feet below the general level of the uplifted peneplain and well-developed flood plains are common. Dissection has progressed to the point where the original plain surface now remains only along the stream divides, and the cubic contents of the valleys approximately equal the cubic contents of the ridges between the valleys.[1]

South of the Great Lake region the uplifted and dissected peneplain may be clearly identified. In eastern Missouri and in Illinois it has been described as a plain of wide extent now much dissected, its remnants being represented by the accordant hill and ridgetops. In a general view this regularity of level of the summit areas makes the sky line nearly flat, a dominating topographic feature. Such striking accordance of summit levels is the more significant when it is realized that the plane thus denoted truncates inclined strata offering very unequal resistances to erosion.[2]

In Indiana the surface appears to display two erosion levels forming an upper and a lower plain. The level summits of the higher hills and ridges mark the position of the now greatly dissected older topographic level about 600 feet above the sea. One hundred feet lower are rolling uplands which exhibit smooth, gently rounded hills and ridges or flat divides separated by broad and relatively shallow valleys.[3]

In the prairie plains of eastern Kansas the uplift appears to have been insufficient to occasion dissection of the peneplain formed during the Tertiary. The beveling of the strata is here still in progress. The divides are smooth and broad, truncation is now in progress; if the land retains its present level there will be even more complete leveling of the surface, and the region will finally exhibit an ultimate base-leveled plain. All relation between structure and topography has, however, not yet vanished. In the Osage Prairie, for example, are broad structural terraces surmounted by a few outlying and isolated hills, though the relief is far less gentle and faint as compared with the relief of the region during the earlier periods of the present erosion cycle. The terraces face eastward and have frontal scarps from 100 to 200 feet

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[1] Grant and Burchard, Lancaster-Mineral Point Folio U. S. Geol. Surv. No. 145, 1907, p. 2, cols. 1–2.

[2] N. M. Fenneman, Physiography of the St. Louis Area, Bull. Ill. Geol. Surv. No. 12, 1909, pp. 17, 52.

[3] Fuller and Clapp, Ditney Folio U. S. Geol. Surv. No. 84, 1902, p. 1, col. 3.

high. Each terrace has a long and relatively gentle westward slope whose total descent is less than the descent of the frontal scarp. Each terrace therefore stands above its neighbor on the east and below the next terrace on the west, so that the series rises in westward succession and the rate is about 10 feet per mile. The north-south drainage lines show a marked tendency to migrate down the dip of the individual terrace, i.e., westward; hence the eastern valley slopes are commonly gentle and low, the western, steep and high. Stream courses at right angles to the terrace fronts show alternations of broad open stretches on the terrace tops and narrow steep-sided stretches on the terrace fronts.

Both the topographic and the drainage features are related to the structure in still other respects. The westward-dipping shales, sandstones, and limestones are of variable thickness. Where the resistant sandstones are thick the topography is irregular and has marked relief; where the soft shales are thick and the resistant strata thin or absent the surface has very gentle gradients, broad valleys, and but little relief. The average elevation of the district is about 900 feet, and the difference in elevation between adjacent hills and valleys is from 50 to 200 feet.[1]

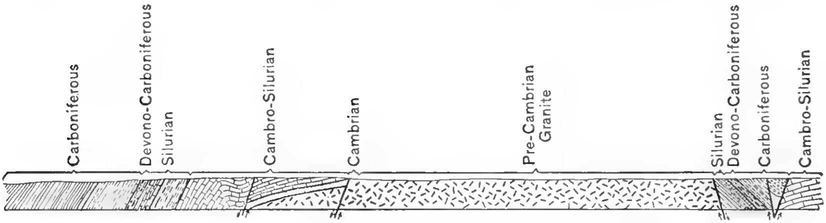

Fig. 175. — North-south section near Tishomingo, Oklahoma, showing the peneplaned surface of the Prairie Plains on the south. (Taff, U. S. Geol. Surv.)

Toward the south, as in Oklahoma and northern Texas, the Prairie Plains once more take on the character of an uplifted and dissected peneplain, Fig. 175. The uplift was not great, however, probably not more than 100 feet, and large remnants of the former featureless plain occur on the interfluves. The valley topography is a feature of the present cycle of erosion; the inter-valley topography exhibits many characters inherited from the preceding cycle of erosion in which a peneplain was formed.[2]

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[1] F. C. Schrader, Independence Folio U. S. Geol. Surv. No. 159, 1908, pp. 1–5.

[2] J. A. Taff, Coalgate Folio U. S. Geol. Surv. No. 74, 1901, p. 4, col. 4., and C. N. Gould, Geology and Water Resources of Oklahoma, Water-Supply Paper U. S. Geol. Surv. No. 148, 1905, p. 12.

CENTERS OF GLACIATION [1]

The ice sheets which overrode the northern Prairie Plains originated in two centers of glaciation known as the Keewatin, west of Hudson Bay, and the Labrador, in the Labrador peninsula. A third, the Cordilleran center in northern British Columbia, is of little interest here, for it lay too remotely to the west to affect to an important degree the topography of the Plains, Fig. 176. The Keewatin glacier formed in a great gathering ground close to the western coast of Hudson Bay, from which the ice radiated in all directions — eastward into Hudson Bay, northward to the Arctic Ocean, westward to the Mackenzie Valley, and southward toward Manitoba and the Great Plains. At or near the center of glaciation the striæ are very indefinite and appear to have changed in direction as the center slightly shifted its position, but no evidence of more than one glaciation has been found, nor has it been

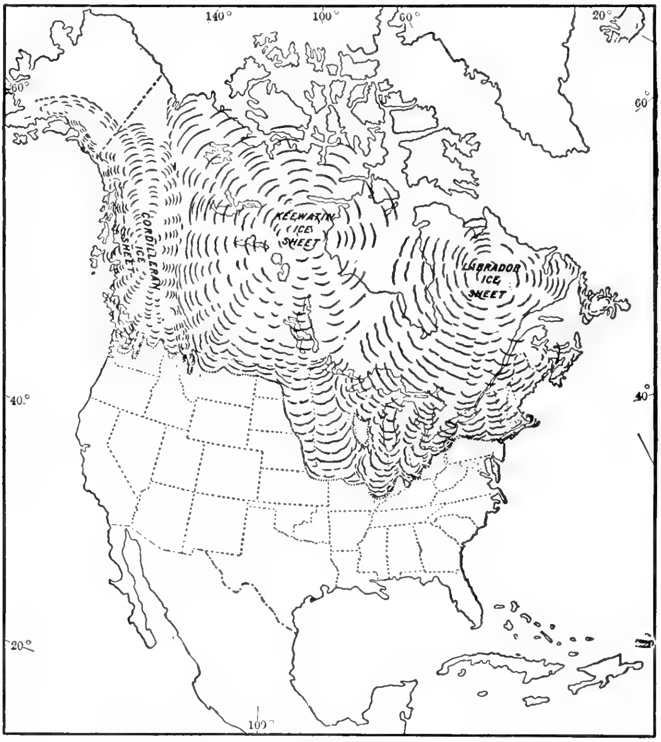

Fig. 176. — The centers of ice accumulation, the position of the Driftless Area, and the southern limit of glaciation. (Alden, U. S. Geol. Surv.)

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[1] J. B. Tyrrell, The Genesis of Lake Agassiz, Jour. Geol., vol. 4, 1896, pp. 811–815.

determined that the ice left the country uncovered at any time during the glacial epoch.

The Keewatin glacier advanced southward and southwestward until it came in contact with the high escarpment of Cretaceous shales in eastern Manitoba, followed the course of Lake Winnipeg and Red River and in this direction advanced far into Minnesota, Dakota, and Iowa. The eastern margin of this lobe did not extend very far east of the present eastern shore of Lake Winnipeg, and it is probable that throughout its advance there was a free drainage eastward, probably into Hudson Bay.

The evidences of the time of advance of the three continental ice caps which formed over northern North America go to show that these three seem to have reached their widest extent and to have retired in succession from west to east, and that a fourth ice cap, probably similar in character to those that have disappeared from the American continent, covers Greenland at the present time.

GLACIAL AND INTERGLACIAL STAGES

The different glacial and interglacial stages of the glacial period are numbered in the order of their occurrence below.[1] Their deposits are represented in part on the accompanying maps showing relations of the drift sheets in the Middle West.

XIII. The Champlain substage (marine).
XII. The glacio-lacustrine substage.
XI. The Later Wisconsin, the sixth advance.
X. The fifth interval of deglaciation, as yet unnamed.
IX. The Earlier Wisconsin, the fifth invasion.
VIII. The Peorian, the fourth interglacial interval.
VII. The Iowan, the fourth invasion.
VI. The Sangamon, the third interglacial interval.
V. The Illinoian, the third invasion.
IV. The Yarmouth or Buchanan, the second interglacial interval.
III. The Kansan, or second invasion now recognized.
II. The Aftonian, the first known interglacial interval.
I. The sub-Aftonian, Jerseyan, or Nebraskan, the earliest known invasion.

I. The sub-Aftonian or Nebraskan[2] glacial stage is represented in Iowa as a very old drift sheet whose surface bears sand and gravel, peat,

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[1] Chamberlin and Salisbury, Geology, vol. 3, 1906, p. 382 ff.

[2] B. Shimek, Bull. Geol. Soc. Am., vol. 20, 1909, p. 408.

old soil, and other products of prolonged weathering. The Nebraskan drift consists largely of compact blue-black bowlder clay. In many places it is thickly set with woody material gathered from forests that were overwhelmed by the ice. The wood is largely spruce, cedar, or coniferous species that indicate a cool-temperature flora in advance of glaciation. The drift filled the deep preglacial valleys to depths of nearly 350 feet, but it formed only a thin cover on the uplands, where it was nearly removed by erosion before the next glacial invasion.[1]

The interglacial stages are of little interest in the present connection. Rather typical conditions are represented by the first epoch in the series.

II. The Aftonian interglacial stage is represented by sand and gravel deposits and by beds of peat and muck, with stumps and branches of trees, and shows prolonged erosion and weathering. Several bones of the camel have been found in the deposits of this epoch; also the antler and fragments of bones of a large stag, three species of elephant, the American mastodon, and a large variety of molluscan remains of both aquatic and terrestrial species. The fauna and flora indicate a climate not greatly different from the present, though the fossils merely represent the conditions at the time of their burial, and still leave largely to conjecture the full range of temperature of the period.[2]

III. The Kansan glacial deposits, p. 473, occupy a large area in Kansas, Missouri, Iowa, and Nebraska and probably extend under the later glacial formations far to northward. The Kansan till is pronouncedly clayey and has very little water-laid material either within the body of the till or on its margin, where the usual fluvio-glacial deposits of sand and gravel are very meager. The surface of the Kansan till although originally quite flat has been considerably eroded and its topographic features notably altered from their original expression.

It is estimated that the Kansan drift occupies only from 10% to 30% of the original plain. The streams flow in valleys with broad and low (3° to 5°) slopes and bottoms. The average drift removed by erosion in the exposed portion of the Kansas drift is estimated to be not less than 50 feet. The material is deeply weathered and it has been deprived of its finer and more readily dissolved calcareous material and even limestone pebbles down to 5 or 8 feet.[3]

V. The Illinoian till is chiefly clay and is similar to the Kansan till in showing a marked absence of assorted drift in most places. Drainage modification brought about through the Illinoian glacial invasion in the Mississippi Valley is of uncommon interest. The western edge of the Illinoian ice lobe crossed the Mississippi Valley between Rock Island and Fort Madison, and pushed the Mississippi River out of its course a score of miles (p. 475).

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[1] Frank Leverett, Comparison of North American and European Glacial Deposits, Zeitsch. f. Gletscherkunde, Berlin, vol. 4, 1910, p. 250.

[2] Idem, p. 253.

[3] Idem, p. 258.

The bowlder clay of the Illinoian drift appears originally to have been very calcareous but to have been leached since deposition to a depth of from 5 to 8 feet and nearly all the limestone pebbles completely removed. Much of the deposit has become partially cemented because of the large calcareous element in the drift. Where erosion has been most rapid it has destroyed scarcely more than half the original plain.[1]

VII. The Iowan till is thin and is noteworthy for the exceptional number of large granitoid bowlders which lie chiefly on the surface. This drift was formed by a lobe of the Keewatin ice sheet. The moraines formed about the borders of the lobe were very feeble and the outwash scant.

IX. The two Wisconsin ice sheets are the most important of all, not because of their greater original extent or their thicker drift deposits but because their drift deposits are the last of the series and have therefore been more extensively preserved. The interval since the occurrence of these last glacial stages has been so brief, furthermore, that but little modification of topography, drainage, or soils, has been possible. The outermost limits of the Wisconsin ice sheets are marked in most places by pronounced terminal moraines, and in addition the surfaces of the till sheets are diversified by terminal moraines due to the periodic recession of the ice. Their surfaces are also diversified by various glacial and fluvio-glacial forms not developed, as a rule, on the deposits of the earlier glacial stages. The chief varieties of these deposits are the outwash plains formed by streams discharging from the ice front, also kames, eskers, and drumlins. In a number of noteworthy cases these forms have a marked tendency toward aggregation. The Sun Prairie topographic sheet of Wisconsin represents the remarkable drumlin accumulations of that and adjacent portions of the state; and a similar swarm of drumlins may be seen in central New York between the Finger Lake district and Lake Ontario. The drumlins are oriented in the direction of ice movement and are composed of unstratified and very compact till.[2]

The two glacial advances of Wisconsin time were separated by a rather short interval of deglaciation, and the readvance in the second of the two stages was along slightly different lines, so that the relative sizes and relations of the ice lobes appear to have undergone consider-

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[1] Frank Leverett, Comparison of North American and European Glacial Deposits, Zeitsch. f. Gletscherkunde, Berlin, vol. 4, 1910, p. 279.

[2] For discussion of drumlins or, more properly, rocdrumlins, formed out of shale and earlier till deposits in Menominee County, Michigan, and that drumlins are forms of aggradation in some cases and of degradation in others, see I. C. Russell, The Surface Geology of Portions of Menominee, Dickinson, and Iron Counties, Michigan, Rept. Geol. Surv. of Mich. for 1906, and H. L. Fairchild, Drumlins of Central Western New York, Bull. New York State Mus. No. 111, 1907, pp. 393 et al.

able change, and the moraines of the later stage cross those of the earlier at distinct angles, as at some points on Long Island (p. 470). The drift sheet of the later of the two stages is characterized by enormous terminal moraines, great bowlder belts, and an unusual development of kames, eskers, drumlins, outwash plains, valley trains, etc., all formed in such a manner as to show the disposal of the ice in the form of great lobes which in turn reflect the influence of the basins in which they were formed. The late Wisconsin drift is in many notable instances thin and overlies the interglacial fluvial deposits as a veneer of till.

Topographic, Drainage, and Soil Effects

TOPOGRAPHY

In the successive periods of glaciation the ice advanced over the uplifted and dissected peneplain of the northern Prairie Plains described in the preceding pages. In places it increased the relief by irregular deposition on a flat plain, in other places it decreased it by deposition in the valleys of a dissected plain. Had the country been mountainous an overriding ice sheet would not have produced till plains of such topographic uniformity and continuity. The present relief is therefore a function not only of glacial but also of preglacial topographic form.

The topographic and drainage effects of the successive ice invasions are of the first magnitude in the region in which they occur, while the distribution of the soils is almost everywhere related to the material which the ice laid down or which the draining streams swept forward in the region immediately beyond that covered by the ice. The southern limit of ice advance is indicated upon the map, Plate IV, but it must not be thought that a single vast sheet of ice at any one time occupied the entire region north of the line indicating the limit of glaciation. There were in all at least six ice sheets which swept from the north at as many different times, from two of the three recognized centers of ice accumulation. The deposits produced by the successive ice invasions occur as distinct drift sheets between which, in intervals of deglaciation, soils and beds of peat and marl were formed (p. 467). In addition to these lines of demarcation between successive till sheets there are differences among the sheets themselves; they vary in extent and physical constitution in a marked way. The lines of flow in successive invasions of ice were in many cases far from coincident, so that ice fields in some places fell short of earlier ones and in other places exceeded them.

Another important feature is the existence of pronounced morainic ridges along the fronts of some of the till sheets, although this is not a constant feature, since a wide stretch of country in Illinois, Kansas, and Iowa is marked by the absence of a terminal moraine. Where the moraines are present it is noteworthy that the earlier ones have been very extensively eroded, so that many irregularities found upon the later moraines are wanting in the earlier. A typical occurrence is found in southern Illinois east of St. Louis, where practically all the kettle holes and minor depressions of the Illinoian moraine have been either filled up, or drained by the cutting down of their outlets, or both, while the detailed irregularities of the slopes of the hills and ridges have been so completely smoothed and rounded as to appear to a certain extent artificial. This group of qualities is in marked contrast to the numerous sags, depressions, kettle holes with lakes or swamps on their floors, and the extreme rugosity of moraines formed during the last (Wisconsin) ice advance.

TERMINAL MORAINES AND TILL SHEETS

The terminal moraines marking the margin of the last or Wisconsin invasion are pronounced features of the landscape and often rise from 100 to 200 feet above the surrounding surface. They may be traced almost continuously westward from Long Island to and beyond the Great Lakes. Not all the ice invasions of previous glacial epochs resulted in the development of pronounced terminal moraines. Some of the till sheets have distinct marginal ridges, while others are marked by mere swells of thicker drift at the margins, and still others have very thin edges.

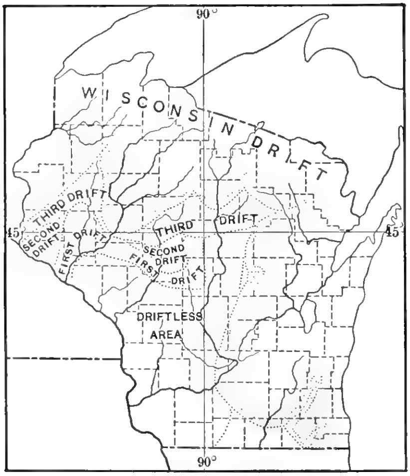

Fig. 177. — The four drift sheets of Wisconsin. (Weidman, Wisc. Geol. Surv.)

The marginal deposits of the Wisconsin drift are in the form of bold terminal and interlobate moraines of such topographic importance that they have served to modify or to form entirely the divides between the smaller rivers. They fill a number of preëxisting river channels and deflect many of the small streams and even many larger ones from their former courses.

The concentric trend of the morainic ridges is to be ascribed to the lobate character of the ice margin, a feature imposed upon the continental ice sheet by the irregularities of the topography which it covered. The depressions appear to have been lines of maximum flow, and in the

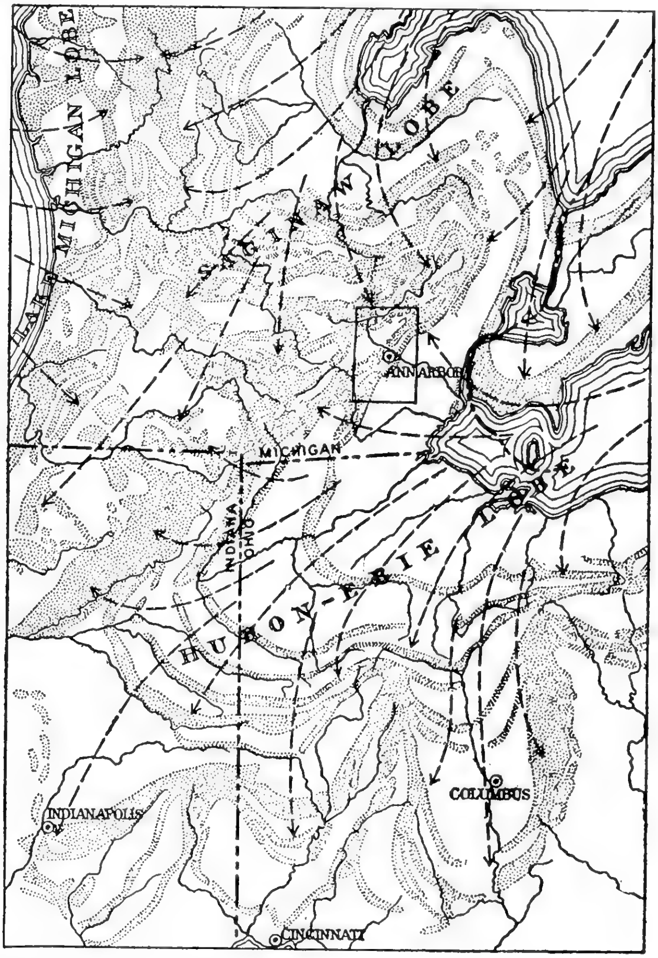

Fig. 178. — Distribution of glacial moraines and direction of ice movement in southern Michigan and northern Ohio and Indiana. (Russell and Leverett, U. S. Geol. Surv.)

Great Lake region this resulted in the strongly looped quality of the morainic systems as shown in Fig. 178.

The extent to which drift deposits dominate the glacial topography is further indicated by the fact that the present divide between the Great Lakes or St. Lawrence drainage and the Mississippi drainage is determined very largely by moraines and thick drift deposits. The drift is heaped up in greatest amounts at the ends and along the sides of the Great Lake basins where it was accumulated on the margins of tongues or lobes of ice that once occupied the basins. Such modification of not only the drainage but also the topography and the soils is clearly indicated by the nature of the drift covering in the southern peninsula of Michigan, northwestern Ohio, northern Indiana, and northeastern Illinois. The till deposits here attain their greatest thickness. The southern peninsula of Michigan is quite remarkable in this respect since the geographic position and relations of the Great Lake basins determined a maximum convergence of the ice lobes in this district. The northern half of the peninsula has a drift cover from 700 to 800 feet thick; the surface rises in places to 1000 or

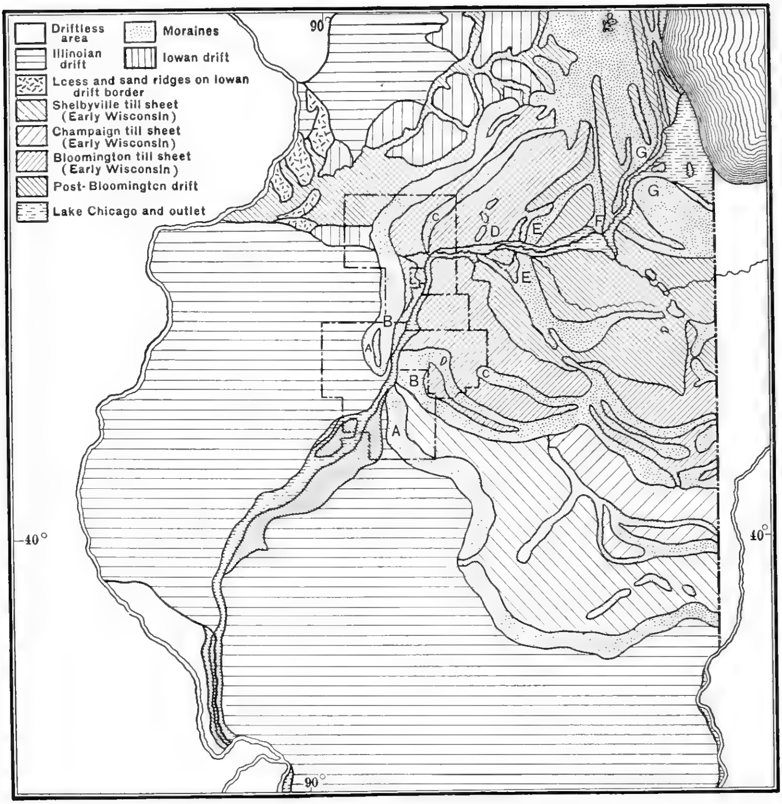

Fig. 179. — Generalized glacial map of northern Illinois. (Barrows, Bull. 15, Ill. Geol. Surv.)

1100 feet above the surface of the lakes; there seems to be no rock more than 250 feet above the lakes.[1] It has been estimated that the entire southern peninsula of Michigan has an average of about 300 feet of drift. The drift cover in the adjoining states on the south is about 100 feet thick. These heavy glacial deposits do not consist of a single sheet, but embrace three, and in places four, distinct drift sheets which are the products of repeated glaciations at widely separated intervals. The upper surfaces of the older sheets are marked by beds of peat and river and lake deposits containing remains of life forms similar to those now existing in the region, an indication of a temperate interglacial climate not markedly unlike the climate of to-day.

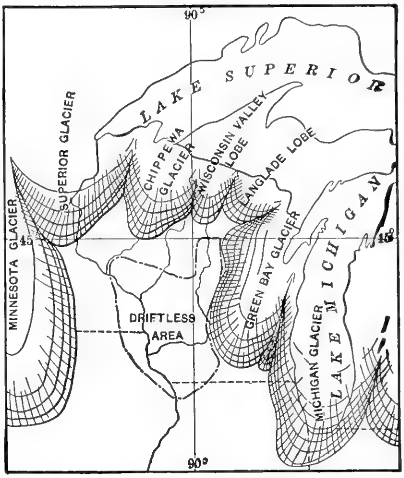

Fig. 180. — Positions of the Wisconsin ice lobes about the Driftless Area. (Weidman, Wisc. Geol. Surv.)

Farther west, as on the plains of eastern North Dakota, are many

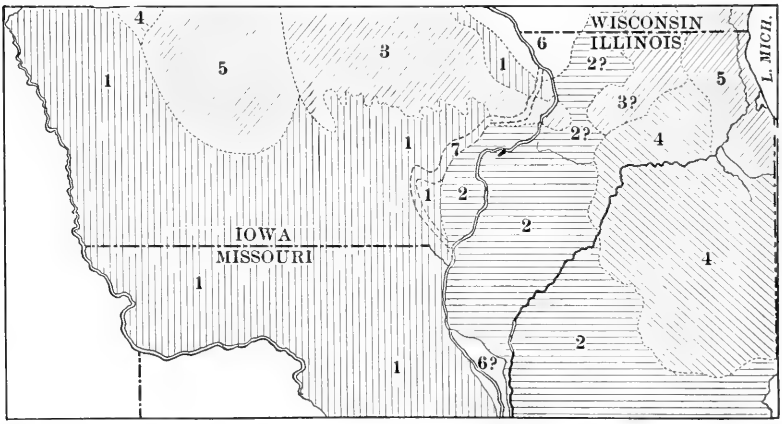

Fig. 181. — Relations of the drift sheets of Iowa and northern Illinois. 1, Kansan; 2, Illinoian; 3, Iowan; 4, Early Wisconsin; 5, Late Wisconsin; 6, Driftless area; 7, course of the Mississippi River during the Illinoian glacial epoch. (After Leverett, U. S. Geol. Surv., and Calvin, Iowa Geol. Surv.)

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[1] W. F. Cooper, Water-Supply Paper U. S. Geol. Surv. No. 182, 1908, Plate II.

surface features which also show the characteristic effects of glaciation. The country is here for the most part level, but it also presents long rolling slopes rising from 300 to 800 feet above broad valleys. The most important topographic elements are massive ridges or mesas due to preglacial erosion. The mesas are in many instances bordered or crowned by long morainic ridges representing halts in the glacial advance or retreat. The morainic material is derived chiefly from the underlying shales (Cretaceous), and is a compact clay which also contains erratic fragments and bowlders of crystalline rock derived from northerly localities. The upper 5 to 10 feet of till has been oxidized to a light yellow color. The intermorainic tracts consist of rolling plains of till from a fraction of an inch to a hundred feet thick or of more level plains due to alluviation on the floors of glacial lakes. A typical instance of lake-bed topography is found in the upper James River and the valley of the Red River.[1] Postglacial stream dissection has further diversified the topography, the Missouri River having cut a trench several hundred feet deep whose sides are for the most part steep.

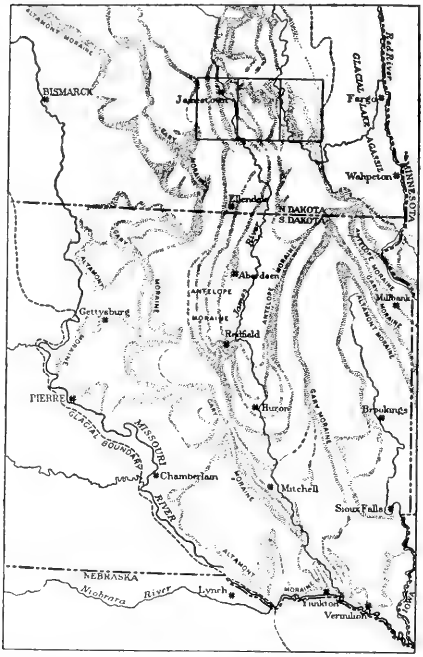

Fig. 182. — Southern limit of the Pleistocene ice sheet and distribution of moraines of the Dakota glacial lobe, North and South Dakota. (Willard, U. S. Geol. Surv.)

DRAINAGE MODIFICATIONS

One of the interesting effects of glaciation was the diversion of streams from northward to southward courses; an instance of this is the Mississippi in the southwestern corner of the Driftless Area below Dubuque. The valley maintains an even width of 1¼ miles for about 12 miles, then widens gradually, and in a stretch of about 60 miles its width increases, except for a slight local contraction near the mouth of the Wisconsin River, and finally becomes 3¾ miles. This decided widening of a low-gradient valley upstream suggests that in preglacial time the valley was occupied by a northward-flowing river.

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[1] J. E. Todd, Aberdeen-Redfield Folio U. S. Geol. Surv. No. 165, 1909, pp. 7 et al.

Other cases of stream diversions are discussed in connection with the Appalachian Plateaus, page 685, the Great Plains, page 405, and the Connecticut Valley, page 638.

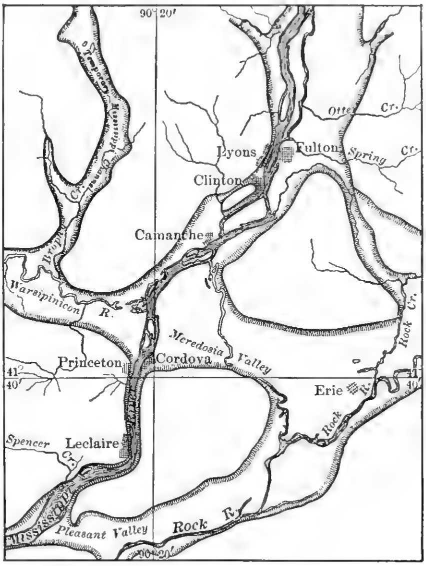

Fig. 183. — Old and new channels of the Mississippi at the upper rapids, Fulton, Ill.

More general and quite as conspicuous are the influences of glaciation upon the drainage systems laid out upon the surfaces of the various till sheets or disposed along their margins. The Ohio and the Missouri have courses in marked sympathy with the glaciated tract, as if they had been pushed bodily out of preglacial courses, and such indeed is the case at many points on both streams. The Ohio in particular exhibits a valley whose most striking characteristics are open-broad stretches alternating with rock-walled gorges which closely confine the stream; and abandoned channel stretches are exhibited at many points. Many less conspicuous illustrations of stream diversions along the border of the glaciated country have been discovered.[1]

Within the borders of the till sheets influences no less striking are found. The moraine crests are the chief minor divides of the glaciated country and in many cases they are also the major divides. Numberless tributaries starting on the slopes of moraines are gathered into trunk streams which flow for long distances along the margin of a moraine or between parallel moraines before finding an outlet across one or the other of the moraines into a transverse stream (pp. 471 and 479). Stream courses within the morainic belts are characteristically irregular and marked by many lake-like expansions alternating with steep stretches and often by falls and rapids of great economic value. These conditions are in sharp contrast to the regular drainage lines and the general absence of lakes and waterfalls in the streams draining the smooth outwash plains that in many cases front the moraines.

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[1] Frank Leverett, The Illinois Glacial Lobe, Mon. U. S. Geol. Surv., vol. 38, 1899, pp. 102–103 et al.

The preglacial drainage of the Great Lake region was probably very unlike the drainage of to-day, for borings along the line of the buried channel that runs across Michigan from Saginaw Bay to Lake Michigan indicate a fall toward the southwest and also a widening of the channel in that direction. Similar deep borings in western Indiana between the head of Lake Michigan and the Wabash show a lower rock floor than any yet discovered across Illinois, and suggest a preglacial drainage southward, toward the Wabash and the Ohio.[1] It seems probable that there was a divide on the line of the present St. Lawrence below Lake Ontario where the river now flows among the Thousand Islands from which the drainage was southwestward.

The outlines of all the lake basins have been notably affected by the deposition of drift in part on their margins, in part on their floors. Near the mouth of the Cuyahoga River at Cleveland the drift extends more than 470 feet below lake level and to within 100 feet of sea level, while the greatest depth of water of Lake Erie is but 210 feet and the average depth only about 70 feet. These figures indicate a very notable modification of the western end of Lake Erie by the deposition of till, and such modification when brought about by a large ice mass must inevitably be associated with very notable changes in the preglacial drainage.

Fig. 184 is a profile across Lake Michigan, showing the extent to which drift forms a barrier to the lake waters at the present time.

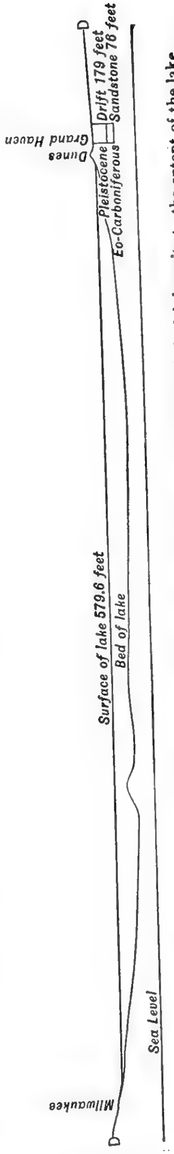

Fig. 184. — Profile across Lake Michigan from Milwaukee to Grand Haven, showing the relation of glacial deposits to the extent of the lake. (Leverett, U. S. Geol. Surv.)

LAKE PLAINS

The so-called Lake Plains of the Great Lake region are special features of the Prairie Plains province. They have an aggregate extent of several thousand square miles and form long narrow strips of smooth country bordering the

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[1] Frank Leverett, Outline of History of the Great Lakes, 12th Rept. Mich. Acad. Sci., 1910, p. 22.

Great Lakes in sharp contrast to the rough morainic country about them. Many portions of them have low gradients, smooth surfaces, regular consequent drainage, fine soils, and extensive marshy tracts that remind one strongly of portions of the Atlantic and Gulf Coastal Plain. They have an aggregate extent of several thousand square miles, but this is far less than the area usually assigned to them. There is no doubt that their extent as represented on Powell's physiographic map of the United States[1] is greatly exaggerated. For the most part they are closely confined to the borders of the Great Lakes. In places they extend inland for 50 or 60 miles, but such breadths are exceptional. Commonly their width is under 20 or 30 miles.

The Lake Plains lie between morainic ridges and the lake shores. The morainic ridges are concentric with respect to the existing lakes since the lake basins were lines of movement of the glacial lobes along whose margins the moraines were developed. The lakeward slope of the innermost moraine formed the border of the lake and against this slope beach ridges and wave-cut platforms were developed in many cases. Where the innermost moraine was feebly developed or lower than its outer neighbors it did not determine the lake border. Furthermore, the lakes once lying over the lake plains were constantly changing in level and hence in outline. Shore lines are found between the outermost abandoned shore line and the present lake shores. These were developed not upon moraines but upon smooth lake floors uncovered by the retreat of the lake waters as they fell to lower levels.

The shallowness of the glacial-marginal lakes and the gradual movements of the shore zone of maximum wave action over the entire lake floor exercised a smoothing effect upon the lake bottom elevations. These lake bottoms, now exposed, in many cases exhibit a topography varied only by recent stream channels opened in them and by shallow depressions filled with small swamps, ponds, and lakes.

PROGLACIAL LAKES[2]

It was known even to the first settlers that lakes formerly occupied not only the present lake basins but also the bordering lands thus overlying the present lake plains and forming the prominent beaches developed

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[1] J. W. Powell, Physiographic Regions of the United States, in Physiography of the United States, Nat. Geog. Mon., 1896, pp. 98–99.

[2] Whittlesey and Warren, The Great Ice Dams of Lakes Maumee, Am. Geol., vol. 24, 1899, pp. 6–38. See Frank Leverett, The Glacial Formations and Drainage Features of the Erie and Ohio Basins, Mon. U. S. Geol. Surv., vol. 41, 1902, for an excellent brief historical review of the problems of the abandoned shore lines of the Great Lake region as well as for a compact summary of the physical changes and a good working bibliography. See also J. W.

in numbers about the existing lakes at both high and low levels. Many of the beaches once served as trails for the Indians. Their level, dry, and moderately straight courses are also ideal for modern purposes. They are generally known as " ridge roads " and are fairly common in the southern part of the Great Lake region.

It was early demonstrated[1] that the lakes owed their origin to ice dams now extinct, and that the water impounded in front of the ice dams rose to the level of the lowest point on the rims of the enclosing basins and then overflowed into valleys draining to the sea. The ice dams were nothing more or less than the frontal lobes of the retreating continental ice cap of late glacial time.

To understand these relations one should conceive of a great continental ice sheet whose front was being melted back from a southern limit, Plate IV, so that it finally lay on the northern side of the great divide which separates the St. Lawrence drainage system from the Mississippi and Atlantic drainage. From the pattern of the terminal moraines shown in Figs. 178 and 182, the border of the continental ice sheet is known to have been lobate. Each lake basin as well as each subsidiary bay, such as Green Bay or Saginaw Bay, was occupied by an individual lobe of ice connected at the north and east with the main ice sheet.

In front of each ice lobe and in the southwestern and western portions of the St. Lawrence basin there eventually formed a glacial-marginal or proglacial lake which was at first crescent shaped, but with continued retreat of the ice its shape would be modified by the general outlines of that part of the basin that was not occupied by the ice lobe. It is also clear that the lake water could not discharge over the thick ice sheet or under it, but must have discharged along its front or across the divides on the distal margins of the basin. Lake Chicago is the name applied to the crescent-shaped lake that formed in front of the Lake Michigan lobe and discharged through the Desplaines-Illinois rivers. In a similar way Lake Maumee was formed in front of the Erie lobe and dis-

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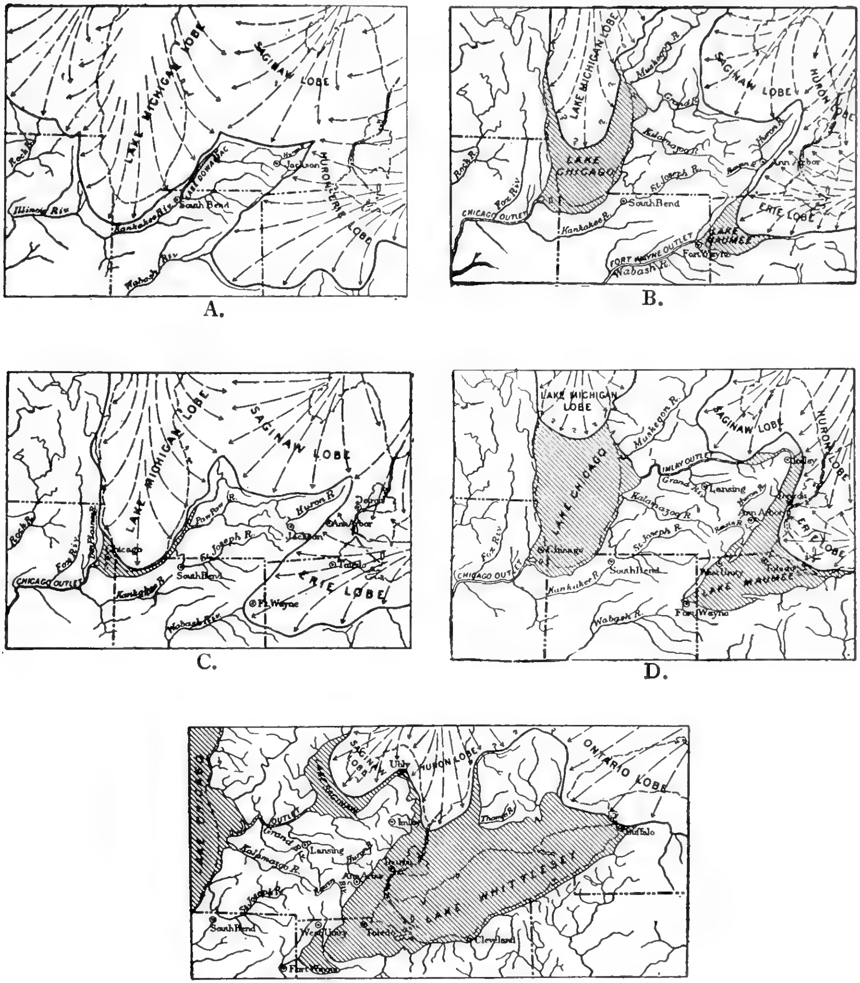
Goldthwait, The Abandoned Shore Lines of Eastern Wisconsin, Bull. Wisconsin Geol. and Nat. Hist. Surv. No. 17, 1907, for historical data of interest and for unusually accurate and detailed studies of abandoned shore lines in Wisconsin. More recently observation has been extended into Canada by Taylor and Goldthwait and the conclusions based on studies in the United States correlated with the observations of Coleman and others on the Canadian Geological Survey. The results of the refined studies of recent years point conclusively to the truth of Spencer's early contentions that the deforming movement of the region was differential and greater toward the north, a conclusion long neglected outright or regarded with undeserved skepticism chiefly because of the author's retention of the overthrown hypothesis of marine submergence.

[1] G. K. Gilbert, On Certain Glacial and Postglacial Phenomena of the Maumee Valley, Am. Jour. Sci., vol. 1, 3d ser., 1871, pp. 339–345.



A. B.

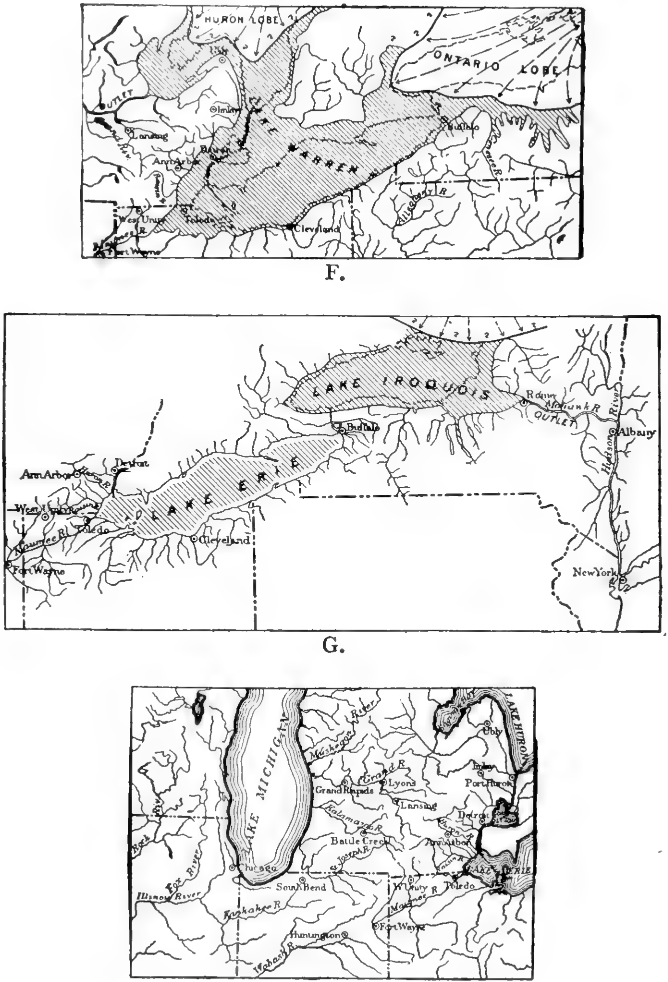
C. D.

E.

Fig. 185. — Drainage history of the southern Great Lake district. A, position of glacial lakes before lakes were formed; B, beginning of Lake Chicago; C, D, E, F, later stages in retreat of ice and expansion of proglacial lakes; G, retreat of ice from Mohawk valley and discharge of proglacial lakes down the Hudson; H, present drainage.

charged through what is now the valley of the Maumee into the Wabash past Fort Wayne. Lake Duluth was formed in front of the Superior lobe and discharged down the Chippewa to the foot of Lake Pepin in the Mississippi Valley.

On the borders of the glacial-marginal lakes, deltas, shore lines, and offshore deposits were formed, and on the bottoms, muds, sand, and silts were deposited. One side of each lake had a temporary shore line — the unstable ice wall which marked the front of each glacial lobe. It must also be noted that this ice wall was not fixed. Sometimes it advanced slightly, overriding the beaches that had been formed by the lake water in front of it; sometimes it remained stationary long enough to accumulate a water-laid moraine on the lake floor and a land-



F.

G.

H.

Fig. 185. Continued.

laid moraine on the adjacent land surface; but the net result of all the changes of ice front was a gradual retreat northeastward. Associated with this retreat was the gradual extension of the glacial-marginal lake waters and to a certain degree their coalescence along the ice front, as in the case of the water bodies at the heads of Saginaw Bay and Lake Erie, Fig. 185-E. Numerous changes in outlet also took place, among which only the principal changes are noted below. The principle which controlled these changes is, that with each marked retreat of the ice lower surfaces were exposed which would have different relations to each other with respect to elevation.

Thus Lake Maumee for a time discharged into Lake Chicago by way of the Saginaw basin and the Grand River Valley. Lakes Michigan and Huron for a time discharged through Georgian Bay and the Trent Valley into Lake Iroquois (Ontario), and a still later and lower outlet was afforded through the Ottawa River Valley on the uncovering of this drainage way through the further retreat of the ice. This stage is known as the Nipissing stage.

At this time Lake Erie drained across the Niagara escarpment and Lakes Huron, Michigan, and Superior drained eastward through the Ottawa Valley to the St. Lawrence. The small amount of water discharging over Niagara Falls during this period resulted in the production of a very narrow gorge, but the gradual tilting of the land toward the southwest caused the Ottawa outlet to be abandoned and the low col south of Port Huron to be occupied by a new drainage channel marking the outlet of these three great lakes into Lake St. Clair and Lake Erie. Associated with this change in outlet and the greater discharge of water over Niagara Falls was the widening and still more marked deepening of the gorge between the whirlpool and the Suspension Bridge, changes which are conceived to have occurred in the last 5000 years, judging by the present rate of retreat of the falls. The St. Clair outlet of Lake Huron is thus seen to be a very recent geologic event, as may be seen clearly also by the youthful character of the valley of that river and the recent formation of a feature which is anomalous in physical geography — the delta at the head of Lake St. Clair, formed by the short St. Clair River. A river draining a lake is singularly free from sediment at the intake, and it might be expected that a very small delta or none at all would be formed at the mouth of so short a stream as the St. Clair. Instead, the recent occupation of the valley of the St. Clair by the St. Clair River has caused very rapid channel cutting that is still in progress, an action that is reflected in the large delta at the head of Lake St. Clair. Tending toward the same result are the shore currents of Lake Huron, which deliver a large amount of beach sand to the intake of the St. Clair.[1]

The former small size of the lake in the Erie basin and the fact that it did not then cover the western part of the basin are established by the deeply submerged lower courses of the streams in the western part of the basin, especially that of Sandusky River, which has been traced entirely across the bed of Sandusky Bay. More recent changes of water level at this end of the basin are shown by the submerged level of the valleys discharging into Lake Erie and the submerged stalactites in the caves of Put-in Bay Island at the western end of the lake.

During still later stages of their history the lakes discharged through the Mohawk and down the Hudson. The great sand plain at Albany and Troy was the delta of this large-volume, temporary stream. Through the later uncovering of the St. Lawrence Valley by continued ice melting a lower point of discharge was offered to the lake waters and the Mohawk channel abandoned. The present Mohawk River occupies but a small portion of the ancient glacial channelway.

The earliest formation of glacial-marginal lakes in the Lake Superior drainage basin appears to have been in the area now drained by the St. Louis River, where the waters were ponded at

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[1] L. J. Cole, The St. Clair Delta, Mich. Geol. Surv., 1905.

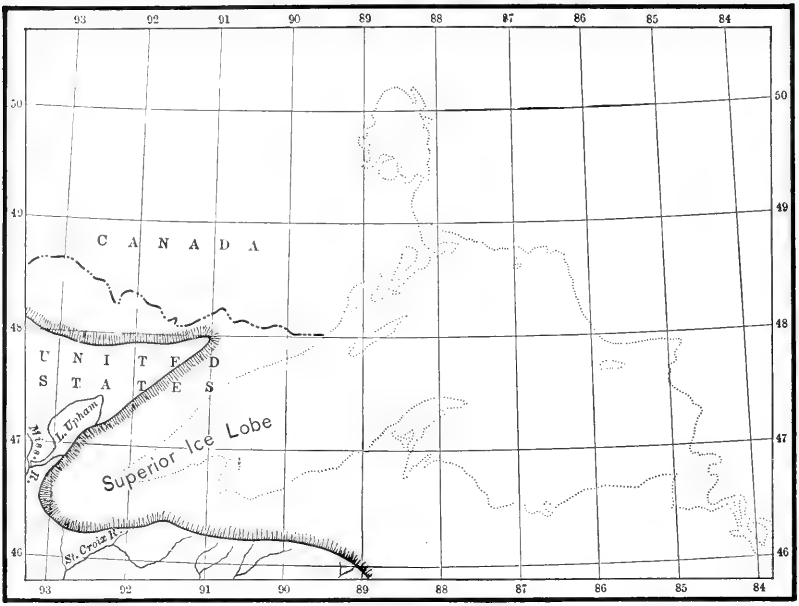

Fig. 186. — Superior ice lake and glacial marginal Lake Duluth. (Leverett.)

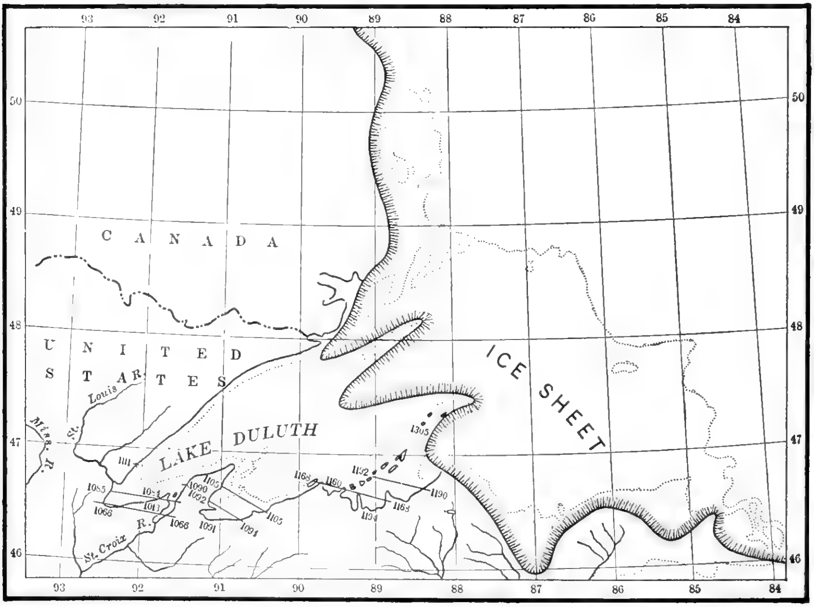

Fig. 187. — Lake Duluth at its greatest extent and the contemporary ice border. (Leverett.)

an altitude of about 700 feet above Lake Superior, Fig. 186. To this small transient body of water the name of Lake Upham has been given. The fringing ice later afforded a lower passage about 530 feet above Lake Superior, and the resulting lake with outlines quite different from those of Lake Upham and with a different line of discharge has been called Lake St. Louis. Still further retreat of the ice border resulted in the formation of a lower lake about 500 feet above Lake Superior, known as Lake Nemadji, which discharged a large volume of water (from Kettle River Valley) into the St. Croix. These lakes lie quite beyond the border of Lake Superior, and well above it. The name Lake Duluth has been given to the extremely large body of water draining southward from the head of Brule River into the St. Croix River and occupying a large portion of the area now occupied by Lake Superior. The highest shore line of Lake Duluth at the western end of the basin shows a marked rise toward the northeast. At Duluth it is 465 feet above Lake Superior, while at Calumet on the Keeweenaw peninsula it is 702 feet above it. The rise of 237 feet seems to be largely due to differential uplift, though, as in the case of all the other deformed beaches of the region, a small portion is referable to ice attraction, though this will account for but 37 of the 237 feet and was effective only within a few miles of the ice border. The difference of 200 feet seems explainable only on the ground of differential movements since the formation of the earlier shore lines.

During and since the retreat of the ice, tilting of the Great Lake region has been in progress. Elevated and now tilted and abandoned shore lines occur in numbers about the lakes of the Great Lake region. In places they are very numerous, as about the head of Lake Superior, where may be counted more than 30 distinct strand lines, representing as many successive lowerings of water level through the vicissitudes associated with the melting of the ice and the uncovering of lower and lower outlets. The beaches all rise in altitude toward the northeast, with a slightly increasing divergence in that direction, showing that the uplift of the land which gave the shore lines their present attitude was differential and greater toward the north; also that the tilting was not that of a simple plain but of a warped surface.[1]

With a view to determining the degree of stability of the Great Lake region, Gilbert compared the elevations of certain bench marks as determined in 1876 and again in 1896. After a careful elimination of all irregularities of lake levels due to wind, tide, etc., it was found that there was a small but definite increase in height in a northerly direction, and that the tilting is greatest in a direction south 27° west, and is at the rate of 0.42 foot per 100 miles per century.

The prolonged tilting of the Great Lake region is also shown by the drowned lake shores on the west side of the lower peninsula of Michigan, where many of the rivers discharge into pouch-shaped lakes separated from the main lake by long slender sand bars, as the Black River, the Muskegon, the Pentwater, and in a similar way at the western end of Lake Erie, the Maumee, the Rouge, the Raisin, and the Huron. In

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[1] J. W. Spencer, Deformation of the Algonkian Beach and Birth of Lake Huron, Am. Jour. Sci., vol. 141, 1891, pp. 12–21.

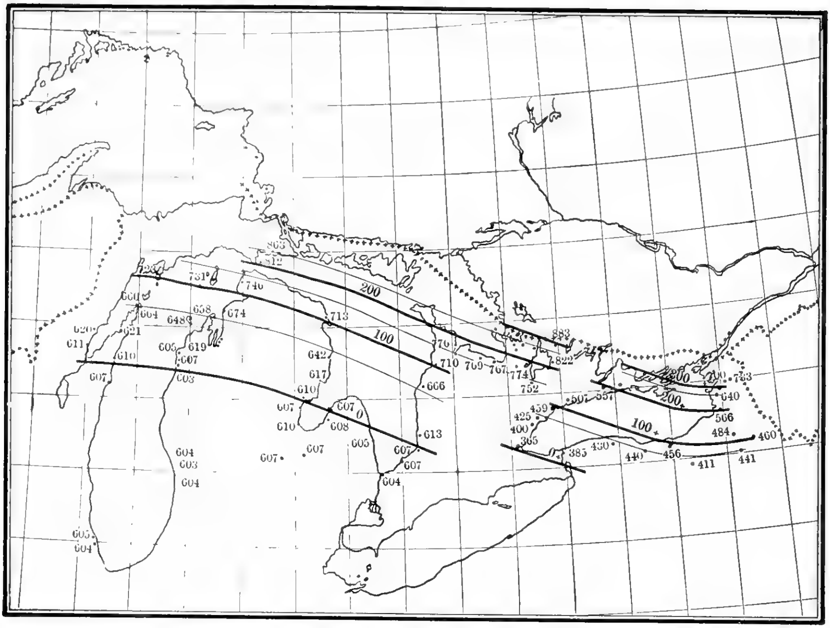

Fig. 188. — Isobasic map of the Algonkian and Iroquois beaches, showing the broader features of warping. Numbers indicate elevations of raised beaches above the sea. (Goldthwait.)

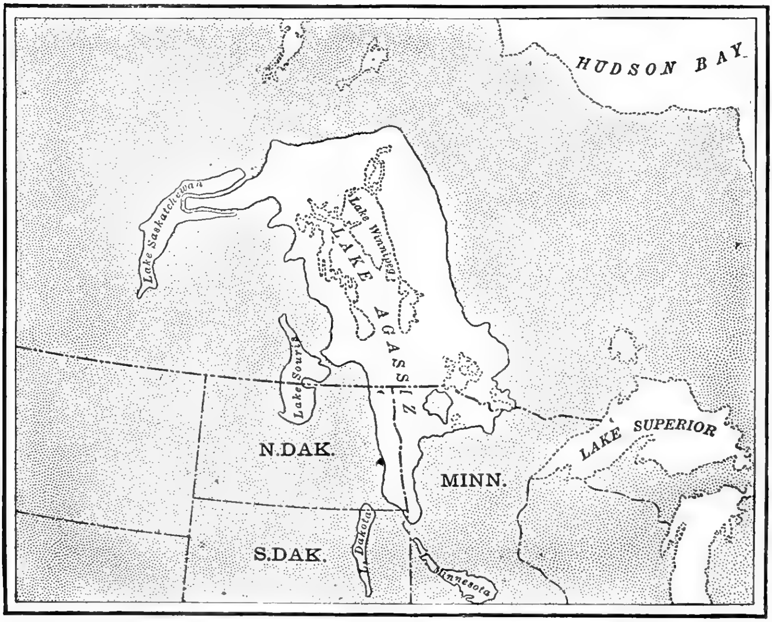

Fig. 189. — Map of extinct Lake Agassiz and other glacial lakes. (Upham U. S. Geol. Surv.)

contrast to these features of shore lines of subsidence are the features indicating elevation on the shore lines of the eastern side of Lake Huron at Kincardine and Goderich, Ontario, where the rising land keeps the lake always at work on new levels, and till, bowlders, cobblestones, and pebbles are everywhere in evidence. The near-shore bottom is stony and the stream discharging into Lake Huron at Kincardine has a stony bed, caving banks, and impetuous flow, indicating uplift and constantly renewed energies.[1] If the tilting continues at the present rate, the water of Lake Michigan will ultimately discharge across the low divide that separates the lake from the Desplaines Valley. Its channel will then be reoccupied and Niagara will become dry. It has been calculated that this change would take place naturally in from 5000 to 10,000 years; but man has anticipated the change by cutting a drainage canal for diverting the sewage of Chicago from Lake Michigan to the Illinois River — a project enforced by the urgent need of a pure supply of lake water for a concentrated population. The old outlet channels of the glacial-marginal lakes are among the most distinctive topographic and drainage features of the entire region. At the present time the Desplaines has a wide steep-walled valley with a flat marshy floor thronged with lakes, bayous, irregular depressions, and stream channels. The present *valley* was the *channel* of the outlet of Lake Chicago, and the irregularities of the present valley are nothing more than the irregularities normal to the channel bottom of a large stream.

In the Red River Valley similar drainage changes of equal importance took place. Upon retreating gradually from the Lake Winnipeg-Red River Valley the Keewatin glacier was met by the gradually advancing Laurentide glacier, and the union of the two caused a ponding of the waters between their fronts, which produced glacial-marginal Lake Agassiz. The lake waters rose until they overflowed southward into the valley of the Mississippi and then gradually declined. The Laurentide glacier advanced to the western shore of Lake Winnipeg; this extreme advance was some time after the advance and retreat of the Keewatin glacier, and between the two till sheets stratified deposits occur near the mouth and on the banks of the Saskatchewan River. The large areas of flat fertile soil in the Red River Valley are largely lacustrine deposits — silts and clays formed on the floor of the ancient glacial-marginal lake and now exposed by the extinction of the lake, Fig. 189.

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[1] Mark Jefferson, The Geography of Lake Huron at Kincardine, Ontario, Jour. Geog., vol. 2, 1903, pp. 144–155.

Soils of the Glaciated Country

Each type of glacial topography in a glaciated country has not only its own distinctive slopes but also its distinctive soils. A map of the glacial forms of a region is therefore to a large extent a soil map of the region. Terminal moraines are noted for stony till, outwash plains for their porous, gravelly, stratified, alluvial nature, eskers for their cobbly material, and kettle and kame topography is marked by sandy hill-slopes and undrained hollows with soils largely of organic origin. These are not hard and fast criteria but they are in general true. Exceptions to the rule are the sandy moraines near the Great Lakes, the stony outwash where a late glacial readvance of the ice veneered the surface with a thin ground moraine, etc. Between the concentric terminal moraines formed during the retreatal stages of glaciation one finds in many cases extensive tracts of sub-level land formed of till, the so-called ground moraine. These tracts are in many cases poorly drained and their soils therefore have a high content of organic material. They form the flattest and richest parts of Illinois and Indiana, and lie in the so-called "corn belt" of these and other states.

The unweathered condition of the soil minerals throughout the most recently glaciated area insures prolonged fertility of the soil. The older glacial deposits have been weathered to an important degree. Both the Kansan and Illinoian drift sheets, Fig. 181, have been greatly leached and large portions of their original calcareous content removed. The Wisconsin drift is fresh and unaltered, one of its distinguishing features. It is also noteworthy that the older drift sheets have a smaller proportion of organic matter in their soils than is the case with the youngest or Wisconsin sheet. Since the deposition of the Wisconsin drift there has accumulated large quantities of organic material along the shores of the small lakes and ponds, indeed some of the water bodies have disappeared through the filling of the basins by sediments, plant remains, and the cutting down of the outlets. The older till sheets have been so extensively eroded, on the other hand, that the accumulated organic remains in the small basins have been largely removed and the soils to that extent impoverished. Corresponding contrasts are exhibited in the value of the soil products, the density of population, and the natural vegetation.[1]

Over the old lake bottoms the soil varies considerably from place to place according to (1) the nature of the underlying glacial deposits, (2) proximity to a well-defined strand line, (3) character of the post-

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[1] Frank Leverett, The Illinois Glacial Lobe, Mon. U. S. Geol. Surv., vol. 38, 1899, pp. 734–736 et al; also An Instance of Geographical Control upon Human Affairs, Geog. Jour. (London), vol. 24, 1904.

glacial drainage, etc. In some places the soil is a fine silt, loam, or clay, and is free from stones and bowlders and very fertile. In other localities it is marked by the presence of stones and bowlders, as where a beach was formed against the slopes of a rocky moraine, although for the most part the beaches are composed of sand and gravel. The poorly drained portions of the lake plains are in the aggregate of considerable extent and are marked by post-lake accumulations of vegetation in sufficient amounts to form a surface layer of peat or muck of great fertility when properly aerated by drainage. Many of the most productive of the market gardens that supply the cities of Port Huron, Detroit, and Chicago are formed upon these extensive, poorly drained muck swamps.

Some of the beach levels are so warm on account of their porous soils and excellent natural drainage as to be ideal sites for vineyards and orchards, a feature well marked in western New York south of Lake Ontario. The lake plains on the eastern side of Lake Michigan and Lake Huron are noted for their large production of fruit, but this development is dependent to a greater degree upon climate than upon soil, for the Great Lakes are exceptionally large bodies of water and mitigate both the heat of summer and the cold of winter. The eastward or leeward side is favored by sufficiently moderate winter temperatures to permit the development of peach, plum, cherry, and apple orchards in great numbers.

In the northern part of the southern peninsula of Michigan the glacial deposits are exceptionally sandy and infertile, and large tracts, aggregating nearly one-sixth of the state, are known as the "pine barrens." Six million acres of these lands have been thrown on the delinquent tax list and are a burden to the people. Formerly they were covered with magnificent forests of white pine. These were so thoroughly cut down, the surface so extensively and repeatedly burned, and young growth and humus so devastated, that great areas have been rendered all but worthless.

Sandy tracts are also found along the lake margins and in some cases, as at the southern end of Lake Michigan, appear to be due to the fact that beach and dune material, formed on the borders of the interglacial Great Lakes, was reworked and redeposited during the last (Wisconsin) glaciation. Further modification has resulted from wind action, the light sands having been blown into dunes some of which attain an enormous size. "Creeping Joe" on the eastern shore of Lake Michigan, near Muskegon, is one of the largest dunes in the world, with a relative altitude of several hundred feet. The dunes are most numerous on the eastern shores of the lakes, as on the eastern shores of Lake Michigan and Lake Huron, where sandy deposits are exposed to the full force of the wind sweeping in from the lakes.

LOESS DEPOSITS

The student of soils must take account of an important deposit in the Mississippi Valley related to glaciation and known as *loess*. The loess deposit of the Prairie Plains extends westward from a point east of the Mississippi and has its greatest development in Illinois, Iowa, Nebraska, and the states to the southeast. The distribution of loess is one of its most important features. It is thick about the borders of the area occupied by the Iowan ice sheet, but thins out on interstream areas when traced away from this border tract, though it retains its thickness along the larger valleys.[1] It follows the Mississippi nearly to the Gulf, and is particularly well developed along this stream and the Missouri. It is habitually found on bluffs immediately overlooking the valleys, and in this position has more than average thickness and coarseness of grain, becoming thinner and finer at a distance from the valley margin.[2] The northernmost limit of the loess in the central part of the United States is about 35 miles below St. Paul, Minnesota. In central and eastern Illinois and south-central Ohio it passes under the Wisconsin drift. In the Mississippi basin the loess is rarely over a score or two of feet in thickness, though exceptional thicknesses of nearly 100 feet have been noted. It is composed of angular undecomposed particles of calcite, dolomite, feldspar, mica, and a certain number of rarer minerals. It is generally light brown in color and is a variety of silt intermediate in size of grain between the finest sand and clay. Stones are generally absent except at its base. On erosion it often exposes vertical faces for long periods. It is markedly porous, owing in part to vertical tubes usually found in it and supposedly due to root action.[3]

The loess is preponderatingly on the east sides of the main rivers, and this fact suggests the hypothesis of an eolian origin, which has perhaps more to commend it than the rival aqueous hypothesis. It appears that the loess is chiefly wind derived and that favorable opportunities for its formation were afforded by the periodic flooding and drying up of the alluvial deposits along the streams of the region either in the in-

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[1] Chamberlin and Salisbury, Geology, vol. 3, 1906, p. 407.

[2] Frank Leverett, Comparison of North American and European Glacial Deposits, Zeitsch. f. Gletscherkunde, Berlin, vol. 4, 1910, p. 297 ff.

[3] For an excellent discussion of the various phases of the loess problem, and for recent data of great consequence, see B. Shimek, Jour. Geol., vol. 4, pp. 929–937, and various loess papers, Bulls. Lab. Nat. Hist., Univ. Iowa, 1904.

terglacial period preceding the Iowan glacial invasion or during the Iowan invasion itself. The absence of fluvio-glacial deposits in important amounts on the margin of the Iowan till sheet would appear to favor the idea of a dry glacial stage, strange as this may seem.

It is found that the loess is thicker on eastern or lee sides of ridges and prominent hills than on the windward sides, a feature that harmonizes with the thicker deposits on the east sides of the stream valleys in pointing to wind action as the chief factor in loess deposition. The diminishing amount of loess in an eastward direction suggests that a considerable part of the material was derived from the Great Plains east of the Rocky Mountains, where dust storms are frequent even to-day.

That the loess was deposited in an interglacial period is supported by the fact that buried soil occurs between the loess and the glacial deposits, and appears to indicate a long period between the melting of the ice and the deposition of the loess. This view is strengthened by the finding of a molluscan fauna in the loess strikingly similar to the existing fauna, showing that the conditions which prevailed when the loess was forming were not greatly different from those now existing in the region.[1]

The shells found in the loess are almost exclusively those of land species or such as frequent isolated ponds. There is a practical absence of forms that frequent rivers and lakes. Fossils of land mammals, chiefly in the forms of bones and teeth, have also been found.

Tree Growth of the Prairies

By definition a prairie is an extensive tract of land, level to gently rolling, without a timber cover. The definition includes the idea of a meadow or at least a grassy vegetation. The distinction between *plain* and *prairie* as the terms are actually employed in the United States is not sharply drawn, but in general they are considered to differ in two main respects. The prairie country is dotted with groves of trees and has a continuous grass cover or sod; the plains country is without timber except along the streams, on prominent elevations, and in places about springs; the grassy vegetation of the plains is disposed in clumps separated by bare spaces. A view in any direction on the typical prairies includes groves and bands of trees and even tracts of true forest. The phrase "Prairie Plains" as here used means the whole great region in which patches of prairie occur and not merely the true prairie land exclusive of wooded tracts (see Plate I and Fig. 23).

Since the whole prairie country lies in the belt of moderate to light rainfall between the semi-arid West and the humid East, Fig. 19, it follows that there are great differences in the relative amounts of woodland and true prairie. On the east, north, and south the province borders

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[1] See especially Proc. Iowan Academy of Science, vol. 15, 1909, pp.57–75.

heavily forested tracts; on the west it borders an all but treeless region. In general the largest tracts of true prairie within the province are found toward the west in the direction of diminishing rainfall. Locally, however, there are extensive tracts well within the western border. South of Chicago, for example (Fig. 190), is a large tract known as the Grand Prairie with a rainfall of 35 inches a year. Extensive prairie tracts occur also in northern Indiana, southern Michigan, etc.

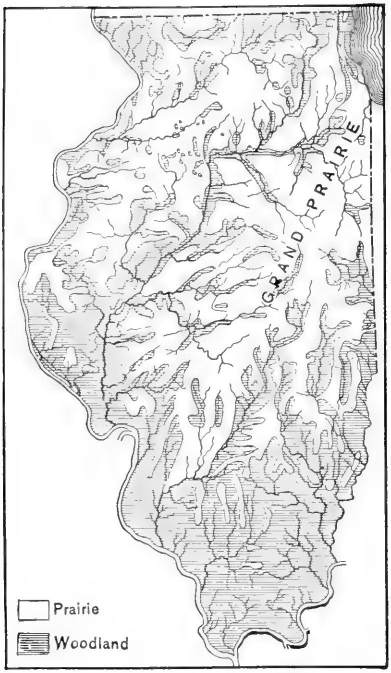

Fig. 190. — Original distribution of prairie and woodland in Illinois. (Barrows, Ill. Geol. Surv., modified from Gerhard.)

On the north the Prairie Plains province is covered with the southern edge of the great pine and hemlock forests of the Lake Region. The individual trees attain great size, especially on the sandy glacial material south of the Straits of Mackinac in Michigan; the virgin growth of this district consisted of extensive stands of superb forest. Farther south is the zone of hardwoods with many outliers of the northern pine forests, especially where the land is either too wet or too dry. The sandy, dry situations have a growth of pines; in the wettest situations are growths of cedar and hemlock. In the intermediate situations are woodland and a true forest growth of mixed hardwoods. The occurrence of the hardwoods on the richest land is notable and in part explains why they were so extensively destroyed in clearing the land for agriculture. It is a common saying that the soil supporting a good growth of beech and maple forest is better than open prairie soil or land so wet that it must be drained before being cultivated. While the saying has a great deal of truth in it, it must also be noted that the peaty soils of low situations have a high fertility when they are properly drained and sweetened and are better than the upland soils for the production of many vegetable products. What measure of truth the saying contained led the settlers rapidly to clear away the hardwood forests until now the supply of hardwood is greatly diminished and in urgent need of conservation.

Many owners are beginning to realize the value of their wood lots and are no longer cutting them for fuel but for timber.

The strongly marked topographic and drainage features of the heavily glaciated country about the Great Lakes have had an important control over the forests not only in the distribution of the forest flora but also in the development of the forest products. It is noteworthy that the steeper slopes of the terminal moraines are wooded because too steep for cultivation, just as bottom land and upland are in many places cleared of their original timber cover while the steep undercut river bluffs are allowed to remain tree-covered. The terminal moraines are not only rough, they are also stony and clayey; many miles of terminal moraine are composed of tough stony clay too difficult of cultivation to compete with better favored tracts of outwash and ground moraine in the intermorainic belt. Such tracts are commonly left wooded or used for pasture-land or for special crops such as flax and rye. It is also noteworthy that the steep slopes of drumlins in the glaciated country are commonly left in their original wooded condition. Some drumlins have narrow summits, others have broad rounded tops. In the latter case a farm may be located on the summit, in the former case the timber cover may be left undisturbed. In the same way the borders of marshy tracts and the floors of undrained depressions are covered with a growth of swamp vegetation including the swamp oaks and maples, buttonwood, elm, cedar, and other types. The aggregate of such land is large and with suitable improvement might be made to grow a steady supply of valuable timber.

On the east the forests of the Prairie Plains grade off into the more or less continuous stands of the Appalachian region in the belt of heavier rainfall. On the south they merge into the pine forests of the Coastal Plain and on the west into the scattered hill and escarpment timber of the Edwards Plateau and its outliers in central Texas. Farther north, as shown in Fig. 23, long finger-like extensions of the Prairie Plains timber follow the stream valleys. For some distance this growth covers both bottom lands and valley slopes and bluffs; farther west it is confined to the bottom lands wholly and still farther west it is found only along the margins of the streams.

The tree growth of the Prairies of Texas has such a close relation to the geology, water supply, and soils as to warrant a more detailed description of its occurrence. The Prairie Plains are here but 100 miles wide and consist of two main subdivisions, — the Black Prairie on the east and the Grand Prairie on the west. The Black Prairie is developed upon a series of marls, sands, and limestones that dip gently eastward. The marls have weathered into a uniform and very gently undulating type of topography terminated on the west by a low inward-facing escarpment that never exceeds a relative altitude of 200 feet. It is known as the Black Prairie. West of the Black Prairie is the Grand Prairie, developed upon nearly horizontal limestones of great extent as a series of flat structural plains terminated in succession on the coastal side by low inward-facing escarpments. The western border of the Grand Prairie is a pronounced escarpment with a lobate or crenulated outline that extends from Arkansas, west and south through Oklahoma and Texas, to the Rio Colorado, whence it curves about to the west and north and becomes the eastern escarpment of the Great Plains.

The most important forest tracts of this region are the Western and Eastern Cross Timbers, two narrow forest belts developed upon the inner edge of the Grand Prairie and Black Prairie respectively. They are of peculiar interest since they form long narrow ribbons of forest in what is otherwise a prairie country. Both belts have been developed upon the outcrop of two sandy formations (Cretaceous). The open sandy soils not only permit thorough aeration, but also favor the rapid absorption of water during periods of rainfall, whereas the close-textured soils of the intervening prairies shed water to an exceptional degree and are too dry for tree growth. The limited rainfall of the district thus makes the porosity of the soil a determining factor in forest distribution. The Eastern Cross Timbers consist of a belt of timber whose extent is shown in Fig. 191. It has many outliers towards both the east and the west and like the Western Cross Timbers sends finger-like extensions up and down the stream-ways. Within the Cross Timbers are many local prairie tracts. The Western Cross Timbers are about 10 miles wide and have about the same extent north and south as the Eastern Cross Timbers. The various irregularities of the belt in response to geologic changes and to relief are clearly indicated in Fig. 191. The western border of the Western Cross Timbers is the more indistinct since it merges into local forest tracts developed upon other sandy formations. Wherever compact marls and clays outcrop there is a marked absence of forest growth except in cases where the mesquite grows. In general the surface is without tree growth between and on either side of the Cross Timbers; it is here that the prairies of Texas have their most typical development.[1]

Among the effects of glaciation none is perhaps more directly interesting to the forester than the overwhelming effects of the continental

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[1] R. T. Hill, Geography and Geology of the Black and Grand Prairies, Texas, 21st Ann. Rept. U. S. Geol. Surv., pt. 7, 1899–1900, pp. 65–85.

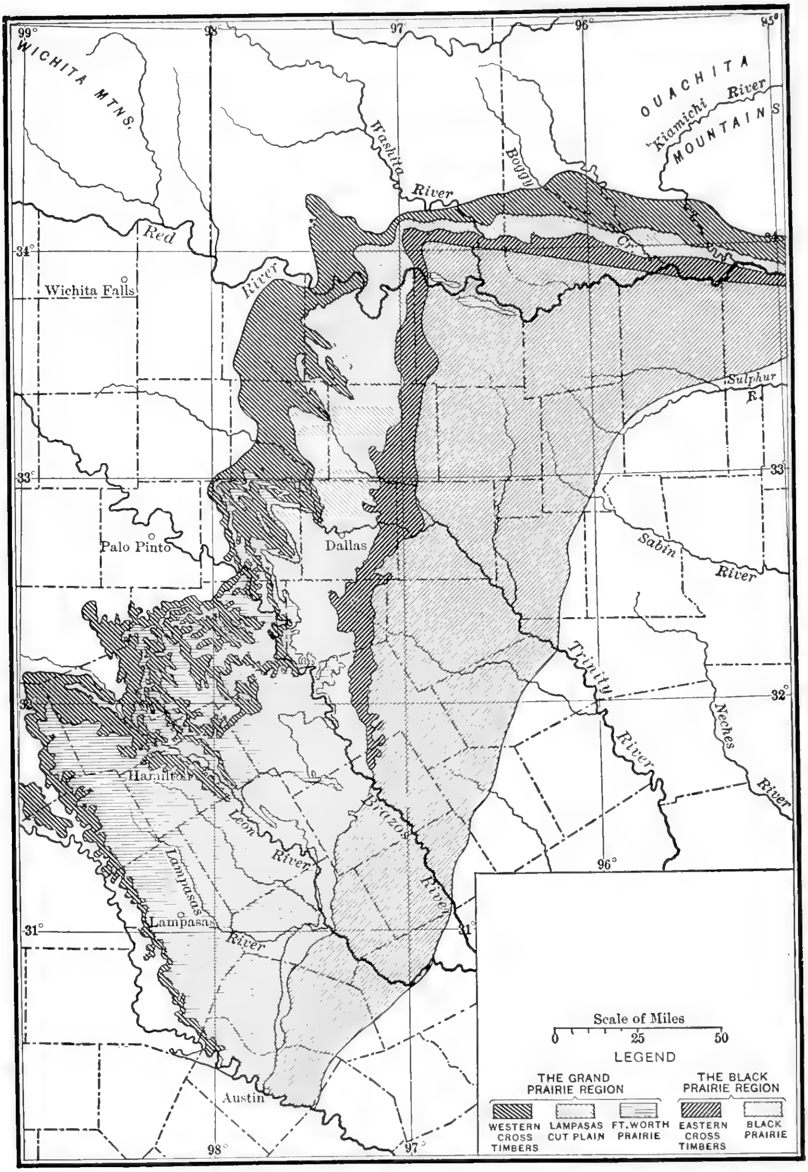

Fig. 191. — Cross Timbers of Texas.

ice caps upon the forests whose regions they invaded.[1] During the period of maximum development the ice had a most disastrous effect

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[1] C. H. Merriam, The Geological Distribution of Life in North America with Special Reference to the Mammalia, Proc. Biol. Soc. Washington, vol. 7, 1892, pp. 42 and ff.

upon animals and plants, not only in the great area occupied by it, but far south of its actual border. As the ice advanced from the north, northern species were driven southward and more southerly species correspondingly displaced or exterminated. It appears that the gradual southward movement of the cold zone greatly restricted the range of the plants, compressing them from north to south within very narrow limits. Perhaps the most interesting evidence of the strength of this hypothesis is the presence of colonies of Arctic species on isolated mountain summits in southerly latitudes where at a high altitude abnormally low temperatures exist similar to those which exist in their northern homes. Such colonies could not in many cases have reached their present position during existing climatic conditions; following the retreat of the ice at the close of the glacial period many boreal species were stranded on mountains where their survival was conditioned by their ability to migrate with a congenial climate.

Driftless Area

Lying well within the southern border of the general region once covered with glacial ice is a small district, Fig. 192, which has never suffered glaciation. It is called the Driftless Area. Its extent is about 10,000 square miles and it lies in the states of Wisconsin, Illinois, Minnesota, and Iowa, the greater part of it occurring in southwestern Wisconsin. The soil of the Driftless Area is residual, derived directly from the decay of the underlying rock. Like residual soils everywhere the surface detritus grades gradually into solid rock and there is not that sharp dividing line that is found between glacial or other overplaced soils and the rock surface.

The surface of the Driftless Area is topographically mature and the drainage is well organized, without falls and rapids and lakes or swamps except within narrow limits and along the river bottoms. The aimless flow of streams developed upon the irregular topography characteristic of till sheets or terminal moraines, as well as the abundant swamps, lakes, and ungraded stream courses of such localities, are here practically absent. At numberless points within the area overridden by glacial ice the bedrock is scratched, grooved, and smoothed, while within the Driftless Area glacial markings are entirely absent.[1] The thoroughly dissected upland plain of the Driftless Area is in striking contrast to the more even country with drift-filled valleys about it. The valleys and ravines tributary to the main streams have been thoroughly organized and the divides reduced to narrow ridges. The

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[1] Grant and Burchard, Lancaster-Mineral Point Folio U. S. Geol. Surv. No. 145, 1907, p. 1.

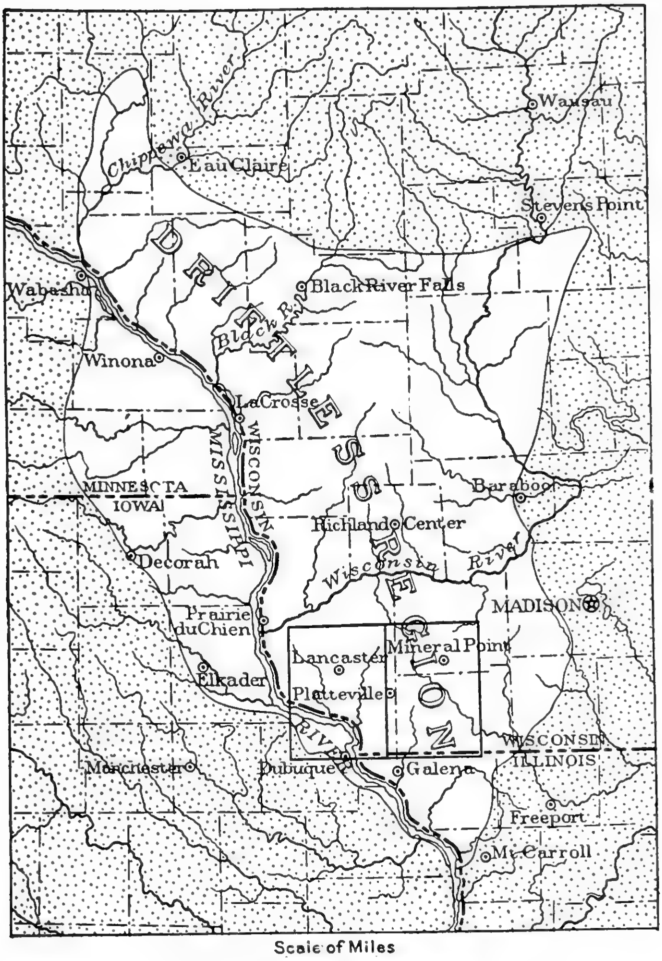

Fig. 192. — Driftless Area of Wisconsin.

valley bottoms toward the south are from 600 to 700 feet above sea level, and the relief of the area is from 200 to 300 feet.[1]

In spite of the extreme irregularity of the drainage of the glaciated region its relief is less than that of the Driftless Area, a condition due to the manner of distribution of the drift, which in general was lodged in the valleys more freely than on the heights. Such plain-like qualities as the drift-covered region exhibits are due less to the glacial denudation

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[1] J. E. Carman, The Mississippi Valley between Savanna and Davenport, Bull. Ill. State Geol. Surv. No. 13, 1909, p. 29.

of prominences than to the grading up of depressions. In a rough manner the driftless region therefore presents the essential features of the preglacial topography of this portion of the United States.[1]

The purely residual products in the Driftless Area have their greatest expression upon the flat-topped upland areas. On the valley slopes the residual products tend to be removed by erosion, and on the valley bottoms there is alluvial filling derived from the uplands in part during an earlier period of alluviation (probably glacial) and in part by wash under existing conditions.[2]

The Driftless Area has created widespread interest since early in the nineteenth century, largely because it has not that exceptional height which on the border of the glaciated country is the general cause of immunity from continental glaciation. Its average summit level falls a little short of 1200 feet, while the effective height of the highlands lying between it and Lake Superior is from 1700 to 1800 feet. The summit level between the Driftless Area and the plains of Iowa and southern Minnesota is about 1300 feet, so that as a whole the Driftless Area is somewhat lower than the surrounding tracts. Furthermore, the immunity from glaciation enjoyed by the area was due not to some accidental condition but to a geographically fixed cause, for none of the repeated invasions of the ice affected it.[3]

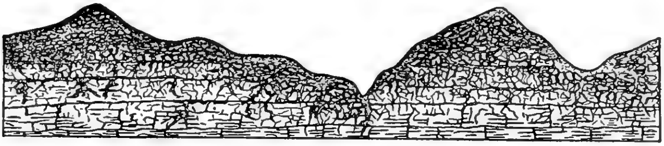

Fig. 193. — Diagrammatic section in the Driftless Area, showing relation of the mantle rock to the solid rock beneath. (Alden, U. S. Geol. Surv.)

The most important elements of the explanation of the Driftless Area are that it is in the lee of the elevated territory of northern Wisconsin and Michigan, which acted as a wedge, forcing the ice away on either side and protecting the region south of it,[4] and that the great valleys of Lake Superior and Lake Michigan lie in such position with reference to the Driftless Area as to tend to divert the glacial streams

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[1] Chamberlin and Salisbury, The Driftless Area of the Upper Mississippi, 6th Ann. Rept. U. S. Geol. Surv., 1884–85, p. 307.

[2] S. Weidman, The Geology of North-Central Wisconsin, Bull. Wisc. Geol. and Hist. Surv. No. 16, 1907, p. 554.

[3] Chamberlin and Salisbury, The Driftless Area of the Upper Mississippi, 6th Ann. Rept. U. S. Geol. Surv., 1884–85, p. 315.

[4] N. H. Winchell, 5th Ann. Rept. Geol. and Nat. Hist. Surv. of Minn., 1877, p. 36.

to right and left and thus to increase the effect of the highlands lying between the lakes in turning the ice from the driftless region.[1] A third cause is found in the retarded feeble flow and relatively increased wastage caused by the thinning ice through the diversion of the main lobes down the lake troughs. An important factor was the broad zone of glacial wastage which probably includes approximately 150 miles of the ice border; on this assumption the meager ice streams that crept down across the highlands south of Lake Superior and the enfeebled tongues which crept down the adjacent depressions were profoundly controlled by the topography and easily directed this way and that according to the relations of the major topographic depressions.

It is also maintained with much reason that the outlines of the ice front would be modified to an important degree by the law of self-perpetuation of climatic conditions; by which is meant that the ice-clad regions increased the snowfall upon themselves and tended toward self-perpetuation, just as the ice-free and therefore relatively warmer area resisted the advance of the ice by excessive melting. While this last agency was not an originating one it would undoubtedly produce a modifying effect and tend to coöperate with the topography in holding the surrounding ice to the depressions down which the invasion first took place.

The Driftless Area is interesting ecologically because of the occurrence therein of many plants peculiar to it alone. Among these mosses and other low forms predominate.

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[1] R. D. Irving, Geology of Wisconsin, vol. 2, 1877, pp. 608, 611, 632, 634.

CHAPTER XXV

ATLANTIC AND GULF COASTAL PLAIN (INCLUDING THE LOWER ALLUVIAL VALLEY OF THE MISSISSIPPI)

General Features and Boundaries

The greater part of the eastern and southern coasts of the United States is bordered by a lowland whose physiographic features are developed upon a mass of soft sands, silts, and clays, chiefly of Cretaceous and Tertiary age, and disposed in strata that incline (dip) gently seaward. The structural features are in the main very simple, though in places there are important departures from the average condition. On the north shore of Long Island the clays (Cretaceous) were disturbed by ice action and quite generally concealed by a cover of glacial and fluvioglacial material; in Louisiana important faults complicate the structure, topography, and drainage; in Oklahoma and Texas some of the coastal plain deposits are indurated, not soft and friable as generally; and in many localities the dip of the strata, almost never great, varies from a mean sufficiently to cause important differences in the width of the coastal tract, the character of the shore line, and the general topographic expression.

The Coastal Plain terminates on the north at Cape Cod, on the south in Mexico. Both ends are narrow and the northern is glaciated and partly submerged. The physiographic features of the province are varied at two places by special features of the first order — the peninsula of Florida and the lower alluvial valley of the Mississippi. Its width varies from a fraction of a mile to 500 miles measured normal to the coast; its greatest inland development is in the Mississippi Valley, where it swings northward into western Kentucky, southeastern Missouri, and eastern and southern Arkansas. The inner edge of the northern portion of the Coastal Plain is bordered by water bodies — Cape Cod Bay, Long Island Sound, etc.; by an inner valley lowland in New Jersey, Alabama, and Arkansas; and these features in turn are bordered by various topographic provinces — the Piedmont Plateau developed on crystalline rocks at the north and east and in succession westward and southward, the Appalachian Mountains and Plateaus, the Ozark Highlands, the Ouachita Mountains, and the Prairie Plains of central Texas.

Fall Line

The Atlantic division of the Coastal Plain borders the Piedmont Plateau along the fall line, as it is commonly termed. This phrase imperfectly describes the boundary, which is not really a line but a zone of appreciable width; hence "fall belt" would be a more accurate designation. As the streams cross from the old land or Piedmont Plateau to the new land or Coastal Plain they descend over rapids and falls of moderate height. Between the Raritan and the Roanoke the rivers discharge directly from rock-walled channels into tidal estuaries, since here the depressed land has brought the sea to the very borders of the Piedmont Plateau; but farther south the fall line is above sea level; on the James it is at tide level; on the Neuse 100 feet above the sea; on the Wateree, near Camden, it is 125 feet; on the Savannah, near Augusta, 125 feet; on the Chatahoochee, near Columbus, 210 feet; and on the Tuscaloosa at Tuscaloosa, 150 feet.

On the interfluves, Coastal Plain and Piedmont Plateau merge into each other in an intermediate zone from a fraction of a mile to 10 or 12 miles wide. The boundary is never a cliff and seldom even a well-defined scarp, and the lowland hills are nearly as rugged and more than half as high as the piedmont hills; but chiefly on account of differences of soil the two provinces present some of the most strongly marked contrasts in the United States, if not in the world. In the Piedmont Plateau the rocks are crystalline, the soils residual, the stream courses flow in narrow gorges with cataracts and rapids; while in the Coastal Plain the soils are derived from clay, sand, and gravel deposits, and the streams flow in shallow valleys and discharge into broad tidal estuaries or coastal swamps. In the piedmont region the topographic details, the soils, and the watercourses reflect the character of the rock, while in the coastal region these features represent the work of streams born upon plains newly uplifted from the sea, or reflect the general attitude of the lowland rather than its rock character. Among the important cities located upon the common boundary of these two great provinces may be mentioned Raleigh, Camden, Columbia, Augusta, Macon, Columbus, Montgomery, Tuscaloosa, Little Rock, Austin, San Antonio, etc.

Relation to the Continental Shelf

The seaward limit of the coastal lowlands on the southeastern border of the United States is a steep scarp which marks the transition from the outer edge of the shallow continental shelf to the abyssal depths of the main ocean floor. This scarp forms the true continental margin and is comparable in height and extent though not in topographic variety with some of the most majestic mountain ranges. Were sea level lowered to its foot, present sea level in this latitude would be a region of ice and snow. The seaward slope of the Coastal Plain is continued as the continental shelf beneath the level of the sea to distances varying from 100 to 200 or more miles; the Coastal Plain is therefore to be considered as the landward extension of a greater plain whose outer border is submerged. The present position of the shore line upon this plain is a purely accidental one and subject to change, indeed is now changing at what from even a human standpoint may be considered a rapid rate. The steady depression of the larger part of the coast is so pronounced that if continued the sea will in a very short time again cover the coastal lowlands. In more recent periods of the earth's history such transgressions of the sea over the land have been frequent and important, and no less important have been the various retreats of the sea which have brought the coastal border of the continent out near the border of the continental shelf and turned what is now continental shelf into dry land.

The repeated invasions of the sea are clearly indicated by the marine fossils found in the flat-lying sediments which constitute the Coastal Plain; and the surface of the continental shelf is deeply scored opposite the mouths of many of the coastal rivers by trenches or submarine canyons whose position and character have led to the conclusion that they represent old river valleys formed at a time when the land stood higher than now.

Materials of the Coastal Plain

ATLANTIC SECTION

The lowest strata of the Atlantic Coastal Plain, as illustrated in the Maryland section, are composed of arkosic sands and clays derived from a deep mantle of disintegrated gneiss and phyllite such as now form part of the Piedmont Plateau. The sands and clays have detached outliers west of the main border of the Coastal Plain which show by their position, altitude, and composition that the plains strata formerly extended farther west over the adjoining portion of the Piedmont Plateau. Higher in the section the strata consist of variegated clays and coarse, irregularly bedded sands. Then follow sands and clays in alternation with but slight variations in character and a gradual transition toward sandy and marly deposits.[1]

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[1] C. Abbe, Jr., A General Report on the Physiography of Maryland, Including the Development of the Streams of the Piedmont Plateau, Md. Weather Serv., vol. 1, pt. 2, pp. 74–75.

GULF SECTION

The Gulf Coastal Plain section is rather typically represented in the Arkansas-Louisiana district where the lowermost beds are sandy and contain vegetable remains and brackish-water shells. Above these basal beds are limestones and marls; higher in the section are sands, lignitic clays, marls, and chalks, a succession indicating a gradual deepening of the water in which the sediments accumulated. Succeeding the deep-water deposits are limestones, marls, and lignitic sands, showing a return to shallow-water conditions.[1] Then came complete and final uplift of the region and the formation of a coastal plain out of what had long been a continental shelf. The migration of the shore zone, characterized by sand deposits, over the surface of the plain from its inner to its outer edge was the last important geologic event and is the cause of the prevailingly sandy nature of the surface deposits.

Subdivisions

(1) Including a broken and glaciated northern section the Coastal Plain may be said to fall into seven well-defined districts. The first includes Cape Cod, Martha's Vineyard and Nantucket islands, Long Island, and a number of lesser islands.

(2) The second extends from the Hudson to the Potomac, and is characterized by a cuesta, an inner lowland, and a gentle outward slope or lowland merging into great estuaries that nearly isolate it from the mainland.

(3) The third extends from the Potomac to the Neuse. It is a low eastward-sloping plain characterized by long arms of the sea reaching far into it, by broad terraced plains of loam, and broad coastal sounds defended on the seaward border by long tenuous reefs partly of sand, partly the narrow and wave- and current-modified outcrops of clayey formations (Cretaceous) that dip seaward.[2]

(4) The fourth section extends from the Neuse to the Suwanee as a gently sloping plain characterized by great stretches of pine-covered sands with swampy marginal development also fringed by coastal reefs.

(5) The fifth section extends from the Suwanee River to the bluffs at the eastern border of the Mississippi flood plain. This division has more important topographic irregularities than the Georgia-South Carolina section of the Coastal Plain, its inner border having been dissected in

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[1] A. C. Veatch, Geology and Underground Water Resources of Northern Louisiana and Southern Arkansas, Prof. Paper U. S. Geol. Surv. No. 46, 1906, pp. 20–28.

[2] Collier Cobb, Notes on the Geology of Currituck Banks, Jour. Mitchell Soc., vol. 22, No. 1, p. 17.

such manner as to develop a rather typical inner lowland and cuesta. Along the coast are long narrow keys, some of which are scarcely able to maintain themselves owing to the depression of the land and to the encroachment of the waves, while some are completely submerged and have the form of offshore shoals. The seaward border of the Coastal Plain of this section is marked by broad lagoons, low coastal swamps, and extensive savannas.

(6) The sixth section is the low, poorly drained, swampy terminus of the flood plain of the Mississippi, an area whose southern end is scarcely yet reclaimed from the sea.

(7) The seventh section extends from Atchafalaya Bayou to the Rio Grande. Its interior development is topographically weak except in Arkansas and Louisiana, where a somewhat regular series of cuestas and inner and outer lowlands has been developed. The seaward margin of this district is bordered by swamps, extensive sounds, and long narrow lagoons.[1]

CAPE COD-LONG ISLAND SECTION

CAPE COD

The northernmost section of the Coastal Plain is broken by dissection and drowning into a number of islands, shoals, and capes of which the most important members are Cape Cod and Long Island. Lesser members are Staten Island, Block Island, and Martha's Vineyard and Nantucket islands.

That these are all members of a formerly more extensive and less dissected coastal plain fringe is inferred from (1) the evidences that stream courses on the present mainland border are superposed from a former cover of gently and regularly sloping marine deposits; (2) the actual finding of fragments of such deposits at Marshfield,[2] Boston,[3] and Third Cliff,[4] at the first two localities below sea level and at the third above it; (3) the occurrence of known Tertiary deposits[5] on Georges Bank east of Cape Cod in line with the general trend of the strike of the unsubmerged portions of the plain to-day; and (4) from the general likeness of the shoal and channel outlines of the sea floor north of Cape Cod to drowned valleys.[6]

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[1] For a characterization of these various districts and a clear description of the coastal plain of the southeastern portion of the United States, see W J McGee, The Lafayette Formation, 12th Ann. Rept. U. S. Geol. Surv., 1890–91, pt. 1, pp. 353–521, with four excellent maps, photographs, and cross sections.

[2] Edw. Hitchcock, Final Report on the Geology of Massachusetts, vol. 1, 1841.

[3] F. G. Clapp, Clay of Probable Cretaceous Age at Boston, Massachusetts, Am. Jour. Sci., vol. 23, 1907, pp. 183–186.

[4] I. Bowman, Northward Extension of the Atlantic Preglacial Deposits, Am. Jour. Sci., vol. 22, 1906, pp. 313–325.

[5] A. E. Verrill, Occurrence of Fossiliferous Tertiary Rocks on the Grand Bank and Georges Bank, Am. Jour. Sci., 3d Series, vol. 16, 1878, pp. 323–332.

[6] N. S. Shaler, The Geology of the Cape Cod District, 18th Ann. Rept. U. S. Geol. Surv., pt. 2, 1896–97, pp. 516, 578, 580.

Cape Cod is the most extreme projection on the eastern coast of the United States north of the peninsula of Florida. In general outline it roughly resembles a great flexed arm, the southern portion being the humerus, the eastern portion the forearm, and the northernmost extremity the clenched fist. It is so narrow at the base where it adjoins the mainland that a canal is building to connect Cape Cod Bay and Buzzards Bay; the land section will be only 8 miles long. Its exposed position, the lack of good harbors, and its featureless shores combine to give the Cape notoriety as one of the two graveyards of the Atlantic. The projection of the Cape eastward and northward would not seem so remarkable if the material composing it were solid rock of great resistance to wave erosion; as a matter of fact no hard rock occurs upon it, only soft, easily washed gravel, sand, and clay.

The extreme northern end of Cape Cod, the wrist and fist of the Cape Cod arm, is composed of wave- and current-derived material entirely. It is low, covered with sand dunes of irregular outline, bears a scanty growth of shrubs and grasses or is entirely bare of vegetation, and has well-rounded coastal outlines where the wear of currents and waves is constantly reshaping the beach. The material added to the Cape at this point is derived from the crumbling eastern side of the arm. The attack of the waves on the steep eastern shore is vigorous and sustained, and at the present rate of retreat, 3.2 feet per year, the Cape will be entirely destroyed 8000 to 10,000 years hence. On the western side of the Cape the shore is low and flat and bordered by wave-built sand reefs which enclose extensive lagoons. Cape Cod Bay is rather quiet, a great natural harbor, yet the shore currents are here attacking the border of the Cape and assisting in its demolition.[1] The same action is exhibited at Monomoy Point, the southeastern extremity of the Cape, where a portion of the material torn from the bold eastern margin of the Cape is drifted southward and built into a long flying sand reef.

The foundation of a large part of Cape Cod is a mass of preglacial sands and clays presumably of Cretaceous or Tertiary age, revealed in well sections, clay pits, cuts, and bluffs. These deposits form the substructure of the east-west section of the Cape where they occur above sea level. The north-south section nowhere reveals similar deposits above sea level, but they have been encountered in well borings. The morainal ridge that forms so prominent a feature of the first-named section rests upon these preglacial deposits and its height is enhanced thereby.[2]

The surface material of the Cape is, however, not derived from the basement deposits; it is of glacial derivation. It occurs in the form

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[1] W. M. Davis, The Outline of Cape Cod, Proc. Am. Acad. Arts and Sci., vol. 31, 1896, pp. 331–332.

[2] N. S. Shaler, The Geology of the Cape Cod District, 18th Ann. Rept. U. S. Geol. Surv., pt. 2, 1896–97, p. 534.

of a thin veneer of till except (1) where actual morainic ridges of exceptional thickness occur, or (2) where outwash deposits were laid down in front of the moraine. Cape Cod is therefore a mass of glacially derived material resting upon a preglacial basement of sands and clays. Its detailed surface features are due chiefly, and in some cases wholly, to ice action. Lakes are relatively abundant; the surface is characteristically pitted with kettle holes; unsorted material, till, is common; and there are many erratic ice-rafted bowlders. The glacial material is prevailingly sandy and this also is the character of the outwash plains that front the moraine. Lying well forward of the main line of the coast where no topographic prominences afford shelter from the wind the Cape is exposed to the fury of every tempest and its porous, light, dry material has been largely blown into dunes and drifts of sand. This is especially true on the immediate shore, where dunes of considerable height occur and where serious effort has been made to stop the progress of the wind-drifted material.

CONTROL OF SAND DUNES

The problem of dune control is a paramount one in the utilization of large portions of the surface of Cape Cod. Similar efforts are required in many other localities in the United States, and since these are more or less alike in natural features and involve the same problems, the following general discussion is included here.

The chief areas of shifting dunes to be found along the Atlantic coast are on Cape Cod, near Provincetown; southern New Jersey, near Avalon and Stone Harbor; Cape Henlopen, near Lewes, Delaware; Cape Henry, Virginia; Currituck Banks, North Carolina; Isle of Palms, near Charleston, South Carolina; and Tybee Island, near Savannah, Georgia. Sand dunes are also found on the Pacific coast in Ventura, Monterey, and Mendocino counties, California, and along the coast of Oregon.[1]

In California drifting sand has played an important part in obstructing the channels in certain harbors on the coast; for example it has been blown into the channels every year near Eureka from a narrow sand spit several miles long between Humboldt Bay and the ocean.[2] Very

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[1] A. S. Hitchcock, Controlling Sand Dunes in the United States and Europe, Nat. Geog. Mag., vol. 15, 1904, pp. 43–47.

[2] S. B. Kellogg, Problem of the Dunes, Cal. Jour. Tech., vol. 3, 1904, pp. 156–159. See this paper for a discussion of various kinds of schemes for controlling sand dunes by sand-binding grasses, such as beach grass (*Ammophila arenaria*) and "rancheria grass" (*Elymus arenarius*); and for a photograph of a dune covering a forest above Fort Bragg, Mendocino County, Cal.

troublesome dunes are developed on a large scale along the Columbia River in Oregon and Washington from Dallas to Riparia, from sand blown about over the flood plain of the Columbia, which is widely exposed during the dry season. Dunes occur in large numbers also about the southern end of Lake Michigan, on the eastern side of Lake Michigan, and east of Lake Huron.

The most important principle of control of sand dunes is the establishment of a cover of material that will prevent drifting, the type of cover usually depending upon climatic conditions, cost of material, etc. Where possible it is best to produce a forest cover, for this is permanent and, if properly managed, yields an income. For this purpose the land must be temporarily fixed in some other manner than by seedlings, and a temporary binding of inert material such as brush, sand sedges, etc., may suffice. Beach grass has given most satisfactory results in the Great Lake region, North Carolina, and Europe. The grass is transplanted in the spring or fall and set 2 or 3 feet apart in the sand. It has the power of continuing to grow up through a cover of drifted sand by establishing root systems at constantly higher levels. If the sand is temporarily fixed by these or other means, young trees, usually conifers, may be planted and a forest established. In southwestern France a forest has been established by sowing the seed of *Pinus maritima* upon the sand and covering with brush. In France and on the coast of Prussia it has been found necessary in places to construct long artificial barrier dunes between the ocean and the forest and to fix the barrier dunes by beach grass and maintain them by constant oversight. In northern Europe the trees employed for reclamation of sand dune tracts are *Pinus montana*, *Pinus laricio*, *Pinus austriaca*, and *Pinus sylvestris*.[1] Extensive pitch-pine plantations are now being experimented with on the sandy areas of Cape Cod, Martha's Vineyard, and Nantucket.[2]

NANTUCKET AND MARTHA'S VINEYARD

The relief and drainage of Nantucket Island afford many parallels to the conditions on both Cape Cod and Long Island. There is a terminal moraine on the northern shore of the island and a very irregular primary or inner shore; the same kind of outwash plain is built forward of the moraine, pitted with kettle holes and creased by shallow drainage ways dry for the greater part of the year; and long tenuous sand reefs and flying spits occur like those on the coasts of the adjacent islands. Underneath the thin mantle of glacial materials lie preglacial deposits

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[1] S. B. Kellogg, Problem of the Dunes, Cal. Jour. Tech. vol. 3, 1904, p. 47.

[2] Yearbook Dept. Agri., 1909, p. 336.

which in places project above the level of the sea, so that were the glacial accumulations removed a number of small islands would still exist where Nantucket stands. For the most part the older surface is masked by glacial till and outwash gravels. The original outline of the island has been much altered by wave and current action; portions of the shore have been cut away, while other portions have been fringed with recently formed marine deposits.[1]

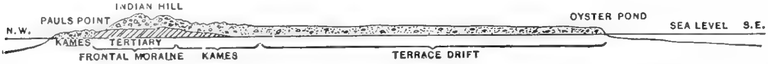

Fig. 194. — Diagrammatic section of Martha's Vineyard. (Shaler, U. S. Geol. Surv.)

Martha's Vineyard lies west of Nantucket and has closely allied physiographic features. Not only are the deposits of the island of the same general nature but they are also disposed in roughly the same way, so that the northeastern and northwestern sides of the triangular island are hilly and morainic, with irregular shores, while the southern side is an almost straight eastward-trending line. It presents almost wholly those features typical of a morainal island. The surface drift is almost everywhere thin (about 10 feet) and as on adjacent islands it to some extent masks the older basement material, Fig. 194. The straight southern side of the island is a sand reef enclosing a large number of water bodies with a branching pattern closely resembling that of a stream system and tributaries, a condition signifying a slight submergence of the land after the formation of the outwash plain bordering the shore.[2]

LONG ISLAND

GENERAL GEOGRAPHY

To a forester Long Island is of peculiar interest. It supports a considerable variety of forest trees under special conditions, and the relations of these to the physical conditions are the more easily determinable because of the detailed studies made by the United States Geological Survey and the Soil Survey. The value of the natural resources of Long Island is unusually great because of their proximity to a great consuming center; and detailed studies of its climate, soil, water supply, and physiography have therefore been made.

The greatest length of Long Island (the "Lange Eyelandt" of the early Dutch) is 118 miles and its greatest width 23 miles. Its outline suggests the shape of a huge fish; the flukes

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[1] Curtis and Woodworth, Nantucket, a Morainal Island, Jour. Geol., vol. 7, 1899, pp. 226–236; N. S. Shaler, The Geology of Nantucket, Bull. U. S. Geol. Surv. No. 53, 1899.

[2] For geologic description see N. S. Shaler, Report on the Geology of Martha's Vineyard, 7th Ann. Rept. U. S. Geol. Surv., 1885–86, pp. 303–363.

of the tail are represented by Orient and Montauk points on the east; the head is represented by the blunt western end with its mouth-like extension at Coney Island. The south shore is double: the inner or primary shore line is the border of a broad lagoon — Great South Bay and its extensions; the outer shore line consists of narrow sand reefs of remarkably regular outline. The eastern half of the northern shore is without notable indentations, but the western half is deeply embayed by a dozen or more well-developed fiords with steep sides and noteworthy depth of water.

GLACIAL TOPOGRAPHY

TERMINAL MORAINES

The principal relief features of Long Island are associated with a double line of eastward-trending glacial moraines fronted by extensive outwash plains of loose alluvium, Fig. 195. The southernmost is known as the Ronkonkama moraine. Its eastern extension gives character to that end of Long Island, and with the eastern extension of the Harbor Hill, or northern, moraine encloses a large body of water known as Peconic Bay. The Ronkonkama moraine is remarkable for the large body of water it encloses and after which it was named, Lake Ronkonkama. This is by far the largest lake on Long Island and extends about 25 feet below sea level. The two moraines are often referred to as the backbone of Long Island, though it should be noted that it is a compound backbone, for east of Huntington the two moraines diverge more and more and enclose broad sub-level tracts between them.

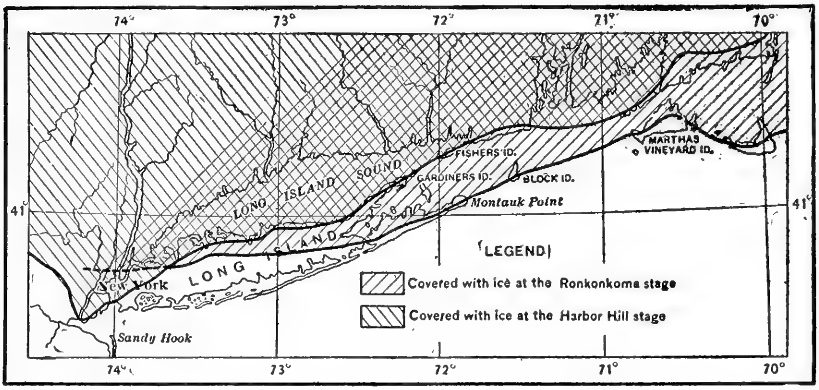

Fig. 195. — Relative positions of the ice during the two stages of the Wisconsin glaciation. (Veatch, U. S. Geol. Surv.)

The seaward slope of a large part of the eastern half of the northern moraine has been largely removed by wave and current erosion, and in a few localities this has been carried so far that in the wave-cut cliffs are exposed sections of the outwash plain through the complete removal of the moraine once fronting and guarding it on the north. Everywhere along this shore the projecting headlands are being modified by vigorous wave action. Cliffs are kept perpetually freshened and so steep that landslides are a common occurrence, bars are being built across the bay mouths, and in the mill of the surf the bowlders and stones of the crumbling moraine are fast being ground to pieces.

The Montauk moraine lies chiefly in the interior of the island and is not subjected to such general attack by shore processes though its eastern extension, exposed to all the fury of Atlantic storms, is being battered rapidly to pieces. That the extreme eastern end must once have extended farther east is self-evident. Erosion has now progressed so far that portions of the once more extensive outwash plain have been destroyed.

Both moraines bear the usual marks of terminal accumulations formed by a continental ice sheet. Their surfaces are deeply pitted by large and small kettle holes, and enclosed, formless pits and depressions, and a maze of mounds, knobs, and ridges of till and other glacial débris still further diversifies their surfaces. Upon the floors of some of the enclosed depressions lakelets or swamps occur, and all others are distinctly moist, but by far the larger number are without standing water. Large portions of both moraines are composed of till of rather typical composition, but there are also large portions which are composed largely and in some localities almost exclusively of sand. The sandy phases are developed chiefly at the eastern end, the clayey phases at the western end of the island. Bowlders, large and small, are scattered freely upon the surfaces and throughout the mass of both moraines. They are of variable composition; gneisses and schists, sandstones and quartzites predominate.

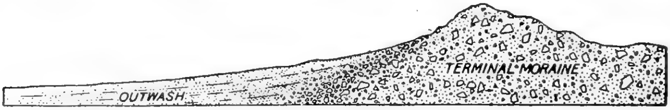

Fig. 196. — Section showing the relation of outwash to terminal moraine. (U. S. Geol. Surv.)

OUTWASH PLAINS

Long gently sloping outwash plains extend southward from both moraines. Their northern margins are in many places pitted by kettle holes, and a considerable number of old broad drainage grooves cross them from north to south. The grooves are not now effectively occupied by streams, for the present drainage consists chiefly of small wet-weather streams extremely diminutive as compared with the ancestral streams whose channels they occupy. The old broad channels have a markedly asymmetric development, the steepened slope being on the west, a response, it is thought, to the right-handed deflective influence of the earth's rotation in the northern hemisphere.[1]

The porous nature of the outwash material greatly reduces the run-

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[1] G. K. Gilbert, The Sufficiency of Terrestrial Rotation for the Deflection of Streams, Am. Jour. Sci., 3d Series, vol. 27, 1884, pp. 427–432.

off, and instead of a normal run-off of about 40% the run-off is only 20% of the total precipitation. The reduced run-off has retarded the dissection of the frontal plains, and the small elevation has favored the same result. They extend mile after mile as almost flat plains of alluvium in striking contrast to the ruggedness and picturesqueness of the terminal moraines.

Fig. 197. — Outwash plain in foreground, the hills in the background are preglacial and have but a slight morainal covering. (Veatch, U. S. Geol. Surv.)

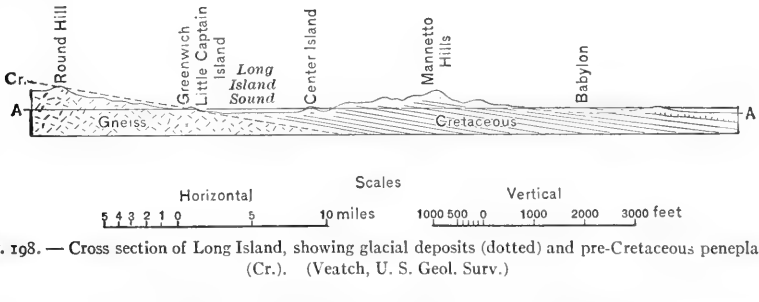

Fig. 198. — Cross section of Long Island, showing glacial deposits (dotted) and pre-Cretaceous peneplain (Cr.). (Veatch, U. S. Geol. Surv.)

TOPOGRAPHIC FEATURES RELATED TO STRUCTURE

The present topography of Long Island can not be fully understood without some knowledge of the substructure, Fig. 198. Cretaceous and Tertiary sands of great thickness occur up to heights of several hundred feet above sea level; their outcrops are exposed principally along the north shore, where the long, deep, and narrow fiords or reëntrants reveal good sections of the white and red sands and white clays of the Cretaceous formations. In the Half Hollow and Mannetto hills and distinctly beyond the limit of the ancient ice sheet preglacial sections also are exposed, and the strata (Tertiary) consist of fine fluffy sands without glacial material of any sort. From such exposures of preglacial material above sea level it follows that an island would now exist even if the glacial material were removed; and in fact such an island did exist before the glacial period, but it was an island of far gentler topography and much more regular outline.

Upon a base-leveled and down-warped rock floor Cretaceous and Tertiary materials were laid down and afterward eroded as the result of uplift of the sea floor. The erosion was at first normal and resulted in the formation of an inner lowland where now Long Island Sound occurs. Following this there were a number of emergences and submergences of complex character, during which the drainage of the inner lowland was first developed to the west and later, through the tilting of the land, to the east.

The essential features of the present topography were developed after the Lafayette submergence. The erosion of the inner lowland was continued to the point where a well-developed cuesta was formed, and it is to the further accumulation of glacial material upon the summit of this cuesta that Long Island owes its present marked contrast between rugged moraine and abrupt high northern shores on the one hand and smooth southern plain with low, reedy, flat southern shores on the other. The scouring action of the ice sheet further deepened the inner lowland, and with the final disappearance of the ice from the region a slight sinking of the land brought out even more strongly the features owing to depression. At a higher elevation the inner lowland of Long Island would have similar relations to the cuesta and the old-land as the inner lowland of New Jersey now has to the cuesta of the New Jersey coastal plain on the east and the old-land on the west.

SOILS AND VEGETATION

SOIL TYPES

A soil map of Long Island, Fig. 199, shows four broadly defined types of soils: (1) stony loams and gravels which occupy the terminal moraines and the narrow plateau between the northernmost moraine and the north shore, (2) coarse sandy loams that constitute the greater part of the outwash plain, (3) fine sandy loams which form the outer fringe of the outwash plain and those portions of it that are adjacent to the old drainage ways, and (4) clay loams that form a transition type between the upland and the salt marsh and the beach sands. While the clay loams have greater natural fertility than the sandy loams they are often found on lands too rough for cultivation, and the great market gardens of the island are found on the outwash principally, where many of the conditions of cultivation are ideal. Agriculture has become so highly specialized in the western part of the island on account of proximity to New York City that the natural fertility of the soil is a far smaller factor than position with reference to the market.

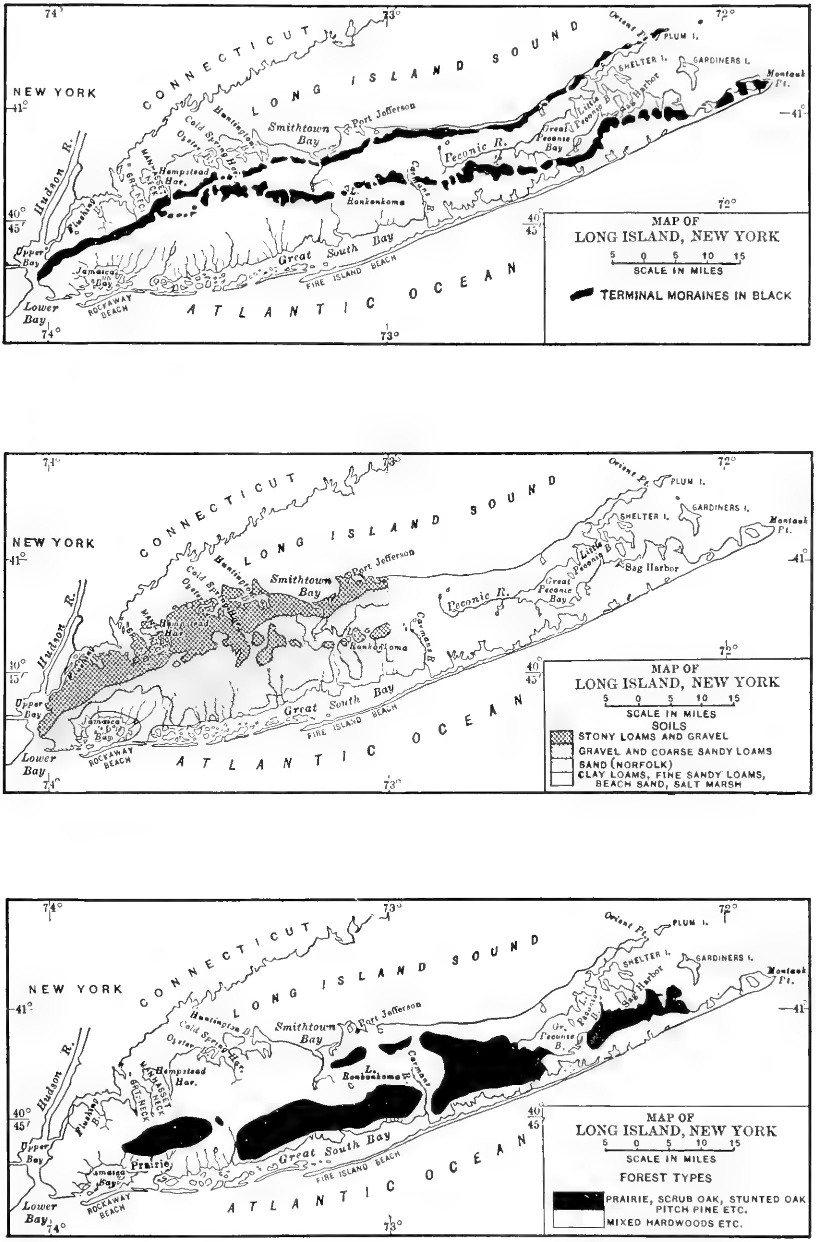

Fig. 199. — Terminal moraines, soils, and vegetation of Long Island.

Fig. 200. — Characteristic growth of pitch pine (background) and scrub oak (foreground) on the outwash plains of eastern Long Island.

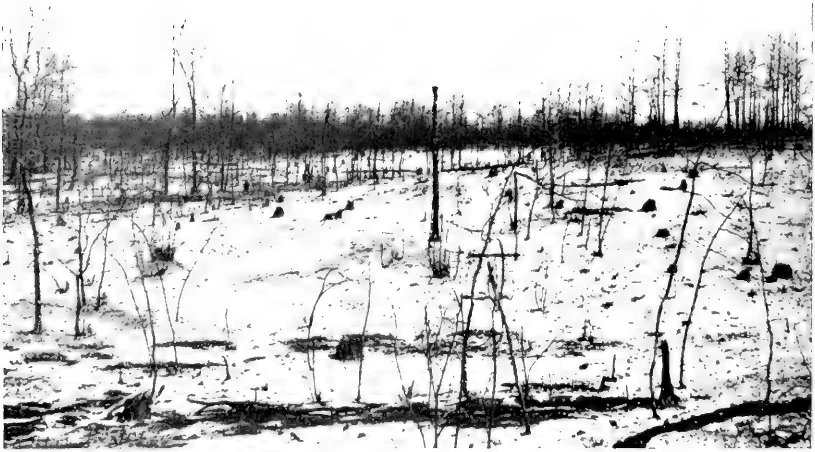

Fig. 201. — The effects of repeated fires on soil and vegetation, Long Island. The raw soil with the humus almost entirely burnt out has the appearance of snow in the photograph.

Fig. 202.—Typical growth of hardwood on the clayey portions of the Harbor Hill moraine, Long Island.

Fig. 203.—Scattered growth of pitch pine and scrub oak on the sandy portion of the Ronkonkama moraine south of Riverhead, Long Island.

NATURAL VEGETATION

In the disposition of the natural vegetation we have a far truer index of soil fertility and water-supply conditions than in the artificial disposition of farms. On the poor, dry, sandy, porous soil of the outwash plains the characteristic growth is pitch pine and scrub oak (*Quercus nana* and *Quercus prinoides*), as shown on the accompanying map, Fig. 200. The natural prairie for which Long Island is famous is also located on the southern outwash plain in the vicinity of Hempstead and Garden City. It bears a growth of prairie grass and has never been covered with forests. In Dutch colonial days it was a famous pasture ground for sheep, horses, and cattle. On the better soils of the outwash plains a better growth of pitch pine is found, and even a small stand of white pine has been reported southeast of Sag Harbor. Where a slight admixture of clay or loam appears, as in a number of scattered localities, a few species of hardwoods grow with pine and oak.

Upon the moister and more clayey moraines excellent growths of hardwoods occur, Fig. 202. Chestnut, oak, elm, beech, and locust constitute the principal types. In a few localities, as several miles southwest of Port Jefferson, the moraine and accompanying outwash are occupied by oak, but it is a stunted growth and reflects the infertile character of the Norfolk sand on which it grows, the distribution of the stunted species corresponding almost precisely with that of the Norfolk sand. The sandy phase of the Ronkonkama moraine south of Riverhead is occupied by pitch pine, which occurs up to the summit of the moraine, Fig. 203. A similar exception on the outwash is the occurrence of hardwoods along the southern shore, where the nearness of the water table to the surface has resulted in hardwood growths and the exclusion of pitch pine and scrub oak.

New Jersey-Maryland Section

The coasts of New Jersey, Delaware, and Maryland are great peninsulas formed by the drowning of the major valleys, and here the lesser waterways discharge through reedy swamps or shoal inlets into landlocked bays. In Delaware and Chesapeake Bays these secondary reentrants are fronted by small banks and bars similar to those that fringe the outer shore except where low cliffs have been formed at the ends of finger-like extensions of land between bays. Formerly the whole section of the coast between Cape Hatteras and New Jersey stood at a higher level and was faintly sculptured by the draining streams, but later depression has submerged the lower ends of the valleys, where bays now exist, and the bays still preserve the characteristic dendritic plan of the Coastal-Plain drainage. While the submergence affects a large extent of the Coastal Plain the actual amount of depression has been astonishingly slight. The waters of Chesapeake Bay are so shallow that it is sometimes more miles to the shore from a given point in the bay than it is feet to the bottom of the bay. The depth of the water is seldom more than 18 feet and averages only 10 feet. Twenty-five feet of elevation would cause it to become a low coastal terrace.[1]

NORTHERN PORTION

In the northern portion (New Jersey) of this section of the Coastal Plain there are extensive flats both along the coast and in the interior, but these range in elevation from about 40 feet on the coast to 130 and 150 feet farther inland, and 200 feet in the highest part of the Coastal Plain. The tidal marsh of New Jersey lies principally between the beach of the Atlantic coast and the mainland; but there is also a tidal marsh bordering Delaware Bay which is not fronted by a beach. The width of the marsh varies greatly from place to place and is from less than a mile in its narrowest portion to 5 or 6 miles between Great Bay and Atlantic City. It has its greatest development at the mouths of the larger streams, and along Delaware Bay attains a width of 5 miles. The sand reefs owe their height chiefly to dunes. During times of storm the sandy barrier reefs are piled up above normal water level and on becoming dry are blown into hills and ridges by the wind. As in the Maryland section, the shallow lagoon between the beach and the mainland is gradually being filled up with wind-blown material, vegetation, and sediments. The most striking feature of the Coastal Plain of New Jersey is the line of

Fig. 204. — Sand reef, salt marsh, and coastal plain upland, coast of New Jersey.

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[1] W J McGee, The Geology of the Head of Chesapeake Bay, 7th Ann. Rept. U. S. Geol. Surv., 1885–1886, p. 552.

elevations extending in a northeast-southwest direction from the Navesink highlands on the northeast to Mount Holly on the southwest, elevations which include heights that approach 400 feet.[1] These are due, curiously enough, to widely contrasted conditions. (1) The clays, sands, marls, etc., do not have great inequalities in hardness, but locally the material is cemented into more or less solid rock. This occurrence is most common at the junction of beds of different texture, and in some cases has reached the point where the rock is quarried. Many of the most prominent elevations are capped by such cemented beds of gravel, sand, or marl, and owe their prominence to a protecting cap. (2) Many other prominences in the highest belt of the district by contrast owe their height to the extremely loose and porous condition of the material. The rainfall sinks into the material as into a sponge and does not run over the surface and erode it; consequently the hills formed on the outcrop of the most porous beds are at elevations comparable to the hills formed upon the hardest material. Few elevations of note in the highest part of the New Jersey Coastal Plain are without such a protecting cap of rock or loose gravel.[2]

The strata on the inner edge of this part of the Coastal Plain have been stripped from the crystalline rocks beneath in such manner that a valley lowland has been developed parallel to the highlands that cross the state diagonally. The lowland extends from Raritan Bay to Trenton, and marks the outcrop of a series of less resistant formations whose removal goes forward more rapidly than that of the crystallines and hard sedimentaries on the west or the higher coastal plain formations on the east.

SOUTHERN PORTION

The outer edge of the coastal plain of Maryland is bordered by long narrow sand reefs caused by shore drift and wave action. Behind them are shallow lagoons of variable width ranging from a fraction of a mile to 4 or 5 miles in Maryland. The eastern portion of the lagoon is formed by shallow marshes along the western edge of the sand reef; the western shore is formed by the low, half-submerged topography of the mainland, somewhat modified by salt marshes. The floors of the lagoons are very shallow and flat and are composed (*a*) of sand blown over from the beach dunes, (*b*) of mud deposited by the rivers and tides, and (*c*) of matted roots of marine vegetation.[3]

The surface of the coastal plain of eastern Maryland is broad and

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[1] R. D. Salisbury, The Physical Geography of New Jersey, Final Rept. of the Geol. Surv. of New Jersey, vol. 4, 1895, p. 54.

[2] Idem, p. 64.

[3] C. Abbe, Jr., A General Report on the Physiography of Maryland, Including the Development of the Piedmont Plateau, Md. Weather Service, vol. 1, pt. 2, p. 82.

even and resembles a smooth or gently undulating sea floor. Many portions are characterized by long interstream stretches of plane surface of considerable breadth.[1] The inequalities of the outer border of the Maryland plain were produced during a submergence which took place in very recent geologic time (Pleistocene); the plain has been so recently raised above the sea and to so small a height that time enough has not elapsed for the streams of gentle gradients to drain the swamps and lakes located upon them. It is characteristic of the swamps that they are disposed chiefly along the main divides, as though dissection had not yet progressed to the headward sections of the streams, Fig. 205. The surface has a gentle seaward slope upon which has been developed a characteristic drainage system; the pattern is irregularly branching or dendritic, with the small streams commonly making almost a right angle with the general trend of the larger streams at the junction. Small lakes and swamps dot the surface and are due to inequalities on the sea floor produced by wave and current action.

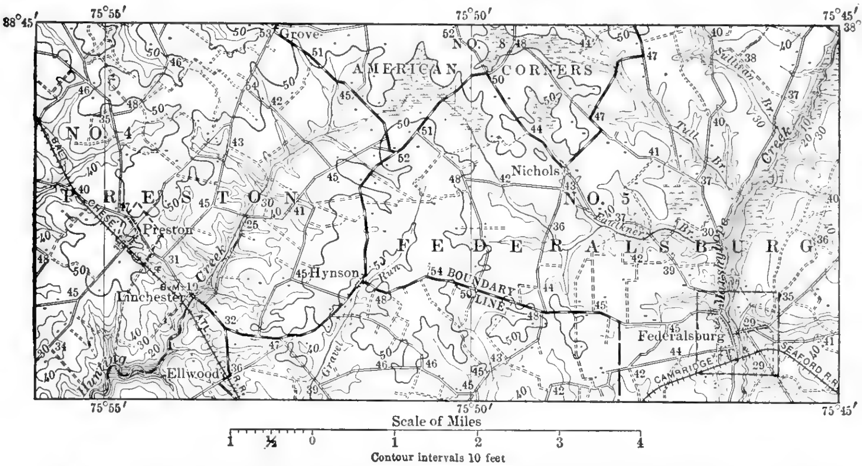

Fig. 205. — Swampy divides in eastern Maryland between the Chesapeake and the Atlantic. The coastal plain is here so young and so little dissected that many of the original irregularities have not yet been destroyed. (Hurlock quadrangle, U. S. Geol. Surv.)

Except in their expanded lower courses the streams are small and unnavigable and are characterized by broad, shallow valleys with very gentle side slopes and smooth contours. In the interstream areas of the southern counties of Maryland one may travel for miles and never cross a well-marked valley. Where forests grow they have still further re-

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[1] C. Abbe, Jr., A General Report on the Physiography of Maryland, Including the Development of the Piedmont Plateau, Md. Weather Service, vol. 1, pt. 2, p. 84.

tarded the run-off, so that wet swamps occur in the original inequalities of the surface. Signs of stream sculpture are rare; the surface seems to preserve the outlines originally imposed by waves and currents. In contrast to these streams are the tidal estuaries and the slow meandering creeks that cross the salt marshes and have low though steep banks deeply fringed with reeds.

Virginia-North Carolina Section

The physiography of the third district of the Coastal Plain is characterized by a gentle seaward slope, smooth and monotonous, interrupted by long tidal inlets. The rivers expand towards their mouths in reedy marshes or in broad shallow estuaries barred from the open ocean by wave-built reefs that stretch almost continuously from Cape Lookout to Cape Henry. The uplands and lowlands of this district have so little difference in altitude that they could be scarcely distinguished from each other if the lowlands were not almost at tide level. The lowlands are the bay bottoms or the tidal marshes or the broad savannas which the highest tides barely fail to reach; the uplands rise in irregular scarps from a few feet to 15 feet in height to form stretches

Fig. 206. — Cypress trees of the Dismal Swamp. (Norfolk Folio, U. S. Geol. Surv.)

of excessively flat plain. Farther from the coast there is again a zone of undulating surface; the depressions containing the waterways between undulations are less conspicuous than in New Jersey and lower Maryland. Toward the fall line the surface is characterized by broad terraced plains with irregular margins, and smooth monotonous interiors whose borders are diversified by labyrinthine ravines.

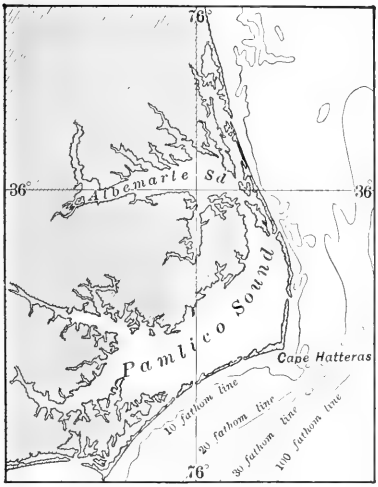

Fig. 207. — Albemarle and Pamlico Sounds and bordering sand reefs, east coast of North Carolina.

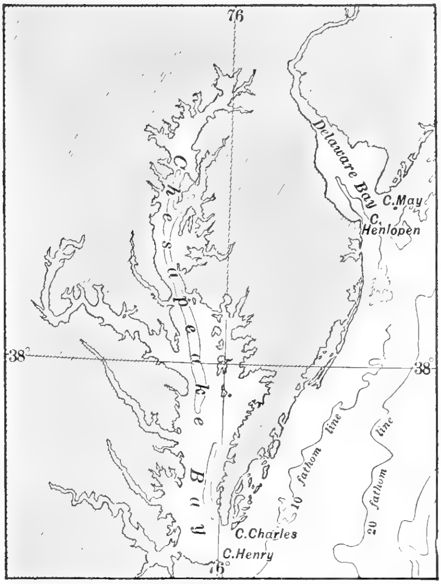

Fig. 208. — Chesapeake Bay and Delaware Bay and the principal bays tributary to them.

South Carolina-Georgia Section

That portion of the Coastal Plain between the Neuse River of North Carolina and the Suwanee of southern Georgia and Florida is a land of gentle slopes which incline from the fall line to the coast. It is a pine-clad, sandy plain with dendritic drainage. The seaward margin of this section is a wave- and current-built sand reef at the north and a line of sea islands at the south, that merge at the extreme south into long low islands locally known as "keys."

Along the Altamaha River the overflowed river bottoms have been reclaimed to some extent by diking and ditching and are cultivated. Their position is excellent for rice culture, since irrigation water is easily applied. Agricultural operations have been confined principally to the diked river lands since the early part of the nineteenth century, and relatively small areas have been cropped on the uplands since the early abandonment of indigo growing and the decline and cessation of cotton production.[1] Near Savannah these diked rice fields have been badly neglected in recent years, but the fertility of the tide-marsh soils is beyond question, and were drainage reëstablished they would constitute a valuable addition to the farming lands of the coast.[2]

In portions of eastern North Carolina the seaward margin of the Coastal Plain bears drainage ways which are merely natural depressions marked by a quick growth of water-loving shrubbery and in some areas no well-developed drainage courses occur. These are the savannas, or open flat lands with badly drained soils that support a poor growth of pine and an undergrowth of berry bushes and bay and pitcher plants.[3] Inland from the low coastal zone is the broad belt of pine-clad sands which more than anything else characterizes the section. It is a vast plain with slight undulations, the depressions slightly accented by streams occurring in the form of old terraced scarps much dissected owing chiefly to the friable character of the material, and now having rounded bottoms and softly contoured sides. With increasing distance from the sea the land stands higher and higher, the streams are more active, the valleys deeper, and the surface more undulating, often rising into rounded hills. Again, as in the north, the hills may be isolated and flanked by terraces or may constitute parts of broad interstream areas, and sometimes the terraces extend a short distance into the Piedmont Plateau. The common boundary of plateau and plain is ill-defined as to topography but rather sharply marked as to drainage and soil characters.

ALABAMA-MISSISSIPPI SECTION

The great section of the Coastal Plain between the Suwanee and the Mississippi is topographically diversified by two pronounced scarps; the first one is the steep river bluffs along the eastern border of the Mississippi flood plain, bluffs due to stream planation; the second is the cuesta of the Alabama-Mississippi section of the plain. The cuesta begins on the river bluffs overlooking the Mississippi in extreme western Kentucky, crosses the Tennessee-Mississippi boundary 50 miles east of the river bluffs, curves southeastward to within 50 miles of the head of Mobile Bay and dies out eastward. This feature represents the inward-facing slope of the dissected Coastal Plain of Alabama and Mississippi. It

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[1] Milton Whitney, Soils in the Vicinity of Brunswick, Georgia, Cir. U. S. Bur. Soils No. 20, p. 3.

[2] Milton Whitney, Soils in the Vicinity of Savannah, Georgia, Cir. U. S. Bur. Soils No. 19, p. 2.

[3] Milton Whitney, Soils of Pender County, North Carolina, Cir. U. S. Bur. Soils No. 20, pp. 1–2.

stands 600 or 700 feet above sea level. The outer lowland averages 200 feet lower, while the inner lowland is a broad trough often 100 and sometimes 200 feet lower than the border of the cuesta. The inner lowland is from 20 to 25 miles on the average and extends eastward a short distance beyond Montgomery. The densest population of the state of Alabama outside the cities is found in the inner lowland where the Selma chalk has weathered into a tract known as the "black belt" because of its prevailingly black soils. These are highly calcareous residual clays and have a black color where they contain much organic matter. They are among the most fertile lands in the South.

In the eastern counties of Alabama a limestone (Clayton) of the coastal-plain series, 200 feet or more thick, is extensively developed into caves and lime sinks with which are associated big springs. This formation is marked by the occurrence of strong limy black soils similar to the black prairie soils of the Selma chalk, but the topography is so broken and deeply eroded as to be in sharp contrast to the smooth-floored Selma lowland.

Late in the Tertiary period a blanket formation was deposited upon the Coastal Plain. This is known as the Lafayette formation and is a mantle of reddish and light-colored loams and sands with frequent beds of water-worn pebbles in the lower parts. It is from 25 to 30 feet thick on the average and formerly covered the entire Coastal Plain, resting unconformably on the older formations. In general it is sympathetic to the topography, though in many large areas it has been in great part removed by erosion. Because of its widespread development it constitutes about four-fifths of the cultivated soil of the entire Coastal Plain of Alabama, and is the chief factor in affecting the character of the soils.[1]

The Cretaceous and Tertiary beds of the Coastal Plain of Alabama have an average dip toward the Mississippi and the Gulf of Mexico of 30 to 40 feet a mile. The surface of the Coastal Plain descends in the same direction at a much less rapid rate, about a foot per mile, so that in going toward the south from the Appalachian Plateaus one passes in succession over the beveled edges of these deposits from the oldest to the newest. Each formation with few exceptions occupies the surface in a belt proportional in width to its thickness and running nearly east and west.

The sandy formations of the outer lowland are commonly characterized by short steep slopes and frequent ravines, the shales by long

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[1] E. A. Smith, The Underground Water Resources of Alabama, Geol. Surv. of Alabama, 1907, p. 12.

slopes and few ravines, and the calcareous formations by smooth-contoured ill-drained valleys known as "black prairies."

The inland margin of this district is even less definite than the neighboring region to the east. In western Georgia and eastern Alabama the rivers cascade over hard rocks to form sluggish stretches in the lowlands, but commonly an arm of sedimentary material extends miles into the adjacent plateau in an ancient estuary and the river transition is seldom sharp. In central Alabama, where the Coastal Plain overlaps the southern end of the Appalachians, long fingers of lowlands stretch into the valleys between the ridges. In northwestern Alabama the line of demarcation between the Cumberland Plateau and the Coastal Plain is so poorly defined that it can not be drawn except as a zone from 10 to 20 miles wide. Still farther north the boundary between the Coastal Plain and the older formations coincides approximately with the course of the Tennessee River, though here and there occur outcrops of the older harder rock west of the river and outcrops of softer coastal-plain deposits east of the river.

The trunk streams of the Alabama section of the Coastal Plain flow across the Cretaceous and Tertiary strata, while the tributaries flow in general parallel to the strike of the outcrops. The infacing or northward-facing slopes of the hills are precipitous, while the southward-facing slopes are gentle. The tributary streams generally flow at the base of the steep infacing slopes. The major streams of the region thus run transversely to the cuesta and preserve their ancient consequent courses gained after the last emergence of the coastal lowlands from the sea. The tributary valleys on the other hand respond to a large degree to the detailed geologic structure and have excavated abnormally large subsequent valleys along belts of weaker strata. They thus join the master streams almost at right angles, and their direction of flow conforms to a notable degree to the outcrop of the strata upon which they have been developed.

The outer edge of the Coastal Plain of Alabama and Mississippi is rather sharply defined by a line of more or less dissected bluffs and hence appears as an upland when viewed from the south. The undissected interfluves are flat everywhere except for shallow depressions (of uncertain origin) sometimes containing ponds and bordered by a shrubby growth of gums. The border depressions are without standing water and are usually grassy savannas or pine meadows without undergrowth.[1]

The southern border of this section of the Coastal Plain is in part not a coastal plain but a flood plain under the dominance of the Mississippi River. It is commonly skirted by keys separated from the mainland by narrow sounds, but the keys are narrow and low and the sounds commonly broad, shallow, and irregular in outline, and pass here

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[1] E. A. Smith, The Underground Water Resources of Alabama, Geol. Surv. of Alabama, 1907, pp. 250–251.

and there into grass-grown marshes, landlocked bays, and tidal flats. The sand reefs commonly lie 10, 15, or 20 miles off shore. The bays and marshes are partly bounded on the Gulf side by low sand banks, while between the bays friable sands and loams stand in vertical cliffs 5, 10, or 15 feet high. Instead of the high grounds and the low grounds of the Carolinas the entire surface of this portion of the alluvial valley of the Mississippi is low ground. The savannas are the most prominent features — broad tracts bounded by low scarps sloping steeply down and overlooking swamps, bays, and sounds. About the margins of the savannas are a certain amount of shrubbery and forests of pine or magnolia, but their interiors are often broad and imperfectly drained tracts of flat grass-land. The swamps are covered with reeds, sedges, and coarse swamp grass on their coastal sides, with live-oak groves on the coast rivers, and with canes and tangled shrubbery toward the interior.[1]

The border of the higher portion of the plain on the inner margin of the coastal swamps is often a confused belt of knobs, crests, divides, spurs, peaks, and buttresses smoothly rounded, divided by flat-bottomed valleys with innumerable ramifications. On the floors of the valleys streams wander through broad plains of sandy alluvium. The summits of the hills and knobs reach elevations of 200 feet above tide and the valley flats to half that height. The upper plain represents the older surface, the lower the younger, and it is evident that after the excavation of the valleys and gorges depression ensued and the ravines were clogged with débris washed down from the hills, the final episode being an uplift of the land sufficient to drain but not deeply to erode the savannas or grass lands of the valley flats.

The 600-mile western border of this district is a line of bluffs of complex character which marks the border of a broad terrace, the bluffs consisting of a series of truncated spurs separated by ravines and broader valleys. At Memphis the bluffs are rounded and about 100 feet in height. At Yazoo and at Vicksburg they are 200 feet above the Mississippi flood plain. The slope of the Coastal Plain of Tennessee is eastward from the Mississippi bluffs, so that the highest portion of the Coastal Plain is immediately on the bluff, a physical feature which in the early settlement of the region determined the position of the roads, for it was the highest and driest portion of the country. The outer border of the district, the edge of the Mississippi flood plain, undulates very gently in long low sweeps sculptured into a labyrinth of rounded hills

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[1] For a description of the shell hammocks and the coastal marshes, the character of their soil, etc., along the coast of Mississippi and Alabama, see E. W. Hilgard, Agriculture and Geology of Mississippi, 1860, p. 373 ff.

and long low valleys with a local relief not exceeding 200 feet and sometimes as low as 50 feet.

One of the most important physiographic conditions of this section of the Coastal Plain is related to the abandoning of the old fields and the removal of the forest cover. It appears that in a state of nature the drainage was accomplished without unduly rapid dissection of the fertile surface soil — a yellow loam from 3 to 7 feet thick. But when the oak forests were removed in the settlement of the country and the plantations abandoned during the Civil War, the hills, no longer protected by a forest foliage, and the soil, no longer bound by the forest roots, were vigorously attacked by the streams and gullied and channeled in all directions. Year by year the formerly fertile fields were invaded by gullies of ever-increasing width, the soil of long geologic growth disappeared down the stream-ways, and the land was gashed and harmed beyond belief.

> "The washing away of the surface soil . . . diminished the production of the higher lands, which were then commonly 'turned out' and left without cultivation or care of any kind. The crusted surface shed the rain water into the old furrows, and the latter were quickly deepened and widened into gullies — 'red washes.' . . ."
>
> "As the evil progressed, large areas of uplands were denuded completely of their loam or culture stratum, leaving nothing but bare, arid sand, wholly useless for cultivation; while the valleys were little better, the native vegetation having been destroyed and only hardy weeds finding nourishment on the sandy surface.
>
> "In this manner whole sections, and in some portions of the state [Mississippi] whole townships of the best class of uplands have been transformed into sandy wastes, hardly reclaimable by any ordinary means, and wholly changing the industrial conditions of entire counties, whose county seats even in some instances had to be changed, the old town and site having, by the same destructive agencies, literally 'gone down hill.'"[1]

Specific names have been given to the erosional features of this district: a "break" is the head of a small retrogressive ravine; a "gulf" is a large break with precipitous walls of great depth and breadth, commonly being one hundred or one hundred and fifty feet deep; a "gut" is merely a road-cut deepened by storm wash and the effects of passing travel.

MISSISSIPPI VALLEY SECTION

The sixth division of the coastal lowland is the great flood plain, or delta and flood plain combined, of the lower Mississippi. It is bounded on the east by a continuous line of bluffs and on the west by a conspicuous ridge known as Crowley's Ridge (north) and by an alternating line of irregular bluffs and valleys (south). This alluvial district is one of the most extensive of the really low areas of the continent, lying practically at base level. In the southern part of the district the surface approximates tide level and indeed the outer border consists of permanent tidal marshes. The surface is very ill-drained, and bayous, lakes, and abandoned channels constitute an irregular maze of water upon a

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[1] E. W. Hilgard, Soils, 1906, pp. 218–219.

plain with scarcely perceptible slope. Between the waterways are ridges of slightly higher land, some of which are the natural levees of channels long since abandoned. In the western part of the district the inter-stream areas lie so high that they are invaded only by the highest floods, but the surface material is fine and compact and the surface itself ill-drained; consequently the trees are either drowned by the floods or withered by the sun in the droughts and the surface is without a forest cover. It supports a patchy growth of coarse grass, the patches being known as the "black prairies" of southern Arkansas and Louisiana.

In the northern portion of the lower alluvial valley of the Mississippi extensive land tracts were converted into lakes, flowing rivers transformed into stagnant bayous with uplifted areas between, and some stream courses actually diverted during the series of earthquakes between 1811–1813. This region includes the "sunk country" of Missouri and Arkansas and the "Reelfoot Lake district" of Kentucky and Tennessee, and forms the uplifted land of Lake County, Tennessee, one of the few sections of the Mississippi flood plain that escape the inundations of the highest floods.

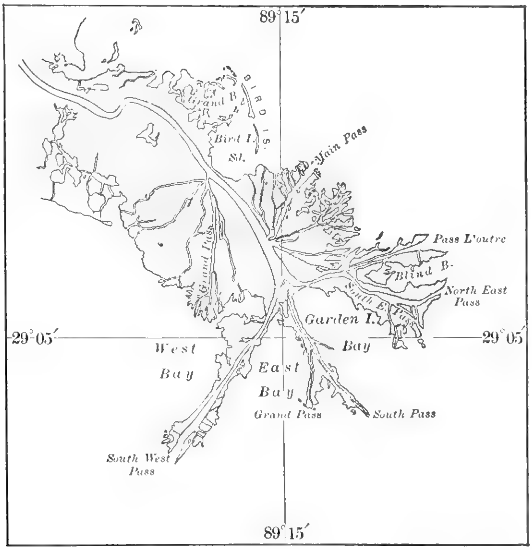

Fig. 209. — Finger-like extensions of the Mississippi delta. The entire area shown as land is swamp-land.

Between Lake Borgne and Mobile Bay the Gulf is advancing upon the land so rapidly that the coastal rivers are nearly submerged and occur as narrow mud banks like the Chandeleur Islands, or as completely submerged bars and shoals that parallel the coast. A further effect of submergence is shown in the excessive breadth of the lagoons.

On either side of the immediate delta of the Mississippi the alluvium deposited by the great river has been modified by waves and currents into bars and reefs and the shore has a smoothly trimmed effect in contrast to the finger-like extensions of the actively growing portion of the delta. In the latter case the rate of deposition exceeds the rate of current wear and the land is being built seaward.[1]

Meander development and sidewise bodily movement of the river as a whole have opened up a river lowland so flat as to make the coastal plains appear as uplands when viewed from the river. This lowland, the lower alluvial valley of the Mississippi, is from 30 to 60 miles wide and about 600 miles long. Over its flat surface the great Mississippi meanders in an extremely indirect course. Receiving the contributions of a vast network of tributaries themselves major streams, it is little wonder that the river is subject to numerous floods transmitted from the tributaries. Formerly they inundated a vast expanse of lowlands and were of yearly occurrence; now a system of restraining dikes or levees and expensive revetments partially restrain the great river, and floods are in a measure under control. At present the levee system comprises about 1500 miles of structure and is about 71% completed. The number of square miles of overflowed land in 1903 was half the mileage for 1897. In 1882 there were 284 crevasses recorded; in 1903 there were only 9 of importance.[2]

The extent of alluvial bottom land that escapes inundation is extremely limited. The higher tracts are confined chiefly to the river border, hence this is where the principal plantations are located. From the low natural levees the land slopes gradually away on either side to swampy back country covered with heavy forests of cypress and gum. The first problem in the utilization of these back swamps is drainage, and until the present canal system is perfected and extended but little development of the forest can be expected. The possibilities are suggested by the large shipments of logs, staves, headings, etc., from the Yazoo basin, where there was practically no lumber industry

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[1] The Mississippi is estimated to carry to the Gulf of Mexico enough land waste to cover a square mile 268 feet deep, an amount of material that would require a train of 44 loaded cars arriving at the Gulf every minute, the specific gravity of the sediment being taken at 2.5 and the capacity of a railroad car being 50,000 pounds. (J. E. Carman, The Mississippi Valley between Savanna and Davenport, Bull. Ill. State Geol. Surv. No. 13, 1909, p. 23.)

[2] R. M. Brown, The Protection of the Alluvial Basin of the Mississippi, Pop. Sci. Mo., Sept., 1906, pp. 248–256. See also W. S. Tower, The Mississippi River Problem, Bull. Geog. Soc. Phil., vol. 6, 1908, pp. 83–100.

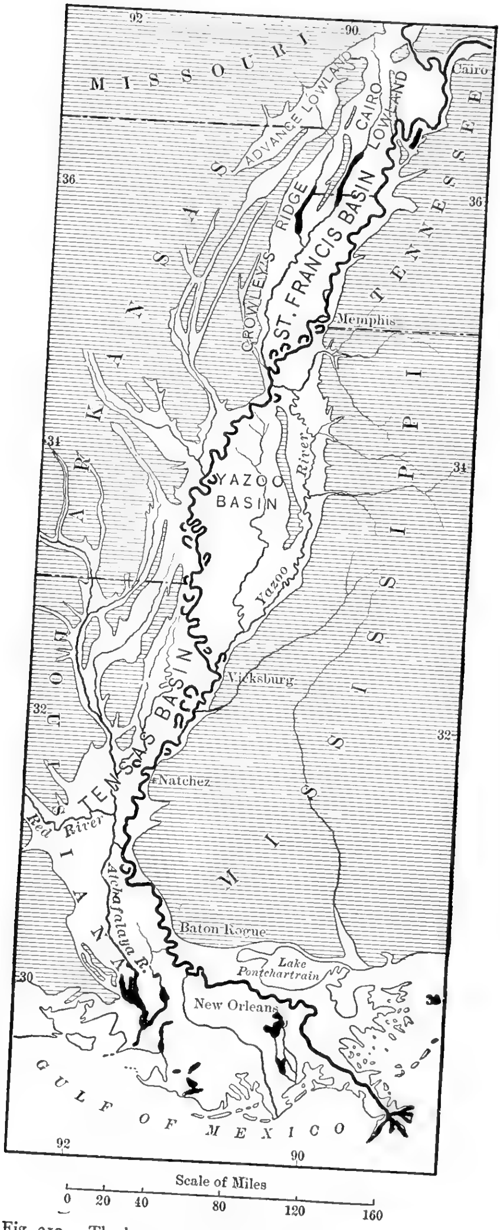

Fig. 210.—The lower alluvial valley of the Mississippi.

until the present levee system was constructed, the floods reduced, and swamp drainage begun.

At the northern end of the lower alluvial valley of the Mississippi are two main belts of lowland separated by a long ridge of varying width. The two lowlands are joined across the ridge by a broad belt of lowland and by several narrow stream valleys. The lowlands are called the Advance (west) and the Cairo (east) lowlands, Fig. 210. The Advance lowland is essentially a unit, while the Cairo lowland is divided into two subordinate belts by a long ridge known as the Sikeston Ridge. The Advance lowland is from 2 to 8 miles wide and is bordered in many places by relatively steep bluffs. The surface deposits of the lowland are sand and clay. A few long, low, flat-topped, sandy "islands" lie upon it at various places and furnish the only bits of land favorable for agriculture.

The Cairo lowland on the east is nearly level and is bordered by prominent bluffs. The surface deposits consist of sand and silt, and on both this and the Advance lowland are numerous sloughs containing varying amounts of water. The small streams draining both lowlands have banks so low that they overflow during ordinary floods and the land is often submerged. The ridge between the two main lowland belts varies in height, form, and material, and is broken into a number of isolated sections. The main ridge extends southwestward, and to it the general name of Crowley's Ridge has been given. At its broadest part Crowley's Ridge is about 20 miles wide. Its upper surface is generally in the form of a rolling plain sloping gently westward. All the creeks flowing upon it have broad flood plains, with high land only in the form of narrow ridges on the main and secondary divides. On the main divide the valleys are deep and narrow and the surface maturely dissected. The eastern side of Crowley's Ridge is a definite and steep bluff throughout; the western edge is not so definite, only a part of its course being marked by bluffs.

The western lowland (Advance) was once occupied by the Mississippi River. The eastern lowland (Cairo), once occupied by the Ohio River, is now occupied by the Mississippi. The change of course in the Mississippi was brought about through stream capture by tributaries of the Ohio working westward into Crowley's Ridge. A second capture of the Mississippi took place at a later time and brought about a further adjustment. The length of the valley abandoned by the first change of the Mississippi was more than 200 miles; the second change effected an abandonment of about 50 miles. The second change took place so recently that the river has not yet had time to clear its channel of rocks, much less to form a flood plain. The first change in the Mississippi brought its point of junction with the Ohio to a short distance south of New Madrid, Missouri; the second change brought it into its present relations with that river.[1]

[1] C. F. Marbut, The Evolution of the Northern Part of the Lowlands of Southeastern Missouri, Univ. Mo. Studies, vol. 1, 1902.

LOUISIANA-TEXAS SECTION

The next section of the Coastal Plain extends from the Mississippi flood plain to the Rio Grande; the coastal margin of this section consists of wave-built ridges or reefs of exceptional continuity, Padre Island, south of Corpus Christi Pass, being 100 miles long. The lagoons back of these reefs are equally continuous; light-draft vessels may sail from the mouth of the Rio Grande through the Laguna de la Madre and through shorter sounds to Matagorda, 250 miles away. The depression of the coast is so rapid that the sand reefs are drowned and the lagoons are increasing in breadth. The combination of lagoons, fringing reefs, drowned river courses, complex estuaries, and clean sea cliffs is an expression of a sea advancing on a low-lying land, and the width of the belt in which these features are developed is in a general way proportional to the rapidity of depression.

The border of the plain is made up of alternating savannas and swamps or shoal bays. The low grounds are abandoned to reeds and sedges. The savannas are so low as to be clothed only with coarse grass and dotted with scrub pine or palmetto. Broad, low, natural levees like those of the Mississippi occur throughout the savannas, and these are commonly wooded, while the interstream tracts are prairie lands. Narrow belts of forest thus occur along the waterways except where the surface has been cleared for agriculture. Along Red River are well-wooded tracts with oak and hickory on the uplands, poplar and liquid amber on the lowlands, cypress and tupelo in the swamps.

Fig. 211. — Coastal features of Texas, long, simple sand reefs enclosing narrow lagoons.

In the coastal plain of Louisiana the rivers are steep and sluggish, such as Vermilion Bayou, Calcasieu River, etc. Each of these streams is narrow, deep, and clear, has scarcely any current, expands into a broad shallow lake, and enters the Gulf through a shallow bay. All of them have features characteristic of drowned streams. In southeastern Texas the streams of the Coastal Plain are similar to those of Louisiana; but west of the Nueces the coast drainage fails almost absolutely, the whole stretch of the coast to the Rio Grande containing only two small creeks. Though the greater part of the Louisiana-Texas section of the Coastal Plain is crossed by large rivers, a considerable part of the surface is poorly drained. Water stands in a multitude of small lakes or ponds throughout the year and there are large tracts covered with water during the wet season.

The innermost belt of country belonging to the Coastal Plain rises rather rapidly from the adjacent seaward belt and has a more broken surface with numerous, small, rounded hills. The general elevation of this belt does not exceed 175 or 200 feet above sea level. The surface is in general timbered.[1]

SOILS AND VEGETATION

In Texas the Coastal Plain consists of a western sandy subdivision and an eastern clayey subdivision; the line of separation is the Guadalupe River in Victoria County. Soil distinctions while of great importance to vegetation in the interior of Texas are of little importance on the low Coastal Plain, where the chief consideration in tree growth is the water supply. The outer margin of the eastern and clayey subdivision is swampy and flat and but little above sea level. Patches of sandy land occur on the borders of the clay area. Forests of pine, oak, and magnolia fringe the northern border of the coastal plain on the higher grounds, various species of gum occur on the benches, and heavy forests of black and red cypress are found on the low river flood plains. The greater part of the Texas section of the Coastal Plain consists of groups of prairies separated by forest tracts.

One of the most interesting forest trees of the low coastal margin is the loblolly pine, which grows on slightly elevated mounds of the Texas lowlands where it forms forest islands. The surrounding prairie is covered with water several months each year and is wet nearly the entire year, so that loblolly pine develops almost undisturbed by fires. The gradual filling in of the prairie by the loblolly groves causes the land to become drier, and strips of young growth bridge the space between groves and finally develop into large bodies of forest. The seeds of the loblolly are scattered partly by the wind in a southeasterly direction if they ripen at the end of September or early October when northwest winds prevail, and partly by the southeastward drainage toward the Gulf during periods of high water. The drying up of the prairie and

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[1] Hayes and Kennedy, Oil Fields of the Texas-Louisiana Gulf Coastal Plain, Bull. U. S. Geol. Surv. No. 212, 1903, pp. 10 ff.

the reclamation of the land is a natural process common to the whole coast of Texas and Louisiana. The swamp vegetation adds by its decay to the surface material and gradually the surface is built upward to the point where shrubs and trees come in. The process is rapid enough to cause marked changes in the distribution of timber in 40 or 50 years, so that the marshes within the loblolly pine forest of eastern Texas, which a few years ago were impassable, are now accessible to man and to cattle.[1]

Southward from San Diego the Coastal Plain is composed of a belt of brown sand probably 25 miles in width. It is a rolling country more or less covered with mesquite and chaparral. Still farther south is a gray sand belt having a width of 50 or 60 miles and, except for a few live oaks, practically without trees. It has been called the Great Texas Desert, and across the face of it stretch two belts of moving sand hills in an east-west direction. Each belt consists of a double row of dunes from a half mile to a mile apart, moving westward under the prevailing easterly winds. Some of them (northern Star County) are from 90 to 100 feet high, but the size of the dunes decreases eastward and near the coast they appear only as white spots lying but slightly above the plain. Some of them are almost circular with a central depression, others are oval, and still others are in the form of great crescents, the typical symmetrical dune shape. The dunes are composed of extremely fine sand of snow-white color, and the lightest wind sets the fine grains in motion. In several instances tall live oaks have been buried so deeply that only the dead tops of the highest branches indicate the fate of the groves invaded by the dunes.[2]

From one to two hundred miles west of the coastal tract the forests disappear or occur chiefly in the form of scraggly growths of blackjack and Chickasaw plum. Still farther west the mesquite is found in low orchard-like groves on the interfluves, with hackberry and acacia along the streams. Eventually these forms give place to the sage and the cactus of the deserts, except where the fertilizing streams have led to reclamation or support a more prosperous native growth.

PHYSIOGRAPHIC DEVELOPMENT

The structure and physiographic history of the Coastal Plain of Louisiana and Arkansas bear such an intimate relation to the major topographic features that a word in regard to them is necessary at this

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[1] R. Zon, Loblolly Pine in Eastern Texas, Bull. Forest Service, U. S. Dept. Agri., No. 64, 1905, pp. 9–10.

[2] Idem, p. 16.

place. In the Arkansas-Louisiana district the relatively soft formations of Cretaceous and Tertiary age which form the Coastal Plain overlie a peneplain developed upon older and greatly deformed strata.

> In Miocene and early Pliocene times erosion was active at a level distinctly lower than that of the old peneplain and resulted ultimately in the formation (late Tertiary) of local base-leveled surfaces, essentially coincident with the Coastal Plain and continuous with an uneroded outer area lifted so slightly above sea level as to suffer no important modification during this erosion period. This Tertiary base-leveling while extensive was not complete, and many remnants of the older and higher surface still project above the common level.

After the partial development of a Tertiary peneplain there came a depression of the entire region of sufficient amount to allow the formation partly by river aggradation, partly by marine deposition, of a great blanket of silts, sands, and gravels (the Lafayette formation), which still occurs widely distributed throughout the region, its materials forming the surface soil to a large extent.[1]

The process of excavation of the material constituting the Coastal Plain has gone on with but one interruption since the deposition of the Lafayette formation. Through either climatic change or crustal deformation or both the streams of the region after cutting out valleys began to aggrade their valley floors, but after the partial filling of the valleys reëxcavation was begun. The result is that the streams are

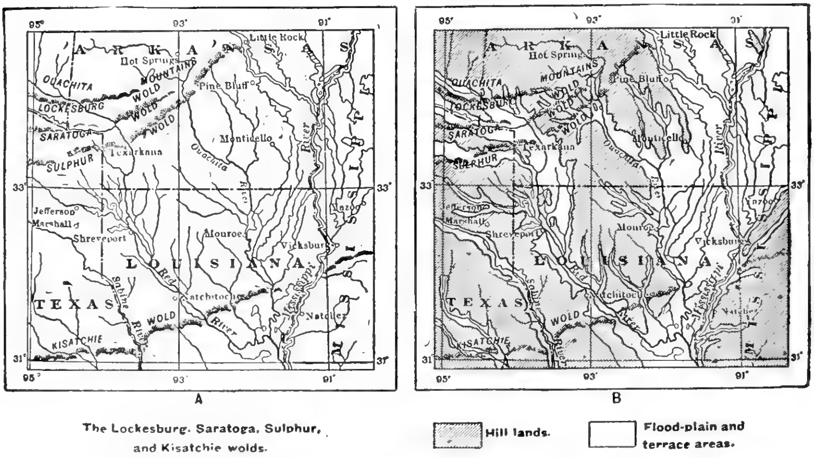

Fig. 212. — Prominent topographic features of the Gulf Coastal Plain in northern Louisiana and southern Arkansas. (Veatch, U. S. Geol. Surv.)

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[1] A. C. Veatch, Geology and Underground Water Resources of Northern Louisiana and Southern Arkansas, Prof. Paper U. S. Geol. Surv. No. 46, 1906, p. 46.

generally intrenched below the level of the upper surface of the alluvium which now occurs in terrace form fringing the borders of the valleys and constituting an intermediate level of bench land of considerable extent between the general surface of the Coastal Plain and the flood plains of the streams.

Besides the terrace and flood-plain areas are extensive areas of upland that are interesting chiefly because of the development of alternating belts of higher and lower lands in the form of cuestas and inner lowlands. The best development of these features is in Arkansas and Louisiana where there are four more or less persistent cuestas that follow the general strike of the formations. The three northerly ones are the Lockesburg, Saratoga, and Sulphur cuestas; the southernmost is distant from the other three and is called the Kisatchie cuesta. It is formed on the outcrop of the hard sandstone formations known as the Catahoula (Oligocene), which have been brought to the surface and exposed by a fault, so that the cuesta is not a typical one but should be regarded rather as a modified fault scarp very similar, however, in its topography to a cuesta formed by ordinary differential erosion, Fig. 213. The Sulphur cuesta is formed on the harder members of the lower Eocene, and the Saratoga and Lockesburg cuestas on the Cretaceous.

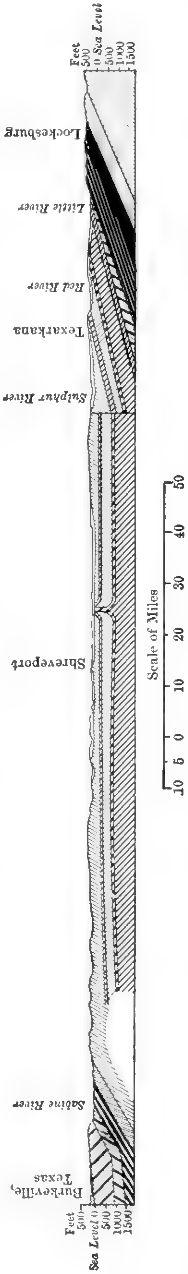

Fig. 213. — Cross section of the Gulf Coastal Plain in Louisiana and southern Arkansas. The formations range in age from Paleozoic and Lower Cretaceous on the right to Tertiary (Oligocene) on the left. Note the structural variations and the topographic complexities to which they give rise. (Veatch, U. S. Geol. Surv.)

SPECIAL FEATURES

MOUNDS

Two important local features merit description at this point, for they constitute notable departures from the normal types of topography and drainage with which we have so far had chiefly to deal. These are (1) the two types of mounds which exist in the district and (2) the lakes at the lower ends of the tributaries of the Red

River. The first type of mound occurs in valleys where erosion has revealed the presence of domes with steep marginal dips attributed to igneous intrusions which did not reach sufficiently far toward the surface to be exposed by erosion. Only the top of the dome has been removed, and the topographic expression is commonly not a mound but a depression rimmed about by harder limestone, from beneath which the softer formations have been removed by erosion.

The second type of mound is not only a structural uplift but also a topographic elevation and has an extremely wide distribution, being well developed on the prairies and pine flats along the coast of Louisiana and Texas, where are found the "pimple prairies" popularly but erroneously associated with the oil deposits. They occur irregularly throughout the Coastal Plain and are best developed along the river terraces, though they are frequently found on the upland as well. No satisfactory theory has yet been formulated to account for them. On account of the wide distribution and unsettled character of the problem they represent, a partial bibliography of references is given at this point for the convenience of the reader. The different theories are discussed at some length by Veatch,[1] from whose paper the following list of references is taken.[2]

RED RIVER RAFTS

Peculiar interest attaches to the great rafts of the Red River Valley on account of the unique combination of conditions which they represent and the important changes they have effected in the hydrography of the Red River and its tributaries. The name *raft* is applied to the natural accumulations of timber along the river caused by the caving of the banks on the outside of the river bends. The main raft of the river began or at least was first known at Natchitoches, a town located below the raft and at the head of navigation. This was known as the Great Raft, and it grew steadily upstream with the constant addition of

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[1] A. C. Veatch, Geology and Underground Water Resources of Northern Louisiana and Southern Arkansas, Prof. Paper U. S. Geol. Surv. No. 46, 1906.

[2] John C. Branner, Science, n. s., vol. 21, 1905, pp. 514–515; E. W. Hillgard, idem, pp. 551–552; W. J. Spillman, idem, p. 632; A. H. Purdue, idem, pp. 823–824; and C. V. Piper, idem, pp. 824–825. Branner and Purdue suggest that these mounds may represent immense concretionary formations. Spillman refers certain mounds in southwest Missouri to unequal weathering of limestone containing large chert masses. Branner gives many references to the mounds of the Pacific coast, for which he states the following theories have been advanced: (1) surface erosion, (2) glacial origin, (3) æolian origin, (4) human origin, (5) burrowing animals, including ants, and (6) fish nests exposed by elevation. D. I. Bushnell, Jr., Science, n. s., vol. 22, 1905, pp. 712–714, has suggested the human origin theory, and this phase of the matter has been discussed by Veatch, Science, n. s., vol. 23, 1906, pp. 34–36.

Fig. 214. — One of the timber jams composing the great Red River raft. In such a jam silt accumulates very rapidly and effectually fills the channel. (Veatch, U. S. Geol. Surv.)

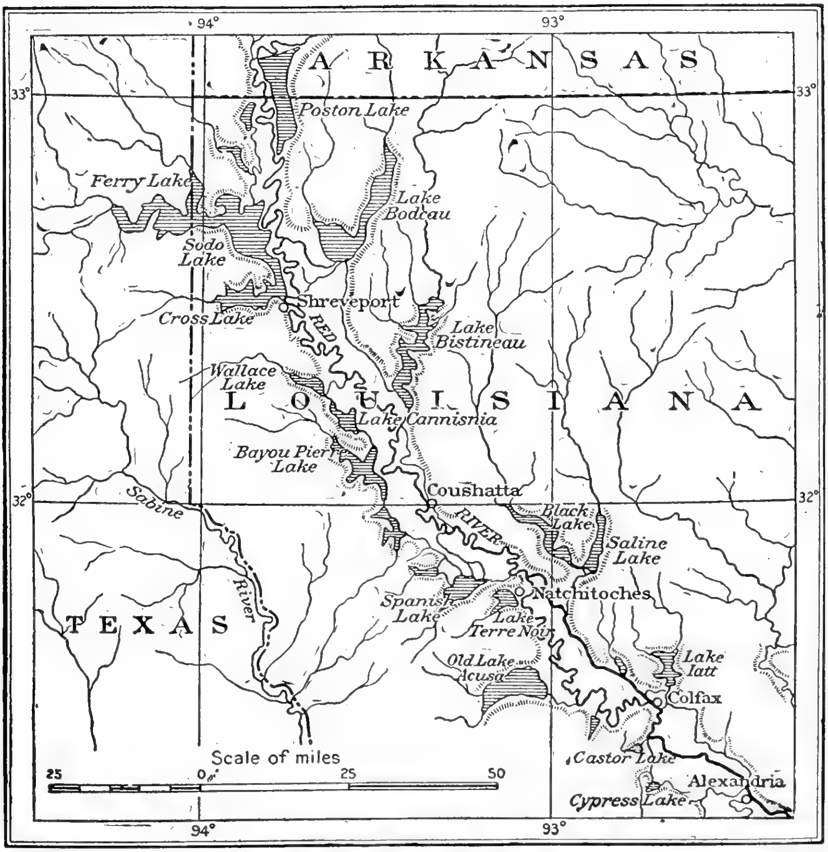

Fig. 215. — Lakes of the Red River valley in Louisiana at their fullest recorded development. (Veatch, U. S. Geol. Surv.)

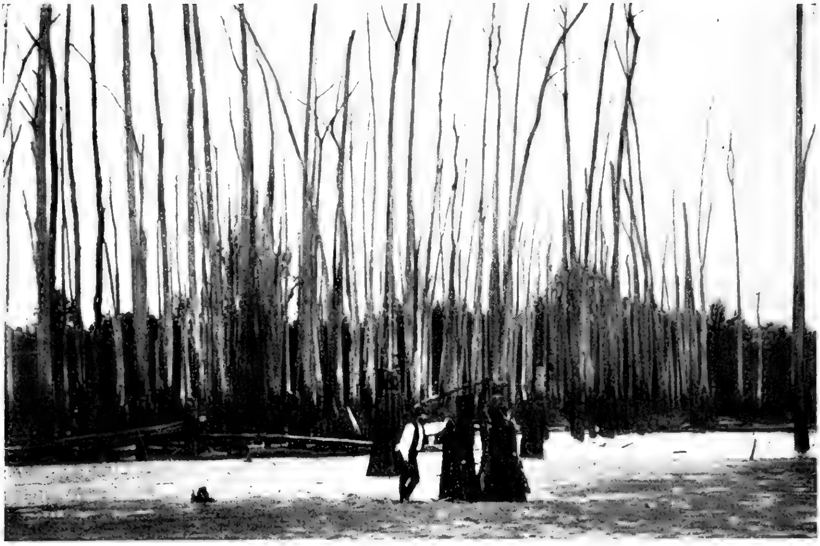

Fig. 216. — Timber deadened in temporary raft lake which was drained by the removal of the raft. (Veatch, U. S. Geol. Surv.)

Fig. 217. — One of the Red River rafts after partial recutting of filled channel, 1873. (Veatch, U. S. Geol. Surv.)

material in that direction until in the latter part of the fifteenth century it had reached a point near Alexandria. The effect of the natural dam which the raft created was to raise the level of the river on the upstream side of it and cause a ponding not only of the main river but also of the tributaries within the reach of the ponded portion of the main stream. In some cases the rise of water in the main stream was sufficient to cause it to discharge about the natural dam and through the timbered bottom lands on one side or the other. Driftwood would be quickly accumulated about the new point of discharge and again the

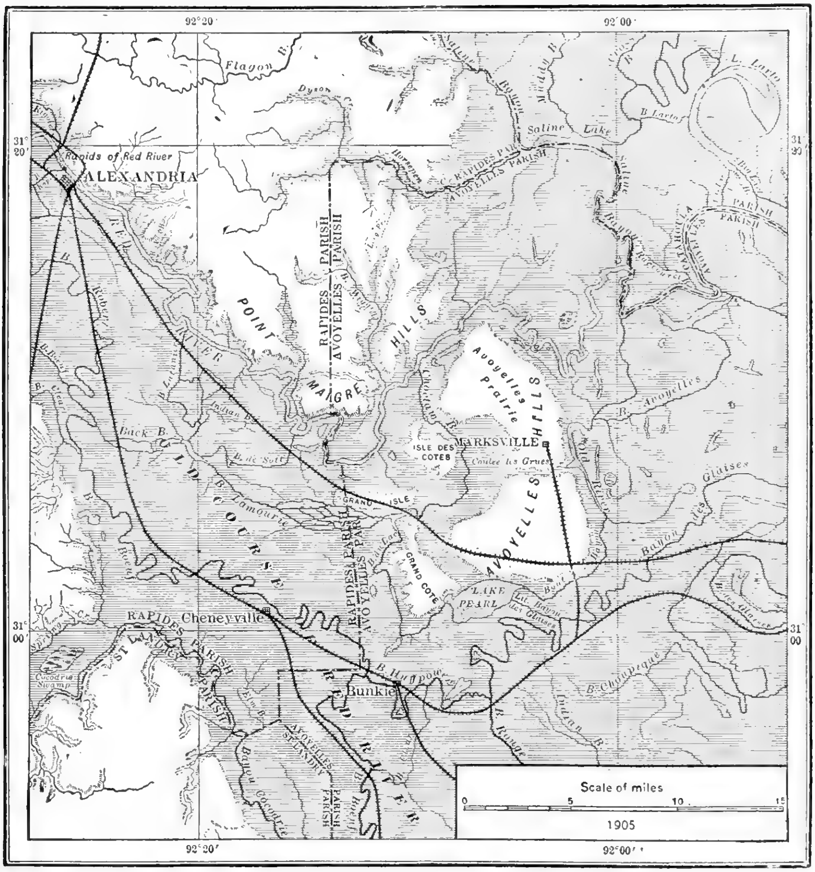

Fig. 218. — Showing diversion of Red River below Alexandria, La., and location of rapids. Map also shows typical drainage features in the Red River and Mississippi River flood plains. (Veatch, U. S. Geol. Surv.)

channel would be shifted. At the end of about 200 years (estimated) the lower part of the raft began to decay and the front of it to move upstream as a great irregular accumulation of log jams and open water about 160 miles in length. Its average rate of advance was about four-fifths of a mile a year during the period between 1820 and 1872, though the rate was intermittent and to a large extent dependent upon the discharge of the stream from year to year.

As the head of the raft moved upstream it blocked all the tributary streams in succession and caused the formation of lakes at the points of junction with the main stream. In similar fashion the tributaries that were freed by the decay and retreat of the raft material along the front of the raft again discharged in the normal way and proceeded to dissect the deposits that had been accumulated on the floor of the temporary lake at their mouths.

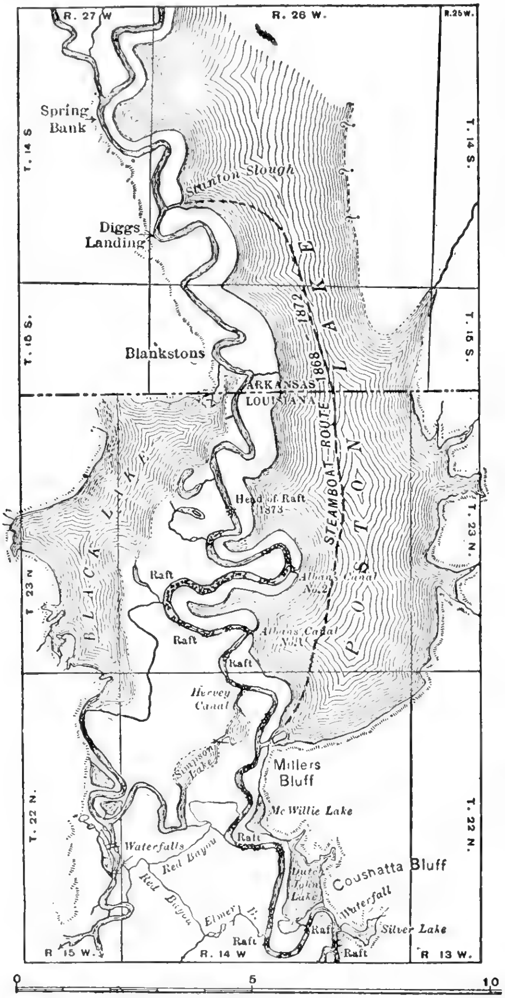

Fig. 219. — Growth and drainage of the raft lakes at the Arkansas-Louisiana state line. (Veatch, U. S. Geol. Surv.)

Since the removal of the rafts from the Red River the water has gradually resumed its old level. From 1873 to 1892 the river had lowered its bed about 15 feet at a point above Shreveport; the lake areas are rapidly draining and the extensive lake system along the course of the Red River shown on most maps is practically nonexistent. The continuance of some of the lakes and the occurrence of rapids and small falls in some of the tributaries are due to the drainage deflections that resulted from the silting up of the floors of the temporary lakes and the assumption of a new channel by the recreated stream. Superposition was inevitable under these circumstances, the stream in certain instances flowing over projecting and now covered Tertiary spurs that have been revealed by erosion. The most notable instance of such diversion is in the case of the Red River itself, which has rapids immediately above Alexandria. The main features are shown on Fig. 218.

SOILS

Although the soils of the various districts of the Coastal Plain have been incidentally mentioned in the discussion of topographic and drainage features, a connected description of their qualities is essential in understanding their geographic distribution and origin.

The soils of the Atlantic and Gulf Coastal Plain are for the most part composed of sands and light sandy loams, with occasional deposits of silts and heavy clays. The heavy clays are found principally near the inner margin of the Coastal Plain. The silts, silty clays, and black calcareous soils upon which the rice and sugar-cane industries of southern Louisiana and Texas are developed have no equivalents in the Atlantic division. Differences in the method of deposition, subsequent erosion, and drainage conditions are responsible for a great diversity of soil types with complicated relationships.

The following are the most important series that have so far been recognized: (1) Light-colored sandy soils underlain by yellow or orange sand or sandy clay subsoils. Where the drainage is insufficient, the subsoil is often mottled. With few exceptions these are special-purpose rather than general farming soils, and constitute the most important truck soils of the coastal plain. (2) Dark-gray to black surface soils, underlain by yellow, gray, or mottled yellow and gray subsoils. The dark color of the soils is due to an accumulation of organic matter during an earlier or existing swampy condition. This series is intermediate between the light-colored soils on the one hand and the peat and swamp areas on the other, and occupies depressed areas, or areas so flat that the water table is at or near the surface, except where the country is artificially drained. In this series the fine sandy-loam type supports a heavy growth of cypress, gum, magnolia, and other water-loving trees and undergrowth. It is characterized by level or slightly depressed surface features. Lack of drainage is responsible for the existence and peculiar characteristics of the type. In most cases artificial drainage is impracticable, owing to the low gradient.

(3) A third series is derived largely, but not entirely, from the Lafayette mantle of gravels, sands, and sandy clays. The surface soils are usually gray to brown in color and are invariably underlain at a depth of 3 feet or less by a red or yellowish-red sandy clay. The prevailing red color of the subsoil is the characteristic feature. (4) A fourth series includes the barrier islands or bars, shore-line deposits, and low-lying marshes of the immediate coast line. The barrier bars consist of sand accumulated by wave action and further modified by winds. The soils of the marshes, consisting of sandy loams, loams and clays, have been built up by the deposition of silt and clay carried in by streams, by wind-blown sand from the adjoining sand areas, and by the decay of coarse salt grasses and other native vegetation. The agricultural value of these lands is very low, depending mainly upon pasturage and the coarse hay, and they are a distinct menace to health, as they form the breeding places of disease-carrying insects. Efforts to drain and reclaim these marshes have been attended with some success. The possibilities of successful reclamation depend upon the keeping out of the tides and the subsequent efficient drainage of the land.

(5) The soils of the black, calcareous prairie regions of Alabama, Mississippi, and Texas are characterized by a large percentage of lime, especially in the subsoil, which in some of the

types consists of white, chalky limestone. They have been derived from the weathering of calcareous clays, chalk beds, and "rotten" limestones (Cretaceous). In some localities remnants of later sandy and gravelly deposits have been mingled with the calcareous material, giving rise to gravelly and loamy members. The soils are very productive and are at present devoted chiefly to the growing of cotton and corn.

(6) The next series includes dark-gray soils found upon gentle slopes or undulations adjacent to streams and upon level or depressed areas in the uplands. Their formation is due largely to the peculiar topographic conditions resulting from the sinking of the limestones which underlie, in some of the areas, the materials from which other soils have been derived. They may be considered as colluvial soils formed by the creeping or washing of material from higher-lying areas. The sandy type has a considerable admixture of organic matter and lies on gentle slopes or undulations adjacent to streams. It is mainly hammock land, supporting a growth of hardwood forest, and is very productive.

(7) A series consisting of gray and brown surface soils underlain by heavy, plastic, red, mottled subsoils. Where the basal clays are exposed by erosion they show brilliant colorings, often arranged in large patches of alternating liver-color, red, and white. These clays are remarkably plastic and constitute the oldest marine deposits along the inland margin of the Coastal Plain. The soils are usually of low crop-producing capacity and are covered chiefly with pitch pine, scrub oak, and other trees of little commercial importance.[1]

TREE GROWTH OF THE COASTAL PLAIN

The special vegetal features of the various sections of the Coastal Plain have been described in the foregoing pages. It remains to note certain general features more or less common to the whole province. Two points are of chief interest in this connection: (1) the effects of water supply and (2) the effects of texture and chemical properties on the native vegetation. Speaking in general terms one may say that the Coastal Plain exhibits (1) a number of inner belts more or less clayey in character and heavy, (2) a broad expanse of sandy land forming the long outer slope of the plain and almost all of the so-called upland, (3) river bottom lands fringed in many places with terraces or higher lands called "second bottoms" or hammocks, (4) a border of marshy land consisting of fresh-water marshes on the landward side and of salt-water marshes on the seaward side, and (5) a line of long, narrow reefs but little above high tide except where blown by the wind into higher sand dunes.

The reefs are for the most part sandy, though coral reefs fringe a part of the coast of Florida and some of the reefs of the Gulf region are covered with shells accumulated by the Indians. The sand reefs generally bear a growth of pine which may be of good quality as originally on the reefs of North Carolina, or it may be stunted and mixed with low, gnarled cedar, etc., as on many of the reefs of New Jersey and Texas. The shell hammocks of Alabama and Mississippi are not restricted to the reefs but are found also on inlets and bayous easily

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[1] Soil Survey Field Book, U. S. Bur. of Soils, 1906.

accessible to the water. Pitch pine, live oak, red cedar, sweet gum, and prickly ash are the most common shell-hammock trees.

On the marshes and wet pine barrens the deciduous cypress (*Taxodium imbricarium*) and the common swamp cypress are the ordinary growths along a large part of the coast line. In addition many of the smaller marshes have a growth of stunted pine, maple, and black gum. The bottom lands along the rivers, the "first bottoms," generally have a stiff heavy soil with an excess of water and are subject to overflow. Their timber is generally luxuriant and consists of chestnut, white oak, sweet gum, black gum, magnolia, bottom white pine, cypress, black walnut, tulip, hickory, and ash. Among these the black and the sweet gums are most numerous and characteristic, hence the name "gum swamps" commonly applied to the bottom lands. The second bottoms or hammock lands are slightly higher than the first bottoms, are never overflowed, have a silty not a clayey soil, and have a poorer tree growth, among which the most common types are white oak, water oak, bottom white pine, magnolia, ironwood, post and black-jack oaks, willow oaks, etc., all more or less stunted and scattered in their growth.

The upland trees are economically of greatest importance and are at the same time most interesting from the ecologic standpoint. The great sandy expanses of the outer slope of the Coastal Plain are covered mainly with longleaf pine. The seaward margin of the sandy belt is, however, level prairie in most cases, on which the trees are disposed in clumps or groves. In Texas the islands of higher lands are covered with loblolly pine. In Louisiana groves of honey locust, red haw, and live oak dot the outer prairie region. Inland from the great longleaf pine belt the calcareous layers of the Coastal Plain outcrop and are covered with a distinctive and for the most part a lime-loving vegetation. Oak and shortleaf pine are the most important types; mixed with them are red cedar, red haw, crab-apple, and honey locust. It is noteworthy that the heaviest clay soils on the inner margin of the Coastal Plain of Texas, Louisiana, Mississippi, and Alabama are marked by large numbers of prairie tracts alternating with groves of stunted trees, mostly red cedar, Chickasaw plum, and scrubby post and black-jack oaks.

The most unproductive soils occur on the so-called ridge lands toward the inner margin of the Coastal Plain where some of the ridges are developed on the outcrop of sandy formations. Scarlet and post oak, black-jack oak, and stunted pines are the principal trees. They are characteristic growths on all the more infertile phases of the coastal-plain soils. The calcareous soils, by contrast, are notably fertile and have a good growth of hickory, ash, sweet gum, and honey locust. So faithfully do the distributions of these types follow the outcrops of the respective formations that a vegetation map on the one hand, and a soil map or a geologic map on the other, show striking correspondences in the positions of the boundary lines.[1]

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[1] For a description of the tree types of the Georgia Coastal Plain see R. M. Harper, Contr. Dept. Bot., Colum. Univ., Nos. 192, 215, 216, 1902–1905; for the timber belts of the Coastal Plain in Texas see W. L. Bray, Forest Resources of Texas, Bull. U. S. Dept. Agri., Bur. For. No. 47, 1904; for the trees of Mississippi see E. W. Hilgard, Geology and Agriculture of Miss. 1860, and Soils, 1906, Chaps. 24 and 25; for Alabama see Charles Mohr, Plant Life of Ala bama, Ala. Geol. Surv., 1901.

CHAPTER XXVI

PENINSULA OF FLORIDA

General Geography

The peninsula of Florida is remarkable for its projection southeastward into the Atlantic Ocean for 350 miles, its smooth, well-developed eastern shore line, its great keys and swamps, and its slight relief. It ranges in altitude from sea level to 200 feet above the sea at various points on the broad flat-topped tract which forms the center of the peninsula and to about 300 feet in the northwestern counties of Florida. A depression of 50 feet would cover all of southern Florida except the tops of sand hills and ridges, while an elevation of 50 feet would extend the shore line westward 20 miles from Cape Romano and make dry land of Biscayne Bay and Bay of Florida.

The northern and western parts of Florida consist of a narrow, deeply eroded limestone (Vicksburg) upland which descends southward rather abruptly to a low coastal region and northward by more gentle descents to the adjacent Coastal Plain. The rivers of the northern region are consequent upon the initial slopes of the land as it emerged from beneath the sea except where they have removed the thin mantle of surface sand and superimposed themselves upon the older strata beneath. The southern and central portions of Florida form a great lake and swamp district, the lakes occupying sinks or depressions in the underlying limestones or shallow and broad depressions in the surface of the deposits overlying the limestones. Extreme irregularity of outline characterizes the shores of the lakes and extreme irregularity of direction the courses of the rivers. Many streams of the peninsula have their sources in springs that occupy underground courses in the limestone. These bring to the surface large quantities of mineral matter, and it has been estimated by Sellards[1] that the rate of solution is sufficient to remove about 400 tons per square mile per year, an amount which would lower the surface of the limestone about 1 foot in 5000 to 6000 years. The underground passages are sometimes several hundred feet in diameter and several miles in length. The level char-

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[1] A Preliminary Report on the Underground Water Supply of Central Florida, Bull Florida State Geol. Surv., No. 1, 1908, p. 16.

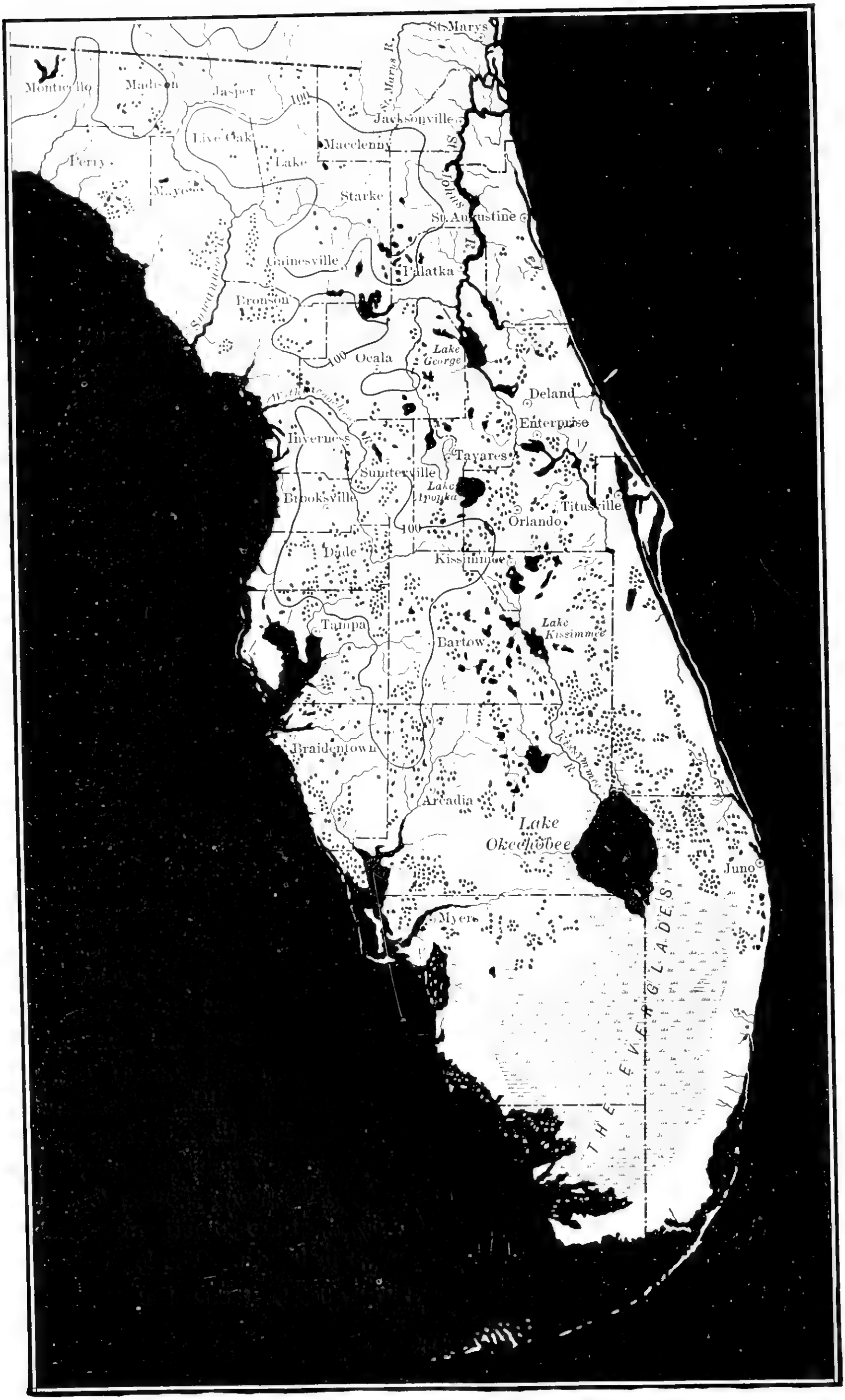

Fig. 220. — Principal lakes and coastal features of Florida.

acter of the surface and the porous soil which mantles the bedrock afford an excellent opportunity for the formation of caverns, since they result in a large absorption of the heavy rainfall. The sink holes are in process of formation to-day and instances are known where sinks have been formed by the collapse of cavern roofs in different parts of the lake region. The same process has resulted in the formation of many natural bridges, as those of northern Walton County, at St. Marks River, and Santa Fé River.

GEOLOGIC STRUCTURE

In respect of structure Florida is an elevated crust block modified by a number of minor folds.[1] The present peninsula is regarded as resting on a much more extensive foundation of Eocene limestone, forming a plateau which formerly extended from the southeastern margin of the continent to Cuba and the Bahamas, and possibly to Yucatan. The isolation of the peninsula may possibly be due to faulting, and in part to current scour. In a number of places are gentle folds whose axes are generally parallel with the trend of the peninsula; these succeed one another in series between Lake Okechobee and Gulf of Mexico.[2] One such fold is near the Atlantic coast, another near the Gulf coast, and a third in the vicinity of Brooksville and Plant City. The eastern ridge includes the well-known Trail ridge and forms the eastern boundary of the central lake basin. The western ridge forms the western boundary of this basin and passes through Lakeland.[3]

PHYSIOGRAPHIC DEVELOPMENT

Recent stratigraphic studies have determined the fact that the Floridian region was outlined in somewhat its present form in pre-Oligocene, probably Eocene time, but that it then existed in the form of a shallow submarine platform swept by ocean currents and blanketed by both organic and terrigenous deposits.[4] During the time between this early period and the final emergence of the crust-block as a peninsula the region was subjected to many changes of level — a series of four emergences and a corresponding number of submergences. During the progress of these changes the surface of the platform was never carried far below and never far above sea level. The submergences were usually about 100 feet and never more than 200 feet, while the latter figure expresses the

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[1] W. H. Dall, Neocene of North America, Bull. U. S. Geol. Surv. No. 84, 1892, pp. 85–87.

[2] Idem, p. 88.

[3] Matson and Clapp, 2d Ann. Rept. Fla. Geol. Surv., 1909, p. 48.

[4] T. W. Vaughan, Sketch of the Geologic History of the Floridian Plateau, Science, n. s., vol. 32, 1910, pp. 24–27.

maximum elevation above sea level, a maximum that was attained during the Pliocene emergence. It was the fourth Pliocene emergence that gave the peninsula the outline that it has to-day. In the time since then the living coral reefs have developed, the Everglades have been formed, and the shores given their detailed characteristics. The net result of all the changes of level has been to leave the eastern side of the peninsula higher than the western and to bring into existence a number of small low folds whose axes run north-south in sympathy with the main axis of the peninsula. The Kissimmee River for example occupies a syncline flanked on both sides by low anticlines.

Topography and Drainage

Although the mainland of Florida has slight relief it exhibits a considerable variety of topographic types, and since even small differences of elevation have a marked effect on the vegetation, it is possible roughly to divide the mainland of the peninsula into districts whose topographic features are intimately related to the vegetal growth. On this basis Florida may be divided into pineland and swamp. The pineland includes "hammocks" — isolated elevated patches supporting hardwood trees of several genera — and many prairie or grassy tracts. The swamps include the marshy borders of the inland lakes and the coastal swamps with their sedges and black or red mangroves. It must be remembered, however, that this line of demarcation between swamp and pineland is extremely irregular and, on account of the low relief, varies with the seasons to a certain extent.

The total area of the pine forests of southern Florida is about 1300 square miles; on the east coast they extend in a narrow belt between the Everglades and the coastal swamp from northern Palm Beach County to near Homestead. This belt is about 20 miles wide at the north, 6 miles wide near Jupiter Inlet, and from 2 to 8 miles wide towards the south. In northern Monroe County the pines grow in disconnected areas alternating with stretches of cypress.[1] The pinelands may be divided according to the relief into dunes, rolling sand plains, flat land, and rock ridges.

DUNES

The dunes of southern Florida lie near the coast and occur as a discontinuous series of irregular mounds and ridges separated by intervals of flat or gently rolling country or by stretches of shallow water.

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[1] The best brief description of the topographic features of southern Florida and the one on which the following paragraphs are chiefly based is by S. Sanford, 2d Ann. Rept. Fla. Geol. Surv., pp. 177–231, where the results of many other investigators are assembled.

They seldom reach more than a few miles inland and but rarely face the ocean. An important group of dunes are those that occur near Jupiter Inlet at West Palm Beach, and on the east side of Lake Osborn. On the west coast of Florida there are few dunes south of the Caloosahatchee River. The dunes are not in movement to-day, and there is no leeward march which overwhelms trees and threatens dwellings as at Cape Henry, Virginia, and on Hatteras and Currituck Banks in North Carolina. When cleared of pine timber and palmetto scrub they may be utilized in the growing of tropical fruits.

ROLLING SAND PLAINS

The rolling sand plains include sandy stretches of the mainland with broad swells and low ridges, the swells being occupied by shallow lakes or lagoons and wet prairies or cypress swamps. On the east these sand plains form a belt with a maximum width of 6 miles and extend from the north side of Palm Beach County nearly to the Miami River and merge inland into the monotonous level of the flat lands and prairies bordering the Everglades. On the seaward side they are bounded by swamps; on the east coast the higher ground and the ridges are frequently covered with a straggling growth of spruce pine. In the hollows are many fresh-water lakes, some of which are several miles long. Most of them are less than 10 feet deep and some are so shallow that they entirely disappear during seasons of deficient rainfall. The rolling sand plains are believed to be the result of wind action and to constitute but a broader development of the present dune topography near the coast.

FLAT LANDS

The name "flat lands" is used to designate the imperfectly drained pinelands lying between the narrow belt of rolling sand plains and the Everglades and their bordering prairies. The soil is a white sand which bears a thin growth of pine trees, with many prairie expanses a mile or more wide. In the rainy season these prairies are shallow lakes. There are also a number of sloughs and shallow ponds that in places support good growths of cypress, the pine and cypress often intermingling in very irregular fashion. On the west side of the lower end of the peninsula the surface between the Everglades and the Gulf is even more monotonously level than on the eastern coast, and the relations of swamp and dry land are more irregular. Much pine occurs in patches and strips separated by cypress swamps, a combination often designated as "pine islands and cypress straits." In places prairies are scattered through or fringe the pinelands, and some of them make excellent cattle ranges.

ROCK RIDGES

This term is applied to those outcrops of solid rock that rise above the general flat expanse of country, though they may not rise more than 2 feet above the general level and probably in no case does their elevation exceed 35 feet. Their extent is estimated at 200 square miles. On the east coast the rock ridges are of oölitic limestone and separate the great saw-grass swamp of the Everglades from the fringe of mangrove swamps and salt prairie along the western shore of Biscayne Bay. Even in the Everglades some of the keys have a rocky foundation, but the only ones which expose bare rock are Long Key and those related to it. On the west coast of Florida hard rock outcrops are more scattered than on the east coast, but cover a wider area, running through the pinelands in strips varying in length up to several miles.

SWAMPS

THE EVERGLADES

The swamp land of southern Florida includes the great saw-grass morass of the Everglades, the cypress swamps about it, and the salt marshes and mangrove swamps of the coast. The most important swamp is of course the Everglades with its wide expanse of sedge, its broad strips of shallow water, its scattered clumps of bushes, its many islands, and its underlying limestone floor. The Everglades reach from Lake Okechobee on the north to Whitewater Bay on the south, and are 50 miles wide in their widest part. Their area is estimated at 5000 square miles.[1] The border of the Everglades is well known, but the vast interior of water- and sedge-covered muck has been visited by few geologists and crossed by none.

The Everglades tract lies in a huge shallow sink, or a series of more or less connected sinks.[2] Countless shallow ponds of clear water are found in which grow bulrushes, lilies, and other water plants, saw grass, flags, and cane. The Seminole name for the Everglades is "Grassy Water." Scattered here and there in the sea of grass are islands of bushes and trees, called keys, which owe their origin to accumulations of vegetable matter; and the slight relief of the region is brought out strikingly by the fact that such slight accumulations of material should produce islands of drier land. The whole region appears to be very young; it is almost without soil or definite surface drainage. As a result of the slight relief there is no sharp dividing line

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[1] L. S. Griswold, Notes on the Geology of Southern Florida, Bull. Mus. Comp. Zoöl., vol. 28, 1896.

[2] A. Agassiz, The Elevated Reefs of Florida, Bull. Mus. Comp. Zoöl., vol. 28, 1896, p. 30.

between the Everglades and the surrounding country, and a difference of two feet in water level means the difference between shallow lake and dry land for hundreds of square miles. No two of the maps of Florida agree either in the number, position, or outline of the lakes of the Everglades because of the variation in these features with the height of the water. Much of the eastern and northern shore of Lake Okechobee is bordered by cypress swamps, some of these containing the tallest cypresses to be found in Florida. On the east the Everglades are bordered by prairie and cypress swamps; in a few places patches of hardwood grow on slight elevations on the western border of the Everglades. Here are low irregular elevations, measured by inches, that diversify the distribution of water and sedge; here, too, are narrow winding sloughs some of which extend for miles.

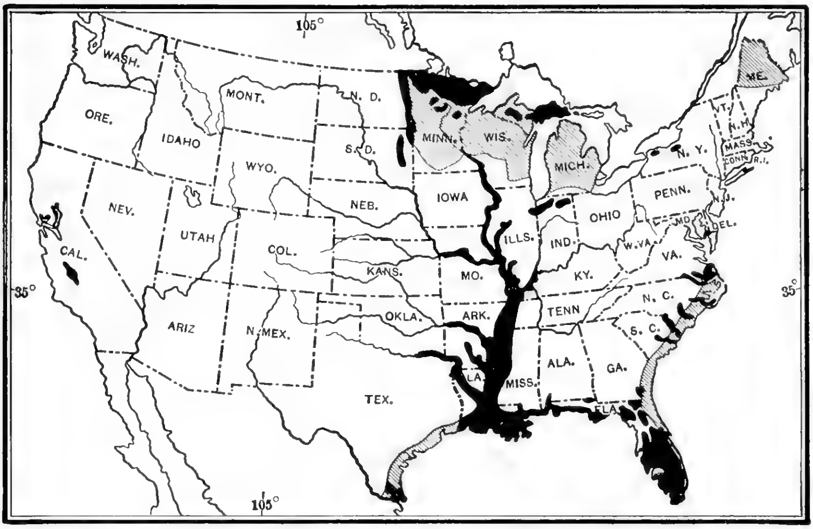

Fig. 221.—Swamp lands of the United States with degrees of swampiness shown in two shadings. (Gannett, U. S. Geol. Surv.)

Lake Okechobee itself is drained by a canal through the saw grass to Lake Hicpochee and the Caloosahatchee River. It is also drained by a few short streams that flow southward from the southern edge of the lake but are closed up after a few miles by thick growths of saw grass. The flatness of the Everglades may be appreciated by the elevations as determined at different times, which run from 6 to 23 feet in various portions, and it has been stated that the damming up of the main canal on the west of Lake Okechobee by raising the water three feet inundated the marginal prairies on many of the east coast ridges and seriously hindered the growing of vegetables. Bedrock lies at or near the surface toward the edge of the Everglades, and near Miami the rock forms bare ridges with a maximum height of 15 feet above the sea. The depth to bedrock in the central portion of the Everglades is 3 or 4 feet, and the flatness is so great that the word "basin" is inappropriate in describing it.

COASTAL SWAMPS

The coastal swamps include the wet lands along the lagoons or the so-called rivers back of the barrier beaches of the east coast. Many of the swamps on the east side support a scrubby growth of mangrove, but on the west side, especially in the Shark River archipelago and the southern part of the maze of land and water known as the "Ten Thousand Islands," the mangrove forms a notable forest, the trees reaching to a height of 60 feet or more, with green smooth trunks 2 feet or more in diameter at the base and without limbs for 30 feet above the ground. The mangrove forest rises from the Gulf like a green wall and is one of the most striking features of the shore line of southern Florida.

FLORIDA IS NOT A CORAL REEF

The work of Agassiz and others has shown that the older and popular view that the peninsula of Florida is an elevated reef is incorrect; the thickness of the coral reef formed since Pliocene times is probably about 15 feet, as determined by borings at Key West in 1895. Beneath the coral reef are Pliocene rocks, and beneath these in turn at a distance of 700 feet are rocks of Eocene age. The coral reefs now visible on the seacoast have but a moderate development inland. An elevated coral reef of notable width constitutes the outer edge of the peninsula of Florida. It has been traced from 20 to 30 miles inland at some points, although in other localities it has a very much more limited occurrence. This great development of reef rock should not, however, obscure the fact that the interior of the peninsula is of totally different origin, consisting of limestone, chiefly of marine origin, although with certain æolian facies. In the shore zone in which the reefs occur there are also found great patches of æolian rocks filling intermediate sinks and alternating with patches of reef rock of variable extent.[1]

DRAINAGE FEATURES DUE TO KARSTING

The drainage of Florida is characterized by the presence of large numbers of sloughs, shallow ponds, and lakes. The interior is chiefly swamp, Fig. 220, with no well-defined river systems or stream valleys, and in spite of the low elevation of the larger part of the peninsula the streams that flow from the Everglades into the Atlantic have rapids in their upper courses wherever bedrock occurs. The drainage irregularities

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[1] The most comprehensive account of the geology and topography of the keys of southern Florida is by A. Agassiz, The Elevated Reef of Florida, Bull. Mus. Comp. Zoöl., vol. 28, 1896, pp. 29–62.

are due in part to the irregularities of the beds that form the land surface and in part to their general features and slight elevation above sea level. Additional factors controlling the stream systems have been the extensive karsting[1] of the limestone areas that underlie so large a portion of the state, with the production of many sink holes, underground channels, caverns, etc. The higher portion of the state is honeycombed with underground passages, but these decrease in number on approach to the coast. No small part of the irregularities is probably due to the irregular manner in which the grasses grow, which in turn affects the distribution of land waste.

The extreme irregularity which characterizes the drainage features of the peninsula of Florida must therefore be ascribed to three causes; first, the youthfulness of the entire surface and lack of time in which the drainage might become organized and the lakes drained; second, to the extremely slight relief of the surface and the absence of any dominating slope, as in the Coastal Plain of the Atlantic region or the Great Plains of the central part of the United States; third, to the influence of the dissolving action of the ground water which proceeds in detail with almost a total disregard of the surface of the slopes of the land. The result is that underground water passages are opened from sink to sink and from lake to lake, oftentimes in opposition to the surface slopes, as in the celebrated case of the Danube and the Rhine in Europe, in which the upper part of the Danube is to a large extent absorbed by porous limestones, which in turn deliver the water to underground passages that lead to the Aach, a tributary of the Rhine system. The result is that the upper Danube belongs almost wholly to the Rhine system.[2] To add to the complexity of such regions the covers of the underground channels are dissolved by percolating water to the point of collapse, passageways are blocked, and the waters rise to the upper level of the obstruction. In brief, it may be stated that the irregularities are in large measure due to the combination of surface and underground drainage systems which originate in different ways and which to a large extent obey different laws.

COASTAL ISLANDS

The islands that fringe southern Florida are of several types. Some are long, narrow, barrier beaches crowned with coconut palms and bordered by mangrove swamps; some are true mangrove islands that resist wave action; some are low-lying sand banks supporting a scanty growth of beach grass and weeds; and some are of rock that reaches above sea level, these being covered with scrubby hardwoods, palms, and pines. Within the outer chain of islands that fringe the mainland or dot the Bay of Florida are other keys in all stages of development, from banks below sea level to banks bare at low tide and covered with mangroves that arrest the movement of sand, seaweed, and driftwood, and contribute to the reclamation of the sea floor.

The existing keys and islands south of the peninsula of Florida are regarded as once having been continuous or practically so. It appears that a process of gradual disconnection has taken place between

[1] The name applied to the process that results in a *karst* topography, i.e., a topography marked by sink holes, underground channels, vertical shafts, etc., as developed on many limestone tracts and typically in the Karst Mountains of Austria.

[2] Petermann's Mitteilungen, 1907, and Naturwissenschaftliche Wochenschrift, 1908, No. 7.

the Florida keys and the mainland proper. It is ascribed to the erosive and solvent action of the sea. The sounds may have originally been sinks similar to those of the Bahamas and the Bermudas, the action of the sea having broken through the barriers separating the sounds from the ocean. Once channels were formed the action of the sea would increase their width and depth, and the sea would thus gradually encroach upon the floors of the sinks, forming more and more distinct sounds out of them, or even huge open bays like Key Biscayne Bay.

The keys forming the small group immediately east of Key West, Fig. 220, have a northwest-southeast alignment. They are not coral reefs but are underlain by oölitic limestone which has an irregular surface more or less covered with marl and calcareous sand. The breaches between the islands are due to tidal currents caused by differences in time and height of the tides of the Gulf and the Strait of Florida. The great curve of the sand reefs on the eastern coast is caused by longshore current action, the currents moving from north to south as an eddy between the Gulf Stream and the mainland.

There is a bedrock floor of limestone in the Biscayne pineland on Long Key and on adjoining keys in the Everglades. The coast of this part of Florida is either stationary or sinking, but if sinking, the rate of depression is extremely slow. At the present time there is in progress an extensive reclamation of the sea by the accumulation of large quantities of shells of marine organisms and by the abundant organic life associated with the mangrove swamps of the coastal border.[1]

There is the utmost difference in the vegetal covering of the islands, due to slight differences in elevation and to differences in the character of the surface. In some places it is bare rock, in others rock with a thin veneer of sand, marl, and leaf mold, and in still others a cover of calcareous sand. On low land near the water's edge mangroves are found, on the beaches coconut palms, on the low marl flats grasses and sedges, while the higher ground, called "hammock," supports a dense growth of scrubby hardwood trees, buttonwood, ironwood, madeira, etc., while on three keys patches of pine are found. The trees seldom reach a height greater than 20 feet.

SOILS AND VEGETATION[2]

The widespread occurrence of Pleistocene sand as a surface deposit a few feet thick results in an intimate relation between the soils of the

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[1] For an excellent description of these mangrove swamps, their great importance in the winning of lands from the sea, and their peculiar forms of vegetation, see N. S. Shaler, 10th Ann. Rept. U. S. Geol. Surv., pt. 1, 1888–9, pp. 291–295.

[2] The common and much more abundant types of vegetation are described in detail in connection with the topographic types with which they are so intimately related, pp. 546 to 550.

peninsula and this formation. Where erosion has been exceptionally active both the Pliocene and the Pleistocene deposits have been removed, leaving older geologic formations to form the soils, but such occurrences are relatively rare and unimportant.[1] In the southern part of Florida and in isolated patches elsewhere in the state peat and muck soils occur. These have their greatest development in the Everglades. They consist of organic matter mixed with a certain amount of sand and clay and are of recent origin. Their occurrence is confined to low upland areas with imperfect drainage. In the upland portion of the state the Lafayette formation is found as isolated areas but these are of little importance except as tobacco soils in the northwest. At various places along the east coast Pleistocene marls and coquina in a more or less decomposed state form the subsoil, and the same is true on the west coast south of Bradentown. The clay and loam soils cover a very limited portion of Florida and are not of much importance. Clay soils are confined chiefly to small areas along the stream courses and are not tilled. The greater part of Florida has a sandy or sandy loam soil of low natural productivity but quickly responding to proper treatment. It is naturally deficient in moisture in spite of the rather abundant rainfall, and irrigation is practiced in a few places.[2] Extensive drainage operations are in progress in the Everglades region which will ultimately mean the reclamation of large tracts of peat soil whose natural productivity is high and which is suitable for the production of a large variety of tropical fruits.

Florida extends so far southward as to exhibit subtropical or antillean forms of vegetation. The subtropical belt encircles the southern half of the peninsula from Cape Malabar on the east to Tampa Bay on the west.[3] The royal palm, Jamaica dogwood, manchineel, mahogany, and mangrove are among the uncultivated tropical plants, and the banana, coconut, date palm, pineapple, grapefruit, and cherimoya among the cultivated plants of this district.[4] It is of interest to note here that the subtropical region enters the United States at two other points besides Florida — the lower Rio Grande region in Texas and the lower Colorado River Valley in western Arizona and southeastern California.

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[1] Matson and Clapp, 2d Ann. Rept. Fla. State Geol. Surv., 1909, pp. 37–43.

[2] Idem, p. 45.

[3] C. H. Merriam, The Geographical Distribution of Life in North America with Special Reference to the Mammalia, Proc. Biol. Soc. Wash., vol. 7, 1892, p. 33.

[4] C. H. Merriam, The Geological Distribution of Animals and Plants in North America, Yearbook Dept. Agri., 1894, p. 211; idem, Life Zones and Crop Zones of the United States.

CHAPTER XXVII

LAURENTIAN PLATEAU AND ITS OUTLIERS IN THE UNITED STATES

Laurentian Plateau

TOPOGRAPHIC FEATURES

The Laurentian Plateau includes all the country north of Lake Superior, Lake Ontario, and the St. Lawrence line, as far as Hudson Bay and the Arctic shore of Canada; east and west it extends from Lakes Athabaska, Manitoba, etc., to the Labrador coast. Its boundaries are indicated on Fig. 222 and include about one million square miles of land. It embraces practically the whole northeastern section of North America. Two outliers of the province lie in the United States:

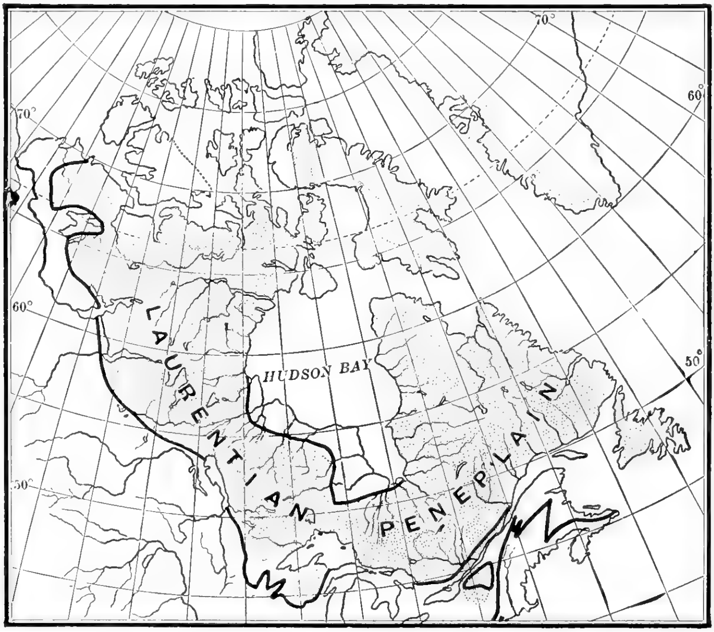

Fig. 222. — Chiefly metamorphic and igneous rocks within the heavy lines, chiefly sedimentary rocks without; the Laurentian peneplain is dotted. (Wilson.)

(1) the Superior Highlands of northern Wisconsin, northwestern Michigan, and northern Minnesota, and (2) the Adirondacks of northeastern New York, while it is practically continuous with the New England Plateau of related origin and character. Indeed the history of this great topographic province is intimately associated with, and its forms are in many respects similar to, those of a considerable portion of the Appalachian region, and it is therefore necessary briefly to sketch its salient features.

The Laurentian Plateau may be considered as a topographic unit, its chief features being those characteristic of a peneplaned region of crystalline rock — granites, gneisses, schists, etc. — bordered by overlapping Paleozoic sedimentary layers which have been eroded into the form of an ancient belted coastal plain, then uplifted, extensively dissected by ordinary erosional processes in preglacial time, and, more recently, heavily glaciated. Two of the three great centers of glacial dispersion lay in the Laurentian province, the Keewatin and the Labradorian, and the effect of the great ice sheets that radiated therefrom was practically to denude the tract of its residual soils. With this set of physiographic conditions and changes we shall find associated practically all the topographic forms found in the region to-day.[1]

The dominating feature of the Laurentian region is the remarkably even sky line whose character is maintained in spite of the great diversity of rock structures and hardnesses which occurs from place to place. Almost anywhere in the interior of the tract the horizon, as seen from an elevation, is nearly as level as that of the sea and, also like that of the sea, is almost circular. The surface from point to point and in detail is decidedly broken, but in a general broad view it is strikingly flat and plateau-like. The degree of evenness may be appreciated from the fact that residual elevations of only 50 or 100 feet relative altitude stand out as prominent landmarks visible for many miles. The Laurentian area has been traversed by the officers of the Geological Survey of Canada in many different directions, and all the descriptions and photographs are alike in representing it as once having been one of the most typical peneplains in North America. Even in those parts of the now uplifted peneplain which have been most thoroughly dissected and glaciated, as in the region south of James Bay, the dominant topographic feature is still the even sky line intercepted only here and there by an occasional

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[1] A. W. G. Wilson, The Laurentian Peneplain, Jour. Geol., vol. 11, 1903.

The true character of the great Laurentian area of eastern Canada was first set forth by G. N. Dawson, then Director of the Geological Survey of Canada, at the Toronto meeting of the geological section of the British Association in 1897, and in 1893 a systematic description of the region was prepared by Wilson.

isolated residual or monadnock which was able during the period of peneplanation to maintain a slightly greater elevation because of favorable position on stream divides or superior hardness or both. The southeastern margin of the peneplain, where it borders the St. Lawrence River, is more rugged and uneven than the rest and is known as the Laurentide Mountains. Toward the extreme northeast and at the base of the Ungava peninsula there is a narrow range of mountains which extend to heights of 6000 to 8000 feet and stand prominently above the surface of the peneplain. The range includes the highest mountains in eastern North America. Broader and gentler undulations which give but slight diversity to the surface of the now uplifted peneplain also occur widely scattered in the form of low rounded domes and ridges roughly parallel to themselves and with their longer axes conforming in general to the strike of the rocks.[1]

Fig. 223. — The Laurentian Plateau as an uplifted, dissected, and glaciated peneplain in Labrador, east of Hudson Bay. Note the even sky line, the network of lakes, and the absence of a soil cover. (Low, Can. Geol. Surv.)

Differences in elevation between different portions of the peneplain are roughly indicated by the numerous lakes, large and small, which occur at levels but little below that of the general surface. From the elevations of these lakes it is found that the average gradient of the valleys is from 1 to 4 feet per mile. East of Cree Lake as far as the junction

[1] A. W. G. Wilson, The Laurentian Peneplain, Jour. Geol., vol. 11, 1903, p. 628.

of Churchill and Little Churchill rivers the surface has an average gradient of 1.8 feet per mile for 450 miles; on the Hamilton River the gradient for about 300 miles, partly above and partly below the Grand Falls, has a mean value of approximately 1 foot per mile. Considering the large number of falls and rapids in the courses of the streams draining the Laurentian Plateau these values appear astonishingly small, especially when compared with such gently sloping surfaces as those developed in piedmont areas. The average gradient of the plains of Alberta is from 2 to 3 feet per mile, a value which distinctly exceeds that of the general slope of the surface in the Laurentian province, although we are accustomed to thinking of the latter as rugged and the former as smooth. The Laurentian peneplain has been dissected to such an extent as to be rough but not rugged, though even its roughness is not expressed in the figures representing the gradient of the hilltop plane.

Although the derivation of the great Laurentian area from a peneplain is clear, it is worth while to see that it now exhibits but few of the characteristics of a peneplain. A peneplain is an old erosion surface of slight relief which has been worn down by normal physiographic agencies almost to the level of the sea. The typical peneplain is one which also bears upon its surface an occasional residual elevation, is mantled by deep residual soils, and is absolutely without lakes, falls, rapids, or any other features indicating a youthful condition of the drainage courses. It is noteworthy that scarcely any of these qualities are present in the Laurentian area to-day. Instead of residual soils there are here almost no soils at all, only locally developed patches of glacial till or of water-laid material glacially derived. Instead of well-organized and low-gradient drainage courses, the Laurentian area exhibits the most irregular drainage features and is, *par excellence*, the lake region of North America; instead of standing near sea level the region is now at elevations ranging from sea level to more than 2000 feet. Although it is one of the oldest portions of the continent, a large number of its features are due to a very recent geologic event — glaciation. In short, the Laurentian region is one which through unequal uplift and differential stream and ice erosion has been so modified from its condition at the end of the preceding topographic cycle that its former peneplain character is recognizable only by the pronounced and uniform discordances that prevail throughout its entire area between general surface and geologic structure — a discordance that can be explained only by the assumption that it was once a region of prolonged erosion and that a pronounced, possibly a mountainous relief, was reduced practically to the level of the sea.

REPRESENTATIVE DISTRICTS

LAURENTIDE MOUNTAINS

With these general features in mind we may now turn to the more detailed features of representative portions of the Laurentian area, beginning with the Laurentide Mountains that border the St. Lawrence Valley on the northwest. Perhaps the most important point in this district is that relating to the deformation which the Laurentian peneplain suffered in the uplifting process that raised it to its present level. The uplift was differential and is still in progress; the general nature of the first uplift was a tilting of the whole northeastern corner of the continent upward at the north; the present movement is in harmony with and in continuation of the earlier movement. The Laurentide Mountains are due only in small part to their residual quality. They are due chiefly to the greater uplift of the peneplain along the border of the St. Lawrence Valley, so that its southeastern margin as viewed from the valley does not appear as the margin of a plateau but as a range of hills of sufficient height to be known as mountains. This marginal swell roughly parallel to the margin of the peneplain is succeeded toward the interior by a number of circular depressions occupied by lakes, of which the St. John at the head of the Saguenay River is the most important. The streams of this portion of the plateau cross the marginal swell or the Laurentides through deep, steep-sided canyons of which the broadest and deepest is the fiord of the Saguenay.

Fig. 224. — The Laurentide Mountains north of St. Lawrence River at St. Anne de Beaupré. The lowland in the foreground is formed on limestone which terminates at the foot of the mountain slope.

HUDSON BAY - ST. LAWRENCE DIVIDE

From the Laurentide Mountains northwest to Hudson Bay the Laurentian area is a plateau formed upon ancient crystalline rock with an average elevation of about 1500 feet above sea level. It rises slowly from 1000 feet near the margin to about 2000 feet in the interior. The surface is dotted with low rounded hills arranged in a series of ridges parallel to themselves and to the general strike of the rocks. These hills are the stubs of extensive and elevated mountain chains subjected to prolonged erosion which brought them down to their present state.[1]

To the south of James Bay in the Nipissing and the Temiskaming regions the surface of the plateau consists of a succession of more or less parallel rock ridges with intervening valleys occupied by swamps and lakes and with a general elevation rarely falling outside the 900 to 1200 foot limits. There are no very pronounced hills, the highest seldom attaining more than 300 feet above the adjacent country, while hills 100 to 150 feet high are rather conspicuous topographic features. The areas of Laurentian granite and gneiss in the southern and southeastern portions of the district have weathered into a monotonous succession of hills and intervening rocky valleys; in the northwestern part of the Nipissing area there are more important elevations owing to the presence of resistant quartzite in country rock consisting of granite, diabase, and slate, the last-named member of the series weathering into a characteristically flat surface.[2]

LABRADOR PENINSULA

East of Hudson Bay is the Labrador peninsula, a great tableland having an elevation of about 700 feet above sea level near its margin and about 2000 feet in its higher interior portions.[3] The interior of the Labrador peninsula is so nearly flat that in an area of 200,000 square miles there is a difference in level of not more than 200 to 400 feet, and the highest general level of the interior is less than 2500 feet above the sea. The divides are often ill defined and never prominent.

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[1] A. P. Low, The Mistassinni Region, The Ottawa Naturalist, vol. 4, 1890, pp. 11–28.

[2] A. E. Barlow, Report on the Geology and Natural Resources of the Area included between the Nipissing and Temiskaming. Map Sheet, comprising portions of the district of Nipissing and of the county of Pontiac, Can. Geol. Surv., vol. 10, n. s., Rept. I, 1899, p. 21.

[3] A. P. Low, Report on Explorations in James Bay and the country east of Hudson Bay drained by Big, Great Whale, and Clear Water rivers, Can. Geol. Surv., vol. 3, n. s., pt. 2, Rept. J, 1888, p. 16.

BARREN LANDS

Likewise the "Barren Lands" in the far north of Keewatin, p. 565, although developed upon rock of most complex structure, are extraordinarily uniform in general elevation and in a broad view closely resemble the great plains of undulating grass-covered country of western Manitoba, Alberta, and Saskatchewan. Only here and there does a hard granite knoll projecting above the general surface indicate the character of the underlying rock and suggest the past history of the region.

BORDER TOPOGRAPHY AND DRAINAGE

Along the outer or southern and western border of the Laurentian peneplain is a group of land forms which represent on a great scale the general features of an ancient belted coastal plain. These features are best preserved in the region of the Great Lakes. The most continuous development of the cuesta feature is that associated with the outcrop of Niagara limestone which appears in the form of a pronounced but ragged escarpment extending from near Rochester on the southern shore of Lake Ontario diagonally northwestward through Ontario, forming the peninsula between Georgian Bay and Lake Huron. Thence it extends through Manitoulin Island and along the southern shore of the northern peninsula of Michigan. Farther west and southwest it constitutes the two peninsulas between Green Bay and Lake Michigan, and its final expression in the United States is in the southwestern corner of the Driftless Area, where it forms the boundary of an upland approximately 100 feet above the general level of the country adjacent to it on the north.[1]

West of Lake Winnipeg the Niagara escarpment again appears and fades out gradually to the north. Lakes Erie, Huron, Michigan, Manitoba, and Winnipegosis are on the outer lowland of the ancient coastal plain; Lake Ontario, Georgian Bay, Green Bay, and Lake Winnipeg lie upon the inner lowland between the cuesta[2] and the old-land;[2] Lake Superior occupies a depression not associated with either lowland or cuesta.

Upon the Hudson Bay side of the Laurentian Plateau a similar margin of Paleozoic sediments may be seen, although they are more extensively concealed by the deposits of the present coastal plain than is the case

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[1] U. S. Grant, Lancaster Mineral Point Folio U. S. Geol. Surv. No. 145, 1909. See geologic map and descriptive text.

[2] The term *cuesta* is applied to the culminating ridge on the inner side of a dissected coastal plain. Its outer slope is long and gentle, its inner slope short and relatively steep. The term *old-land* is applied to any extensive tract of older and higher land that supplied land waste out of which the young land, or bordering coastal plain, was formed.

on the southern margin. Over the peninsula southwest of Cape Henrietta Maria in the angle between Hudson Bay and James Bay these Paleozoic sediments are developed to their greatest extent, but the cuesta feature is topographically very indistinct. On the eastern shore of Hudson Bay and James Bay the Paleozoic sediments have been dissected and submerged to the point where they now appear as chains of islands in some places continuous with anvil-shaped peninsulas. At one time the land stood higher than it now does, and dissection progressed so far that with a later submergence of the region and the invasion of the eroded lowlands by the waters of Hudson Bay the cuesta was almost submerged; the degree of submergence was so great that the cuestas still appear as islands in spite of the great uplifts which the region has suffered in postglacial time.

In a large number of instances the streams of the Laurentian Plateau discharge across its borders in gorges and canyons of noteworthy size and beauty. In places the gorges and valleys are steep-sided, narrow, and long; in other places they are short. They have their best development along the southeastern border, where the numerous streams that enter the Gulf of St. Lawrence from the northwest have deep canyons (sometimes with unscalable walls) cut to a depth of over 1000 feet below the general level of the plateau. A specific case is the Saguenay, through which Lake St. John discharges into the St. Lawrence. Lake Temiskaming and Ottawa River, as far down as Mattawa, likewise occupy long narrow depressions cut beneath the surface of the plain. All of these canyons and deep, steep-sided valleys are marked by topographic unconformities, that is, well-defined shoulders where the steep slope of the valley wall intersects the rather flat slope of the upland surface, a clear indication that the canyon is of later origin than the upland surface below which it is incised. Where the deep preglacial canyons and gorges trend in the direction in which the ice flowed in the last glacial invasion the sides of the gorges have been steepened and the bottoms deepened. This is especially true of the Saguenay, which may probably be regarded as a typical glacial fiord, although it must be remembered that preglacial erosion had to a large extent prepared the valley for the maximum effects of glaciation as expressed in hanging valleys and deep channels below sea level.

The fact that some of the long, narrow, and steep-sided gorges or depressions are at various angles with the direction of ice movement suggests that they owe their origin to the downfaulting of long narrow crust-blocks. This view would seem to be supported by the fact that Paleozoic sediments are preserved in the bottoms of many of the valleys.

The sediments in the Lake Temiskaming and Lake Nipissing basins are in valleys lying below the level of the plateau. The margin is well defined, often cliffed, and the tributary streams spill over the edge of the basin in a series of waterfalls and cascades where they pass from the more resistant to the less resistant rock.

The long narrow depressions may be explained also on the assumption of an early Paleozoic period of valley cutting followed by a period of valley filling. In this view later valley excavation would proceed along the outcrop of the relatively softer filling in the older valleys. It seems quite probable that further work will show the validity of both explanations each being applicable to a number of valleys to the exclusion of the other.

SPECIAL FEATURES OF THE NIPIGON DISTRICT

The topography of the Nipigon area north of Lake Superior is of special interest because the normal erosion features have been either partly masked or greatly complicated by lava flows. To the northeast of Lake Nipigon is the Archæan old-land of crystalline rock containing numerous outliers of sedimentary strata. The southwestern portion of the present basin of Lake Nipigon represents a maturely dissected portion of the inner lowland of the ancient coastal plain.

At a time when the relief of the coastal plain was at a maximum there occurred extensive intrusions of diabase and extrusive flows of basalt which to a large degree filled the inner lowland and even in some places poured out over the adjacent uplands. This period of lava flows followed the erosion that in turn followed peneplanation. Since its formation the diabase has been very extensively eroded so that only from 5% to 10% of it remains, but its occurrence dominates the region to such an extent that practically every prominent feature of the topography for one hundred miles along the southwest shore of Lake Nipigon and the adjacent country is associated with the trap sheets. Their upper surface is usually a tableland or mesa, and gorges have been cut to a large extent through the sheets by the draining streams. Beneath the basalt may be seen from place to place portions of the old peneplain which were still in existence when the flows occurred and which were covered over and so preserved by the resistant rock. The scenery is varied, bold, and picturesque, as determined by the sharp outlines of the igneous rocks whose cliffs were still further cleaned and freshened by glacial action.

CHANGES OF LEVEL

The change of level which the Laurentian Plateau is now undergoing and which it has undergone in postglacial time is shown in a variety of most convincing ways. At Cape Nachvak, one hundred and forty miles south of Hudson Straits, are old strand lines reaching up to 1500 feet above sea level. Also on the east coast of Hudson Bay are well-preserved and numerous terraces cut in till and other deposits reaching to an elevation of 300 feet above the sea. Deep-water species of shells are washed out of the present beach and are found in stratified clays up to elevations of 500 feet; and long, continuous lines of driftwood, chiefly spruce and cedar, occur 30 feet above tide. These data combine to prove that the region has suffered important changes of level so recently as still to preserve in the clearest manner the features indicating uplift. Besides the physical features there are a number of important and convincing pieces of human evidence. The Eskimos of the region catch fish by constructing weirs of stone which at low tide impound fish that have come up close inshore during high tide for feeding purposes. These fish weirs and traps are found at all elevations up to 70 feet above present sea level, and as their use is invariably associated with the shore line of the time when they are employed, it is clear that the level of the land has changed not less than 70 feet since the Eskimos have inhabited the region. Hudson mentions wintering in a bay full of islands where now only a canoe may pass, and the salt marshes about the border of Hudson Bay are drying up to such an extent that the geese and ducks which formerly made their home among them have extensively abandoned them, and the residents of the district find it increasingly difficult to secure the eggs of these wild fowl. Finally, the Indians often remark the growing distances between old buildings, forts, trees, and the shore line, although this piece of evidence is of course far less convincing than the others.[1]

On the east coast of Labrador along the 1100 miles from St. John to Cape Chidley no careful measurements of postglacial uplift have been made, although Daly has approximated the amount by observations upon the distribution of bowlder clay and bowlders.[2] He concludes that the higher bowlder-covered zone has never been submerged since the ice sheet retreated from the country, and that the lower bowlderless zone is a wave-swept zone. He finds that the smooth unbroken surfaces

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[1] R. M. Bell, Proofs of the Rising of the Land around Hudson Bay, Am. Jour. Sci., vol. 1, 4th ser., 1896, pp. 219–228.

[2] R. A. Daly, The Geology of the Northeast Coast of Labrador, Bull. Mus. Comp. Zoöl., vol. 38, 1902, p. 254.

of the roche moutonnées in the bowlder-covered zone (about 75 feet above sea level) contrast strongly with the jagged and riven wave-swept ledges below that level. Low, steep, and rugged cliffs are sometimes found associated with pebble and bowlder beaches of limited development. The elevatory movements continue in both Labrador and Newfoundland, as determined by the testimony of the inhabitants in regard to the decreasing depth of water on the beach and the gradual shoaling of water over ledges and bowlders off shore. The recency of the shore uplift is also shown in the numerous fresh-water ponds lying back of the barrier beaches — ponds that at one time were true coastal lagoons on the landward side of submarine bars. The forms are strikingly fresh, the glaciated, bordering slopes having contributed but little land waste to shore filling.

THE LAKE REGION

The Laurentian area of Canada constitutes the greater part of the lake region of North America whose boundaries are shown on p. 565. It has been stated that there are areas within it 25% of whose surface is occupied by lakes.[1] In order to get a closer value for this interesting condition the actual areas of the lakes represented upon a detailed map by Collins,[2] Fig. 225, were carefully measured. Some thirty independent measurements of the lake areas afford a mean that is close to accuracy. The result: about 16% of the total area of the district is covered with water. When it is considered that this value is for a representative district the figure is very striking indeed. However, even on this map only the more prominent lakes were represented on the original sheets. Were even the smallest lakes included, at least 20%, and possibly 25%, of the surface would be found covered with water. To secure a comparable figure for total lengths of drainage systems composed of lake, about 2000 miles of river course were measured, with the result that the rivers examined showed lake in 57% of their total length.

To a large extent the abundance of lakes in the prevailingly rocky Laurentian Plateau is due not alone to glaciation but to glaciation of a peneplain of such perfect development that the slightest degree of roughening by differential erosion would produce enclosed basins in large numbers. If the region were mountainous the effect of glacial erosion would be in the main to deepen the valleys and basins already formed and accentuate the preglacial differences of level and topographic form. We have only to recall the appearance of the glaciated mountain region of

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[1] A. W. G. Wilson, The Laurentian Peneplain, Jour. of Geol., vol. 11, 1903, pp. 645–650.

[2] W. H. Collins, Report on a Portion of Northwestern Ontario traversed by the National Transcontinental Railway between Lake Nipigon and Sturgeon Lake, Ann. Rept. Can. Geol. Surv., 1908.

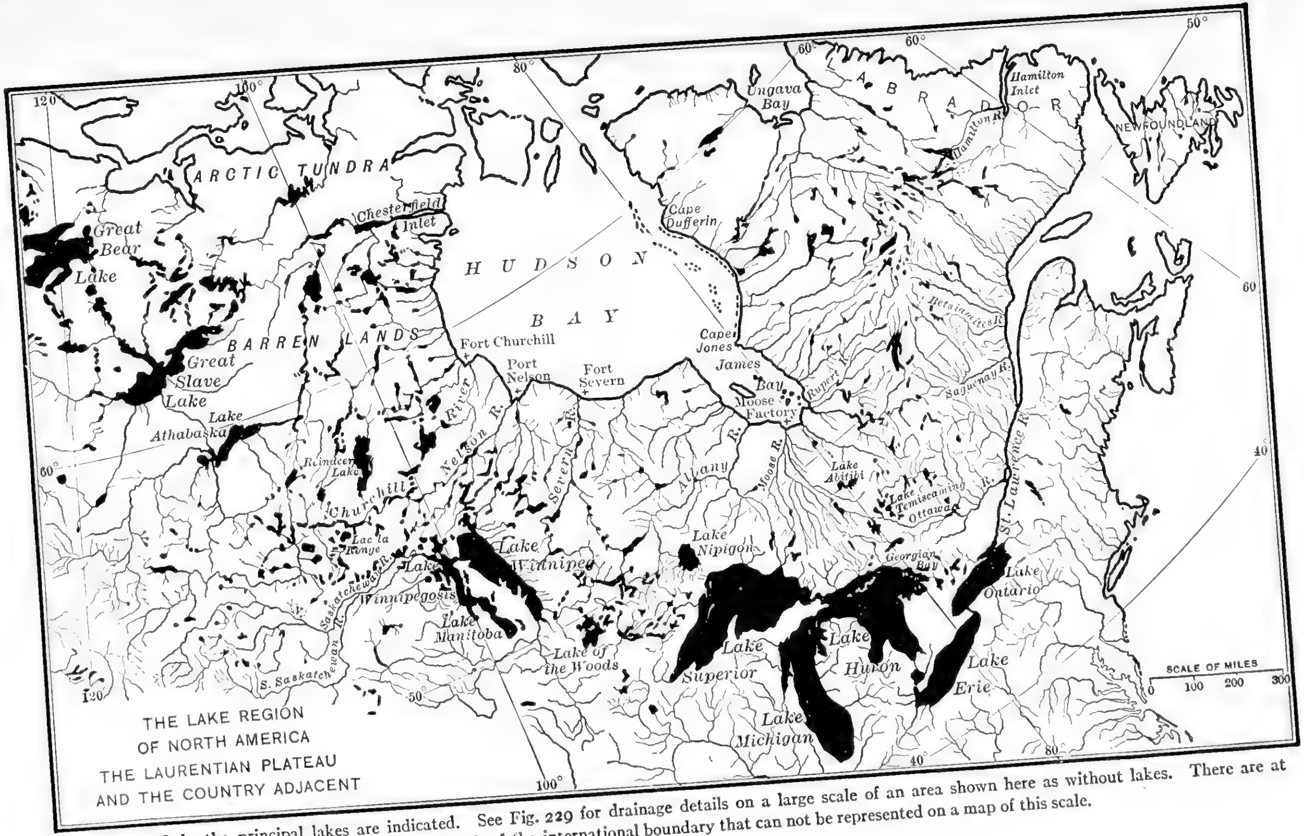

Fig. 225. — Only the principal lakes are indicated. See Fig. 229 for drainage details on a large scale of an area shown here as without lakes. There are at least 20,000 small lakes south of the international boundary that can not be represented on a map of this scale.

the northern Cascades and the northern Rockies, with their strong topographic discordances, to appreciate how different the Laurentian area would appear if its local relief had not been so slight as to be almost negligible. Even rocks of the same geologic age and general character vary sufficiently from place to place to cause important differences in topography; and when it is considered that so large a variety of rocks as granites, gneisses, schists, slates, and trap sheets that occur here extend these differences in resistance from place to place, it is clear that some roughening of the old peneplain must follow upon erosion of any sort and that in the case of ice the roughening would result in the formation of a very large number of lake basins. The preglacial slopes were almost never so strong as to overcome the general irregular scooping action of the ice, and every local overdeepening either as the result of decreased rock resistance or of glacial convergence produced reversed slopes that were occupied by lakes as soon as the glacial cover withdrew.

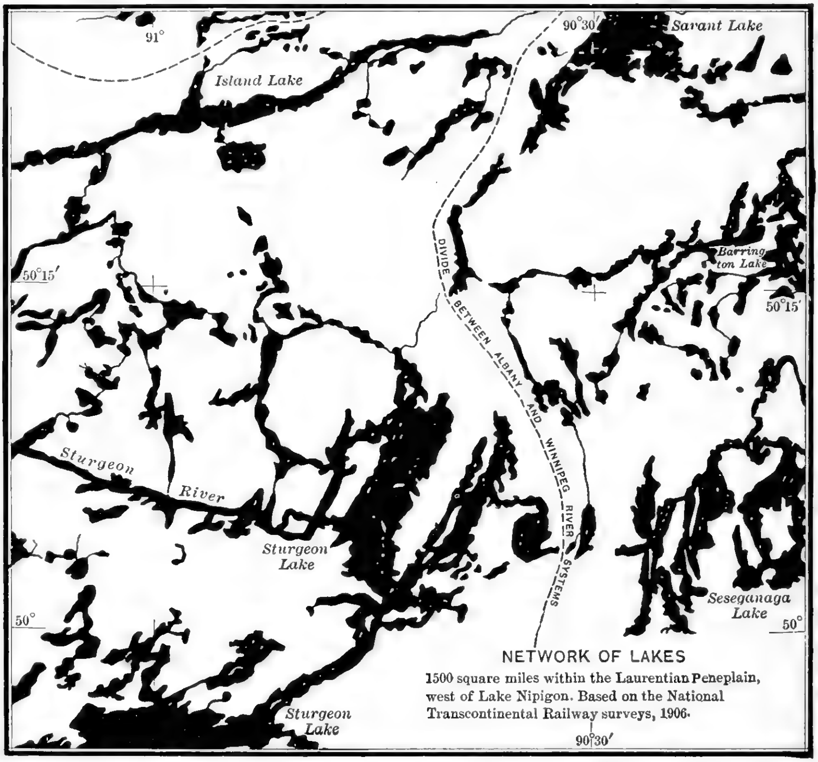

Fig. 226. — Details of drainage in a limited portion of the Laurentian Plateau. (Based on Can. Geol. Surv. Maps and Railway Surveys by Collins.)

It is clear that the glaciation of the Laurentian Plateau would result in the formation of a large number of lakes, and that the lakes would be extremely irregular in contrast to the regularity of the lakes that occupy overdeepened portions of glaciated mountain valleys. Labyrinthine shores and shapeless islands are the rule in the Laurentian of Canada. The maze of waterways displayed by this region is the marvel of every traveler in it.

The readiness with which some of the lake basins were formed may be judged from the fact that but a slight change of level may effect a change of outlet, as has been suggested many times in connection with the two-outlet phenomena commonly displayed by many of the Laurentian lakes. The feature was regarded as a novel one when first described, but the repeated finding of lakes with two outlets shows it to be a very much more general occurrence than was at first supposed. It has already been noted that the whole northeastern corner of the continent is suffering a change of level and that the movement is upward on the north. The result, in the case of lakes lying in depressions with low rims, is to cause a new outlet to come into existence as the old outlet ceases to function through uplift. The abandonment of an old outlet would of course be gradual and for a time two outlets would function. Even without such a change of level it has been thought that two-outlet lakes may have been caused by the formation of exceptionally shallow basins on a peneplain surface. The two-outlet feature is indeed thought to be on such a scale as to be independent evidence of the tilting of the land. In some cases, however, where two and even three outlets are in existence, they are found on the same side of a lake. Lake Chibougamou (50 miles south of Lake Mistassini), for example, is drained by two outlets both of which are on the east side.[1] In such cases the two-outlet feature is unrelated to regional tilting and appears to be due instead to coincidence in the level of low cols on the rim of the lake basin. The condition is perpetuated by the hard rock which is but little affected by the clear streams.

Besides the island-dotted lakes with ragged shores there is a distinct though comparatively small class of lakes that has more regular features. These lakes are usually longitudinal and are caused in a number of different ways. In some cases they owe their existence to the erosion of soft dikes, as, for example, the peninsulated northern shore of Lake Superior with its long narrow bays and points. The dikes are commonly of greenstone, though sometimes they are of pegmatite, and in both cases are usually soft and their outcrop covered with lakes or streams. Sometimes the correspondence of position of former dike and later river or lake is so close that where the dike narrowed the lake or river was narrowed and where it widened the drainage features widen. It must not be forgotten, however, that the dike material is not always softer than the country rock; where it is harder it stands out as a prominent ridge instead of a lake basin or a river valley. The straightness of trend of the dikes within short distances is directly related to the straight-line topography and drainage so characteristic in many portions of the area as to give a pronounced appearance of artificiality to it. Lake Temiskaming and the "Deep River" of the Ottawa drainage sys-

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[1] Data from Bateman, Can. Geol. Surv.

tem are examples of longitudinal lakes, but their origin may have been due to crustal warping or to block-faulting of the *graben* type. In still other cases the longitudinal lakes are due to blocking of valleys by glacial material.

In addition to the lake types of the Laurentian that we have noted there is another class dependent upon broader and less local conditions. These lakes lie on the border of the region and their occurrence is coincident with that of large isolated areas of sedimentary rock within or on the border of the crystalline area. Whether these sedimentary masses represent downfaulted blocks of rock formerly more extensive than now, and preserved by downfaulting because carried below the general level of the peneplain surface, is not certainly known, but the explanation has a high degree of plausibility, for faulted zones have been found about the borders of some of them and everywhere the sediments are sharply localized and extend to great depths below the level of the ancient peneplain. Whatever their origin they were areas of weakness during the glacial period and indeed ever since the elevation of the peneplain, with the result that not only do lake basins lie in them but the outcrop of the softer sedimentaries is always marked by the existence of a lowland whose border is sharply determined by the crystalline rocks that rim about it. A typical occurrence is at Lake St. John, which occupies a portion of an outlier of the Paleozoic sediments that border the St. Lawrence Valley on the north. The outlet of Lake St. John is over a harder rock rim to the

Fig. 227. — View on the shore of Lake St. John, Quebec. The level sky line in the background represents the Laurentian Plateau; in the foreground is a lowland developed on limestone; in the middle distance are alluvial terraces.

Saguenay, and falls and rapids mark the transition from one rock belt to the other. Hamilton Inlet, Great Bear and Great Slave lakes, and many other depressions have a similar origin, and in all cases small portions of the older sedimentary rock still cling to the border of the depressions in the crystalline tract, or, as at Lake St. John, occur in larger masses forming lowlands.

Lakes are known to be ephemeral features of the earth's surface and to be the easy prey of geologic processes. Commonly the streams that feed lakes bear such quantities of material into them and the draining streams cut down the rim at the outlet so fast and vegetation accumulates so rapidly that the life of a lake is in a geologic sense short. It is therefore interesting to find in this great lake region developed on the Laurentian of Canada a set of conditions that insure the longevity of the lakes within it, so that at least a whole geologic period would seem to be a conservative estimate of the length of time these lakes will persist. The principal conditions that are the basis for this conclusion are as follows. The fresh-rock rims have an exceptionally high degree of resistance. Instead of rotten rock the rock enclosing these lakes is firm. The products of decay were swept off by the continental ice sheet, leaving the undecomposed rock of the subsurface. Although falls and rapids abound the average gradient of the draining streams is only one to two feet per mile. In addition to the practical absence of land waste over vast portions of the Laurentian area, lakes are so abundant that the water is thoroughly filtered and the sediments are thoroughly entrapped. The streams are thus deprived of their cutting tools and waterfalls and rapids retreat with amazing slowness in the extremely hard rock. More powerful than these factors in extinguishing some of the Laurentian lakes is the vegetation that grows in such abundance about the borders of the shallower lakes as sometimes quickly to effect their reclamation. Lakes are turned into swamp or muskeg and then finally reclaimed, but the process is largely limited to the smaller and shallower lakes and does not affect to an important degree the conclusions we have just stated concerning the life of the lakes as a group.

VEGETATION

There is a limited forest growth in the hollows and along the borders of the Labrador region, but large portions of the interior are barren tracts of rock and muskeg. Exceptionally good forest tracts are found in a number of places. On the 51st parallel and east of Lake Mistassini, whence the Porcupine Range extends toward the north, is a well-wooded tract. The black spruce is here the predominating species. Other trees are the white birch, poplar, willow, alder, and Banksian pine. The growth is surprisingly large; the diameters of the largest trees exceed 2 feet and the height attains 70 or 80 feet.[1] Quebec and Ontario south of James Bay are densely forested, the forests extending westward to within a short distance of Great Slave Lake. Beyond this point the region may be described as a treeless moss-covered tundra whose subsoil is perpetually frozen. The northern boundary of the great transcontinental spruce forest closely follows the western shore of Hudson Bay from the mouth of Churchill River for a few miles, then curves gently inland; thence it extends northwesterly, crossing Island Lake, Ennadai Lake on Kazan River, and Boyd Lake on the Dubawnt. The next dividing point is just north of 60° on Artillery Lake. From this point the line curves southwesterly, crossing Lake Mackay south of latitude 64°. The banks of the Coppermine are the boundary to 67°. Tongues of timber follow the northward-flowing streams, with their warmer water, well into the Barren Grounds. The most remarkable stream of this kind is the Ark-i-linik, a tributary of Hudson Bay. From a point near latitude $62\frac{1}{2}°$ north, within the main area of the Barren Grounds, a more or less continuous belt of spruce borders the river to latitude $64\frac{1}{2}°$, a distance of over 200 miles by river. A few species of woodland-breeding birds follow these extensions of the forest to their limits. Alders occur in more or less dwarfed condition in favorable places well within the treeless areas, and several species of willows, some of which here attain a height of 5 or 6 feet, border some of the streams as far north as Wollaston Land. These are the only trees which occur even in a dwarfed state in the Barren Grounds proper.

The principal trees of the spruce forest, whose northern limit is thus defined, are the white and black spruce, whose range is coextensive with the forest limits, the canoe birch, tamarack, aspen and balsam poplars, Banksian pine and balsam fir common in the southern part of the belt and terminating from south to north about in the order given. With these are associated, generally in the form of undergrowth, a number of shrubs. The tree limit on the western mountains in latitude 56° is about 4000 feet. The head of the Mackenzie delta is marked by islands well wooded with spruce and balsam poplar. Lower down these trees give way to willows, which continue to the Arctic shore.[2]

South of the line noted above is a belt of conifers stretching across

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[1] R. McFarland, Beyond the Height-of-Land, Bull. Phil. Geog. Soc., vol. 9, 1911, p. 31.

[2] E. A. Preble, A Biological Investigation of the Athabaska-Mackenzie Region, North American Fauna, Bureau of Biol. Surv. No. 27, 1908.

northern North America from Hamilton Inlet to Great Slave Lake, the trees increasing in size and variety toward the south. This is the great spruce forest belt of Canada, whose characteristic growths are spruce, fir, poplar, willow, alder, tamarack, etc., and in the Great Lake region its borders are covered with forests of deciduous hardwood.[1]

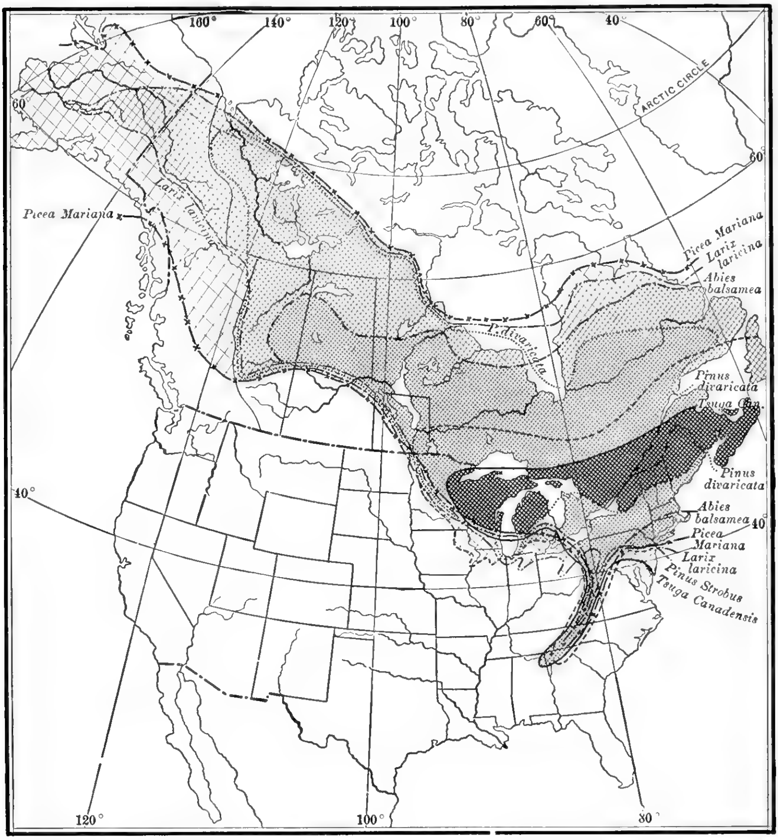

Fig. 228. — Map showing distribution of the dominant conifers in Canada and eastern United States. (Transeau.)

The uniformity of level, the prevailing absence of soils, and the widespread occurrence of lakes, favor uniform life conditions through-

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[1] R. M. Bell, The Geographical Distribution of Forest Trees in Canada, Scottish Geog. Mag., vol. 13, 1897, pp. 281–296.

out the region, a fact well shown by the widespread distribution of the fur industry, which is also favored by the equally widespread forest growth, while the network of navigable streams and lakes makes communication relatively easy as unsettled countries go.

Superior Highlands

After consideration of the topographic, drainage, and soil conditions of the Laurentian area of Canada the features of the Superior Highlands may be easily appreciated, for this physiographic province is but a part, strictly speaking, of the great Laurentian area of Canada. Like the latter, its sky line is distinctly even and gives little hint of the mountainous structures that prevail almost everywhere within it. Its principal topographic feature is an uplifted and dissected plain of erosion which has been glaciated and hence has many secondary features due to ice erosion. It lies neither in the region of pronounced glacial aggradation nor in that of intense glacial denudation; hence those forms that are of glacial origin are due in some cases to ice scour, in others to ice accumulation. A certain amount of glacial detritus occurs here and there; in other localities the surface is swept practically clean by gla-

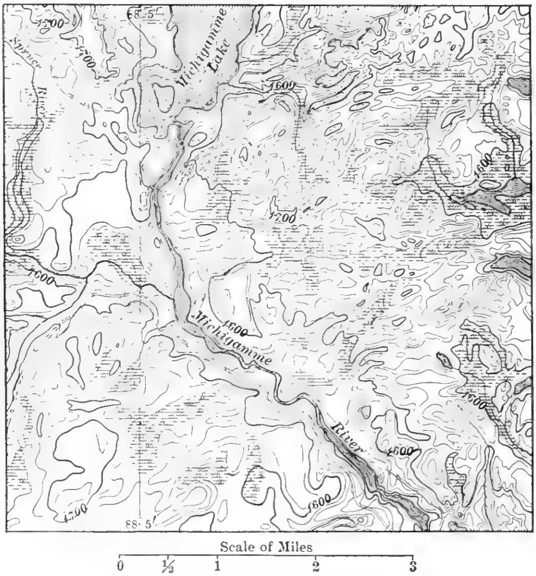

Fig. 229. — Typical drainage irregularities in the Lake Superior Highlands. (U. S. Geol. Surv.)

cial erosion. The glacial material is irregularly disposed in characteristic fashion and blocks the drainage to such an extent that lakes and ponds occur in large numbers. The most common type of depression is in the form of a small basin partly grown up to bushes and grasses, a swampy tract called a "muskeg."

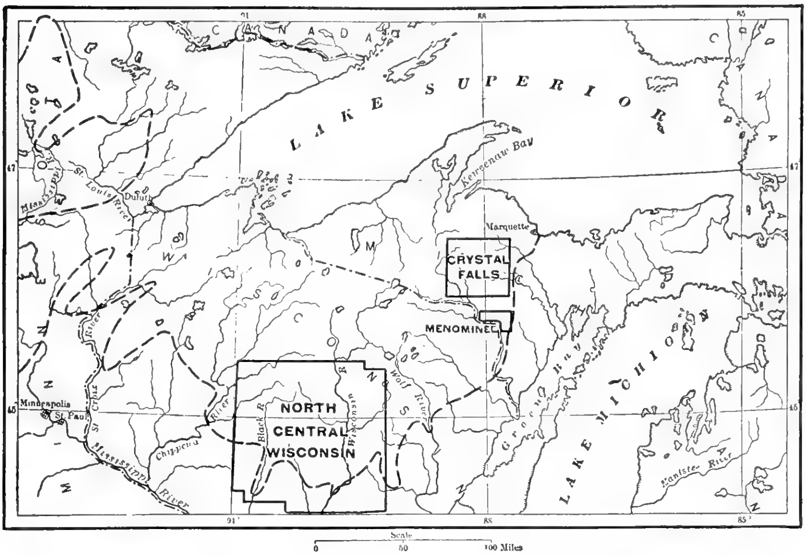

Fig. 230. — The heavy broken line is the boundary between the Superior Highlands on the north and the Prairie Plains on the south. It is, however, more prominent as a geologic boundary than as a topographic boundary. Note the connection at the western end of Lake Superior between the Superior Highlands and the Laurentian Plateau of Canada. The special districts indicated are portions of the region described in the text.

In describing the detailed features of the area we shall select two tracts that have been well explored and that are representative of the whole area. In examining them it is well to remember a number of general features. The region consists of crystalline rock, — gneiss, granite, and schist as well as slate, dolomite, sandstone, limestone, and other types. The crystalline rock predominates throughout the greater part of the area; the sedimentary rock occurs chiefly upon the borders. The crystalline rock dips at so high an angle that it is often vertical, thus exposing rock types of different hardnesses side by side in narrow belts. The result is that a valley carved in the soft rock may not be very deep and yet may have nearly vertical sides, so that the country often has a very rugged appearance in detail that is the result of recent erosion and yet not lose on the interstream areas that plateau quality that is the result of prolonged erosion in early (pre-Cambrian) and later (Jurassic-Cretaceous) geologic time. The structure of the sedimentary rocks (Paleozoic) is in sharp contrast to that of the crystallines. The former lie in comparatively flat attitudes, dipping only slightly outward (southward), Fig. 232. In many places outliers of these flat to gently inclined strata occur beyond the main border of the sedimentaries and in such instances cap the vertical crystallines and accentuate the plateau quality of the region. Their nearly vertical cliffed borders add also to the steepness of the valley sides.

Almost the entire zone of decomposed rocks formed in preglacial time in the Superior Highlands was removed by glacial erosion; indeed glacial truncation was so pronounced as seriously to reduce the amount of available iron ore in the Lake Superior region. In many places the ice cut deeper into the soft ore bodies than into the adjacent harder rocks and thus produced subordinate valleys in sympathy with the ore deposits, a feature that is well illustrated in the Mesabi district. The soft ores were so comminuted that they are not easily distinguishable in the drift, but the hard ores occur in the glacial drift farther southeast and indeed in the whole region so plentifully that it is clear that a great portion was swept away by the ice.[1]

REPRESENTATIVE DISTRICTS

CRYSTAL FALLS DISTRICT [2]

The Crystal Falls district in the Superior Highlands is a somewhat rolling plain sloping gently downward to the southeast at an average rate of a little less than 20 feet per mile. Its average elevation is 1200 to 1300 feet above the sea. This plain is formed in part upon soft and gently inclined sandstones (Upper Cambrian) and in part upon crystalline and much harder and more highly tilted rocks (pre-Cambrian) of varying characters, though it everywhere maintains a very uniform slope regardless of the underlying rock formations. The minor topographic features of the plain have a large variety of form and detail yet very small relief. There are no commanding eminences and the sky line is generally even. Portions of the border of the mountain

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[1] C. R. Van Hise, The Iron Ore Deposits of the Lake Superior Region, 21st Ann. Rept. U. S. Geol. Surv., 1899–1900, pt. 3, pp. 333–336.

[2] H. L. Smythe, The Crystal Falls Iron-bearing District of Michigan, Mon. U. S. Geol. Surv. No. 36, 1899, pp. 331–333.

area are composed of crystalline rock, and here the surface is dotted with rocky knobs generally elongated east and west, which is the direction both of the gneissic foliation and of the ice movement. The elevations rise 5, 10, 20, and in some cases 60 feet above the intervening depressions and have steep smooth walls. The slight relief of the district is indicated by the fact that the more prominent elevations are deposits of modified drift. Only occasionally are they due to small rock masses of harder material, as Michigamme Mountain, which reaches an elevation of 200 to 300 feet above the general level, an elevation sufficiently great in a region of very slight relief to result in the application of the name "mountain" to what would generally be regarded as a very insignificant topographic feature. The details of the topography are primarily glacial in origin and only secondarily a response to geologic structure.

The almost innumerable muskegs or basin-like depressions are the work of either irregular glacial cutting or filling. Where softer rock occurs the ice gouged out a depression; where the rock is exceptionally resistant a knob or ridge is the result. Hills of glacial drift are scattered about the surface in large numbers. A glacial soil is also developed over a large part of the tract but has been entirely washed away and the rock surface laid bare on many steep slopes where it was originally thick and where fires and lumbering operations have removed the forest cover and allowed soil erosion to take place. The structural domes of crystalline rock have a characteristic topographic expression, their margins being frequently abrupt and in places marked for considerable distances by scarp-like slopes in the granites where vertical contacts with softer formations occur. These broad zones of harder rock are separated by broad and slightly lower lying plains, in many of which a valley character is still distinguishable in spite of extensive glacial modification. The existing drainage follows in a general way the older (preglacial) valleys, although the relation is oftentimes much confused in its details since glacial drift now lies irregularly disposed on the floors of the preglacial valleys.

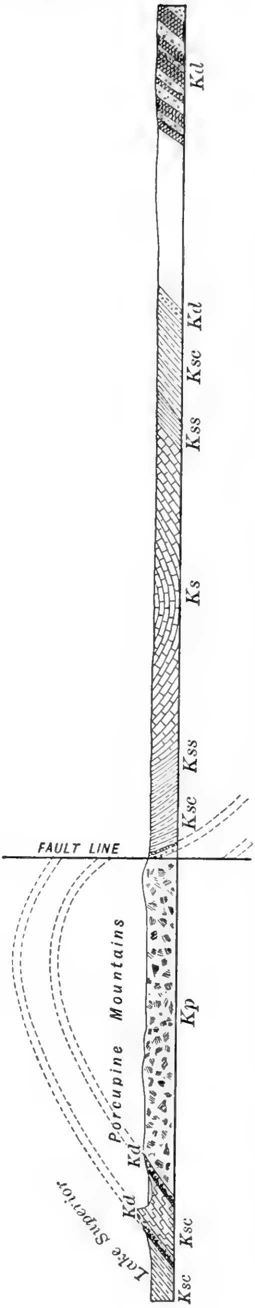

Fig. 231. — Deformation of strata near Porcupine Mountain, northern Michigan, in the Superior Highlands Province. Kd, diabase; kp, porphyry; ksc, sandstone; sandstone, conglomerate; kss, sandstone, shale. Length of section, 15 miles. (Irving, U. S. Geol. Surv.)

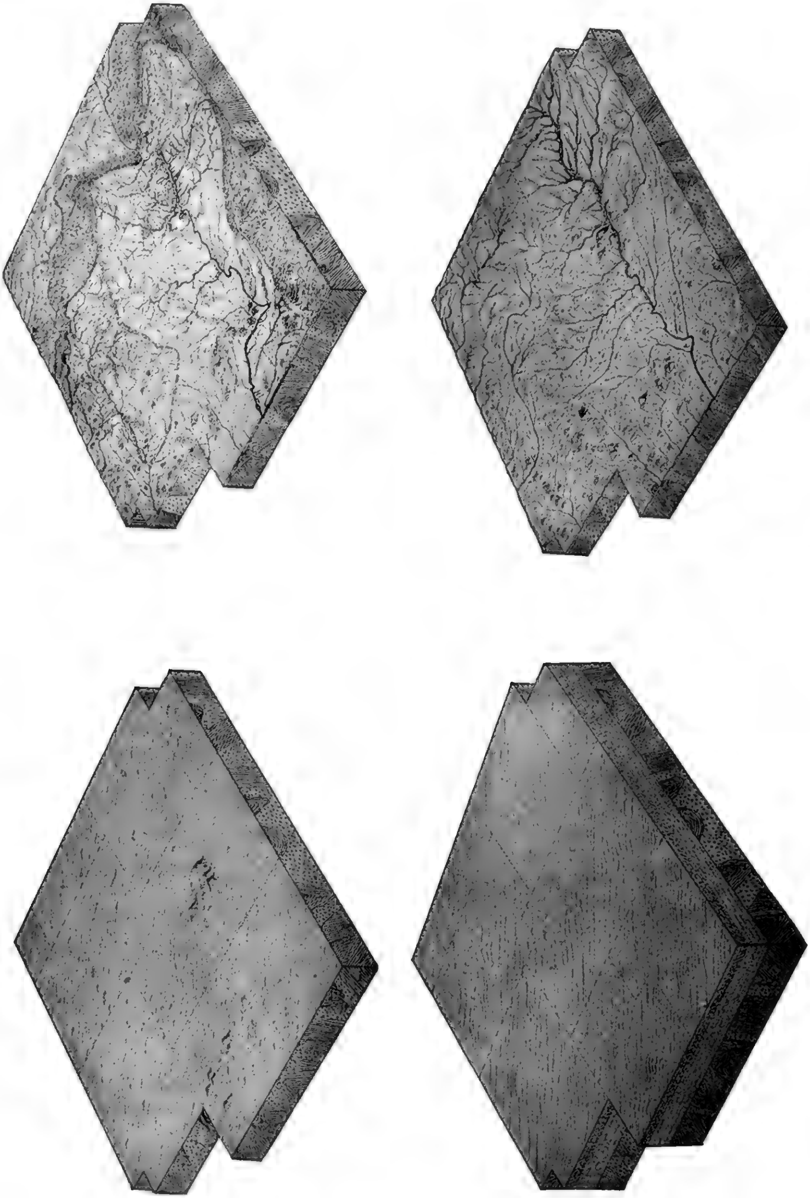

Fig. 232. — Structure and topography of the southern border of the Superior Highlands. (Weidman, Wisc. Geol. Surv.)

SOUTHERN DISTRICT

The southern portion of the Superior Highlands (central-northern Wisconsin) consists of a main upland, an uplifted and dissected peneplain with a very even summit below which the Wisconsin River and its tributaries have eroded their valleys and above which project a few isolated hills and ridges. The plain gradually descends southward and finally diverges; one plane runs under the Potsdam sandstone which forms the northward margin of the Paleozoic deposits of the region and another extends across the Paleozoic formations. In the vicinity of Grand Rapids, Wisconsin, and approximately at the border of the sandstone district, 1000 feet above the sea, the valley bottom of the Wisconsin River practically coincides with the level of the lower or pre-Cambrian plain. The pre-Cambrian and the main crystalline rocks are very much folded and crumpled and the dips are at various angles and frequently almost vertical, Fig. 233.[1]

The structures are such as are associated, in the early stages of a first topographic cycle, with topographic features of mountainous proportions and in their present planed condition indicate that widespread peneplanation has taken place. The stratigraphic conditions show that this peneplain was of pre-Cambrian age and was buried by Paleozoic sediments to be reëxposed by the long interval of erosion between the Cretaceous and the Quaternary. During the Jurassic-Cretaceous cycle of erosion the marginal deposits were in part stripped from the pre-Cambrian peneplain and in part

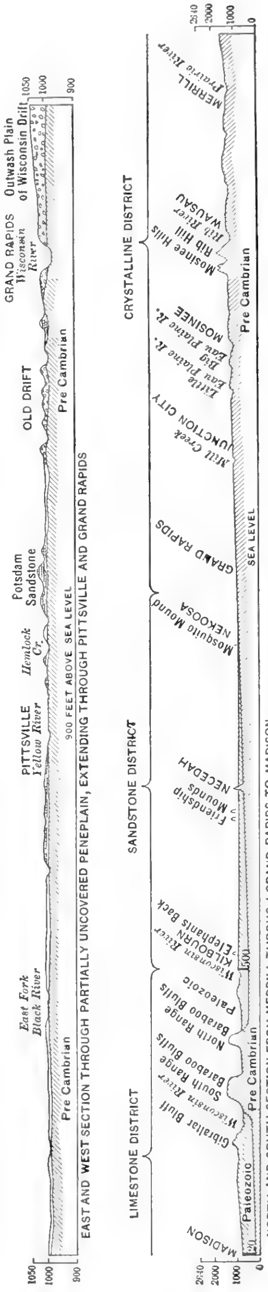

Fig. 233. — Sections showing the character and relations of the pre-Cambrian and Cretaceous peneplains in northern Wisconsin. (Weidman, Wisc. Geol. Surv.)

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[1] S. Weidman, The Geology of North-Central Wisconsin, Bull. Wisc. Geol. and Hist. Surv. No. 16, 1907, pp. 592 ff.

beveled to the form of a lowland plain. The Cretaceous peneplain made but a slight angle with the pre-Cambrian peneplain, and the widespread occurrence of the later peneplain in this region is probably to be ascribed in large part to the earlier peneplanation which had largely obliterated the relief.

Adirondack Mountains

The Adirondacks are a small group of mountains in northeastern New York whose northern and southern slopes descend to tidal valleys, the Hudson and the St. Lawrence. The relative altitudes are therefore great and the absolute altitudes are such that the dominating peaks rank with the highest in the eastern half of North America. Mt. Marcy (the "Tahawus" or "Cloud-Splitter" of the Indians) rises to 5344 feet above the sea, and Whiteface is not much lower with an altitude of 4900 feet. For a long time after the fertile and easily traversed valley of central New York had been inhabited the Adirondacks were still an untamed wilderness. Dense forests clothed slopes and summits alike; deep valleys with steep descents and tillable land of small extent did not tempt the farmer.

GEOLOGIC STRUCTURE

The whole of the Adirondack region consists of a great series of metamorphic rocks,— sediments, gneisses, quartzites, and coarsely crystalline limestones on the one hand and igneous rocks, such as syenites, granites, and gabbros on the other. Roughly speaking, the region is composed essentially of gneiss, with numerous and rather generally scattered limestone belts, the whole cut through on the east by immense intrusions of gabbro. The rocks and their relations are very similar to those of the Laurentian area of Canada. Excepting the limestones all of the rocks are hard and resistant to erosion, so that their weak points are structural features — to a small degree their planes of schistosity and to a greater degree their joints and faults. Wrapping all about the Adirondack nucleus are sedimentary strata, chiefly of marine origin, whose material was largely derived (in so far as it is land-derived) from the Adirondack massif during the prolonged periods of erosion in which the Adirondacks existed as land masses. In some cases, as on the west and northwest, the sedimentary rocks (Paleozoic) overlap the crystalline rocks (pre-Cambrian) of the mountain mass; in other cases, as on the northeast and east, the transition from the rocks of the mountains to those of the bordering plateaus and plains is more abrupt — the result of block-faulting somewhat modified in detail through the influence of post-faulting erosion and glacial action. In general the sedimentary rocks — sandstones, limestones, and shales — have little to do with the physiography of the mountains, for with few exceptions they lie on their border.

TOPOGRAPHY AND DRAINAGE

A striking feature of Adirondack relief is the strong contrast between the eastern and western halves of the mountain tract. The western half of the Adirondack area is really an extensive upland; the eastern half alone is truly mountainous. Broad and moderately deep valleys are characteristic of the western area, and the accordance of summits makes the plateau feature almost as prominent as in the Appalachian Plateaus and decidedly more so than in the Catskill Mountains. The prevailing flatness is diversified solely by the broad valleys and certain low hills which are probably residuals upon the Cretaceous peneplain whose level the even upland seems to represent. The eastern area was never base-leveled, or, if so, all traces of a former erosion surface appear to be lost in the changes that have since occurred. That the area should have escaped base-leveling is so remarkable, considering the perfection of development of the base-leveled surface in other localities around it, that a great deal of attention has been paid by geographers to this fact. Burial and reëlevation have been suggested, with the inference that, during burial, erosion ceased here while it continued elsewhere; later erosion, the stripping off of the sedimentary cover, and the reëxposure of a once buried peneplain or old surface are other assumptions required by this suggestion. Perhaps the most plausible suggestion is that the Adirondacks represent the locus of repeated movement and that the forces of erosion and uplift have been nearly balanced, so that while erosion has been tending toward the production of a base-leveled surface this tendency has been effectively offset by repeated uplift. It is known that the Adirondacks have been free from extensive folding since early geologic time (Ordovician), though they have probably been subjected to broad uplift, for sediments younger than the Ordovician have been uplifted by considerable amounts and the mountains have been uplifted by equal and possibly greater amounts.

The rugged eastern half of the Adirondacks is composed of mountains that have certain very striking features. Mounts Marcy and Whiteface, the two principal mountains of the Adirondack tract, are composed of granite and stand well above the general level. The central cluster of high peaks to which they belong is surrounded by a plateau-like tract interrupted by valleys with rather gentle slopes developed upon softer beds and now largely drift-filled. The granites are, however, not abrupt in form; they have a gentle, rather flowing outline, due to the fact that denudation has passed the stage of greatest activity. Though the Adirondacks were not obliterated during the long erosion cycles in which the surrounding tracts were peneplaned they were greatly reduced in height and softened in form. Those valleys that were developed upon the softer rocks were broadened and reduced to base level, while even those valleys that were developed in the crystallines acquired moderate slopes.[1] This marked roundness of the Adirondack mountain forms has no doubt been slightly increased by the action of the continental ice sheet which overrode the highest peaks of the mountains, although the glacial effects should be regarded rather as finishing touches than as important modifications.[2]

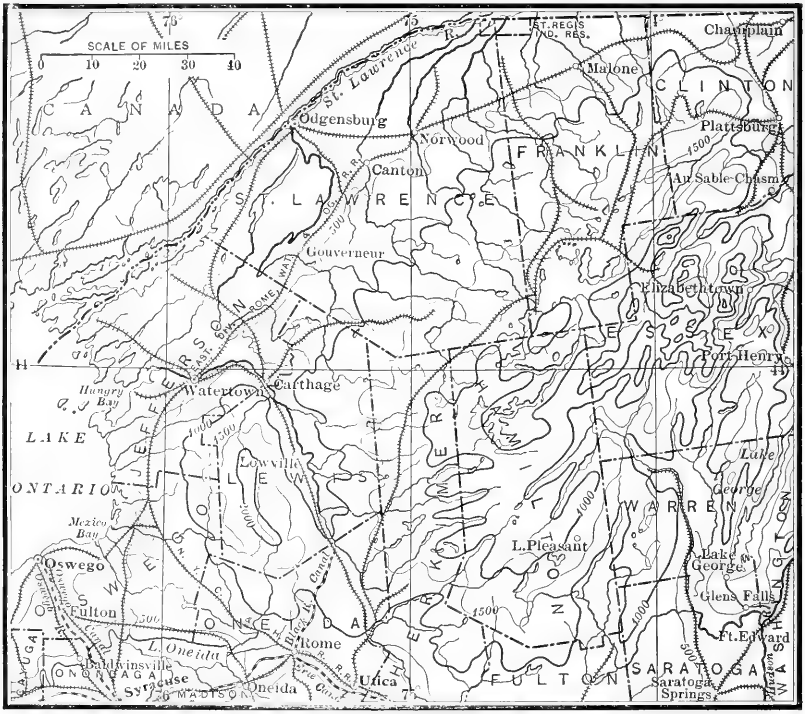

Fig. 234. — The plateau-like western portion of the Adirondack Mountains in contrast to the mountainous eastern portion. Contour Interval, 500 feet.

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[1] I. H. Ogilvie, Glacial Phenomena in the Adirondacks and Champlain Valley, Jour. Geol., vol. 10, 1902, p. 410.

[2] R. S. Tarr, Physical Geography of New York State, 1902, pp. 46–47.

The main outlines of the eastern Adirondacks were determined by faulting, while the detailed features are due to minor structural conditions such as fissures, joints, etc. The eastern section of the mountains, as shown in Fig. 234, is most affected by faults which have given the topography much sharper outlines than are as a rule found elsewhere in the Adirondacks. The faults trend northeast-southwest and northwest-southeast in two major fault systems and north and south in a third system of lesser importance. These faults control the trends of both the mountains and the intervening valleys and give them their most distinctive character. The mountain profiles are typically serrate, with a gradual slope on one side cut off by a steep slope on the other. The slopes that look to the southeast or northwest are particularly steep if not precipitous, with less pronounced steep slopes at right angles to them. So deep are some of the intermontane valleys and so steep their margins, it has been suggested that they look like undrowned fiords. Lower Ausable Lake and the central part of Lake George are illustrations of valleys which occupy depressed blocks or *graben* between the relatively elevated crust blocks that constitute the mountains. The valley trends are curiously related in the case of both tributaries and master streams and even in different sections of a single valley. There is generally a pronounced angularity or trellis pattern to the drainage, which is commonly associated with mountains of the Appalachian type that have been base-leveled and rejuvenated. In the Adirondacks, however, the pattern is unrelated to rock belts; it is due entirely to block-faulting, and had the pattern of the faulting been more irregular the drainage courses would now be more irregular.

The faults of the crystalline portion of the Adirondacks can not be worked out either in detail or with much accuracy, but on the borders of the mountains where sediments overlap the crystallines a means for determining the amount of faulting is supplied. One such fault in which the surface of a down-thrown block forms the bottom of a topographic depression or trough occurs near Northampton. The bordering parallel faults run north-northeast and have well-defined abrupt scarps about 6 or 7 miles apart. They involve up to 1500 feet of structural displacement, and the topographic depression thus created is about 1000 feet deep.[1] The occurrence is of particular interest because it is so clear-cut as to strengthen the previous explanations of the fault origin of scarps and troughs of similar character in adjacent tracts where a stratigraphic means for the determination of the amount of faulting is not at hand.[2]

On the western shores of Lake Champlain and on the shores of many other larger lakes of the Adirondacks, block-faulting has given a characteristic outline to the coastal topography. Sharp headlands with definite

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[1] See the Broadalbin quadrangle, U. S. Geol. Surv.

[2] W. J. Miller, Trough Faulting in the Southern Adirondacks, Science, n. s., vol. 32, 1910, pp. 95–96.

trend project from the general course of the coast and in many cases form the extensions of block-faulted mountains whose intervening valleys, formed on the downthrown blocks, are submerged. In general the faults

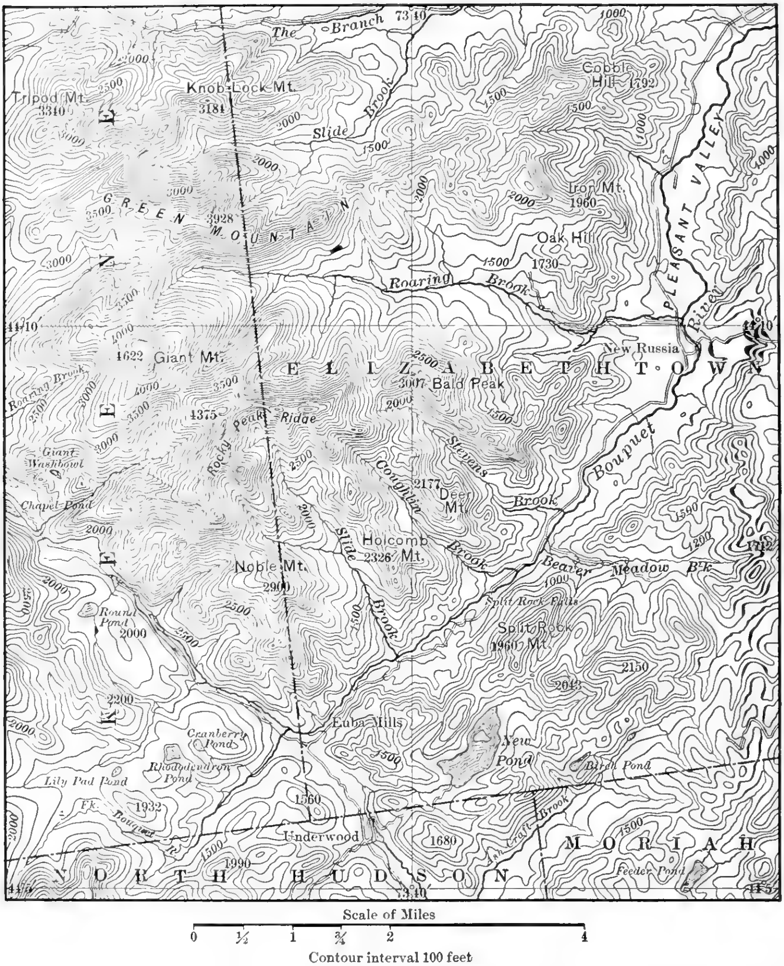

Fig. 235.— Rectangular pattern of relief and drainage lines in fault-block mountains of the eastern Adirondacks. (Part of Elizabethtown quadrangle, U. S. Geol. Surv.)

are compound, giving a terraced quality to the mountain slopes. On the slopes bordering Lake George the trees grow in pronounced rows or bands on these structural terraces, with thinner lines or bands between where the steeper slopes, thinly covered with soil, supply but little available plant food or moisture. The ridge from Black to Elephant Mountain is likewise of this character.

In addition to the fault valleys just described are a second set of valleys of quite different characteristics and origin. These exhibit broad expanses with gentle slopes and a mature topography. They depart from the courses common to the fault type of valley and are generally arranged in two lines, north-south and east-west. The valley of Schroon Lake, parts of the valley of Lake George, and the valley of the Hudson are of this type. The mature characteristics of these valleys suggest far greater age than the fault valleys of more recent origin. They may date back to early geologic time and represent ancient valleys which have not suffered that wholesale transformation of character and direction that the fault valleys appear to have experienced through the agency of faulting and associated forces.

GLACIAL EFFECTS

The faulted and jointed character of the eastern half of the Adirondacks enabled the ice of the glacial period to produce marked topographic effects. The faults and associated escarpments were freshened by plucking and the relief was heightened, while the valleys, which in the main represent the loci of the faults, were in some instances deepened and steepened, in others deeply filled with drift. Certain drainage changes were also effected by the glacial ice. Some streams, as the Sacondaga, a tributary of the Hudson, and the upper Hudson itself, were turned aside from their preglacial valleys and caused to flow across low preglacial divides. Glacial drift was accumulated almost everywhere along the valley floors and spread as a thin mantle over the hill slopes, thinly on the steeper slopes and sometimes to considerable thickness on the marginal terraces.[1]

The greater part of the drift in the Adirondacks is stratified and is in the form of deltas and sand-plains; morainic material is scarce. This is due to vigorous ice movement in the glacial period and to the fact that the late glacial events were associated with submergence in the Mohawk, St. Lawrence, and Champlain valleys. A small number of local valley glaciers existed after the withdrawal of the main ice sheet from the region and formed (1) local moraines which overlie the stratified drift, and (2) cirques at the valley heads.

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[1] For a general description of the Adirondacks see J. F. Kemp, The Physiography of the Adirondacks, Pop. Sci. Mo., March, 1906. See also for rock character and structural relation, Van Hise and Leith, Adirondack Mountains, in Pre-Cambrian Geology of North America, Bull. U. S. Geol. Surv. No. 360, 1910, pp. 597–621.

CLIMATE AND FORESTS

The greater height of the Adirondacks over the surrounding regions causes the precipitation to be decidedly greater. It is almost twice as great as in the lowland district in the western part of the state. In contrast to the temperature maxima of 100° and over, in the Hudson and Mohawk valleys, the summer maxima of the Adirondacks are so low that there is seldom a day that is uncomfortably warm. The winter minima are lower, of course, than elsewhere in the state. In January, 1904, when the minimum in New York City was $-1°$, the temperature was $-26°$ at Binghamton in the plateau of southern New York, elevation about 850 feet, while in the Adirondacks, at Saranac Lake, about 1500 feet above the sea, it was $-46°$ and probably much lower in the higher points.[1]

The influence of the greater height and lower temperature of the central portion of the Adirondacks is strikingly brought out in any detailed map of the forest regions, on which is represented an island of northern spruce forest surrounded by hardwoods which occupy the St. Lawrence, Mohawk, and Hudson-Champlain depressions that rim completely about the tract. To the temperature factor is due the primary grouping of the forests of the region, while secondary influences are the irregular distribution of the drift and the steepness of slope as determined (*a*) by glacial erosion along the main valleys and (*b*) by faulting along the margins of the great crust blocks that form the principal mountain units in the more rugged portions of the Adirondacks, notably along the southeastern border.

The predominating trees of the Adirondack forest[2] are spruce, hemlock, and balsam. There are also scattered individuals and groves of pine on the mountain slopes and cedars on the lake shores and in the swamps. Tamarack grows on the beaver meadows, dense tangled thickets of alder border the rivers, and birch and poplar are scattered here and there on mountain slopes and valley bottoms. Patches of maple, beech, and birch grow on tracts that have been bared by fire, wind, or lumbermen, and are the only important hardwood types that the region supports.

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[1] A. J. Henry, Climatology of the United States, Bull. Q. U. S. Dept. of Agr., Weather Bureau, 1906, pp. 176–177.

[2] C. H. Merriam, The Mammals of the Adirondack Region, 1884, p. 21.

CHAPTER XXVIII

APPALACHIAN SYSTEM[1]

(Introductory to the four succeeding chapters)

GENERAL FEATURES, SUBDIVISIONS, AND CATEGORIES OF FORM

THE Appalachian System, Plate IV, includes the highest, roughest, best watered, most densely forested, and some of the most thinly populated sections of the eastern half of the country. Except the Adirondacks no other part of the eastern half of the United States has slopes of so great declivity and streams of such steep gradients. For a long time the western movement of the American colonists was hindered by the rough barrier of the Appalachians, and communication across their roughest sections is still difficult. In their remoter coves and valleys, as in the mountains of western North Carolina and those of eastern Kentucky, rude mountaineers still follow customs and employ a speech as unlike those of the valley peoples about them as the topography and soil of the one situation are unlike those of the other.

The earliest settlers found the land covered with a great forest mantle; it was an almost illimitable wilderness of forest-covered hills and mountains.

> "Up to the doorsills of the log huts stretched the solemn and mysterious forest. There were no openings to break its continuity; nothing but endless leagues on leagues of shadowy, wolf-haunted woodland. . . . On the higher peaks and ridge crests of the mountains there were straggling birches and pines, hemlocks and balsam firs; elsewhere oaks, chestnuts, hickories, maples, beeches, walnuts, and tulip trees grew side by side with many other kinds. The sunlight could not penetrate the roofed archway of . . . leaves; through the gray aisles of the

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[1] The term "system" is here employed to denote the whole territory affected by related mountain-making movements through successive geologic periods, whether these are in the nature of plateau uplifts or acute mashing and folding in restricted belts. Since crustal movements of sufficient magnitude to produce mountains in many cases result in the uplift of bordering areas of some extent many belts of acute deformation are bordered by transitional upland belts. Though included in a system they are set apart as separate provinces from the mountain ranges formed upon rock belts of great structural complexity. Thus the Appalachian Plateaus and the Piedmont Plateau are included in the Appalachian System. The former was only slightly and locally deformed, then peneplaned, and later uplifted unevenly. Dissection of the more highly uplifted portions has been so deep as to give a relief of mountainous proportions — West Virginia and eastern Kentucky. Since peneplanation in the Tertiary the Piedmont Plateau has suffered only moderate uplift and dissection. It is an extensive upland whose inclusion in the Appalachian System is based not only on its former participation in older mountain-making movements but also on its participation in later and broader uplifts common to the whole territory between the Prairie Plains and the Coastal Plain.

> forest men walked always in a kind of midday gloaming. . . . Save on the border of a lake, from a clifftop, or on a bald knob . . . they could not anywhere look out for any distance. All the land was shrouded in one vast forest. It covered the mountains from crest to river bed, filled the plains, and stretched in somber and melancholy wastes towards the Mississippi."[1]

To-day the forester finds great interest in the possibilities which the region suggests as to the scientific treatment of soils and trees, nowhere more important than in a rough country where the soil is thin and its maintenance bound up with the care of the forest. Some of the most baneful effects of excessive forest cutting are illustrated in the Appalachians. This great forest has been, and even now is, a great source of wealth, but its exploitation is attended by such a disregard of the influence of deforestation upon the soil as to affect not only its productivity but also its very existence. The sociological and political aspects of the forestry problems which await solution here are no less interesting than the scientific aspects. The increasing demands for greater food supplies on the part of a rapidly growing population are now extending the areas of cultivated land at the expense of the forest just as in the past. The state may say how far this shall go; whether clearings shall be made or not; prescribe the conditions of forest cutting; control fires; and guide the population along lines of greatest practical economy. These activities are involved in the question of the Appalachian forest reserves. It is implied in the argument for their maintenance that the state should exercise proper political means for securing the best scientific results; on the other hand is the contention that local experience will guide developmental projects along proper lines. With the political aspects we have here nothing to do; the groundwork for an understanding of the scientific aspects lies in a comprehension of the conditions of drainage, relief, and soils, which are the chief themes of the succeeding sections.

The territory east of the lower Mississippi River consists of six different physiographic provinces — the low and poorly drained Mississippi Valley, the forest-clad Appalachian Plateaus, the parallel and regular mountains of the Great Appalachian Valley, the irregular, forested, and narrow Appalachian Mountains, the gently undulating Piedmont Plateau, and the low, flat-lying Atlantic and Gulf Coastal Plain. The rocks of the Mississippi Valley are nearly horizontal limestones, shales, and sandstones deeply covered with river alluvium, Fig. 210; those of the Appalachian Plateaus are similar except that they are more sandy and have been lifted to a higher altitude, with the consequence that they are more deeply dissected. In the Great Appalachian Valley the

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[1] Theodore Roosevelt, The Spread of English-speaking Peoples (in The Winning of the West), ed. of 1905, vol. 1, pp. 146–147.

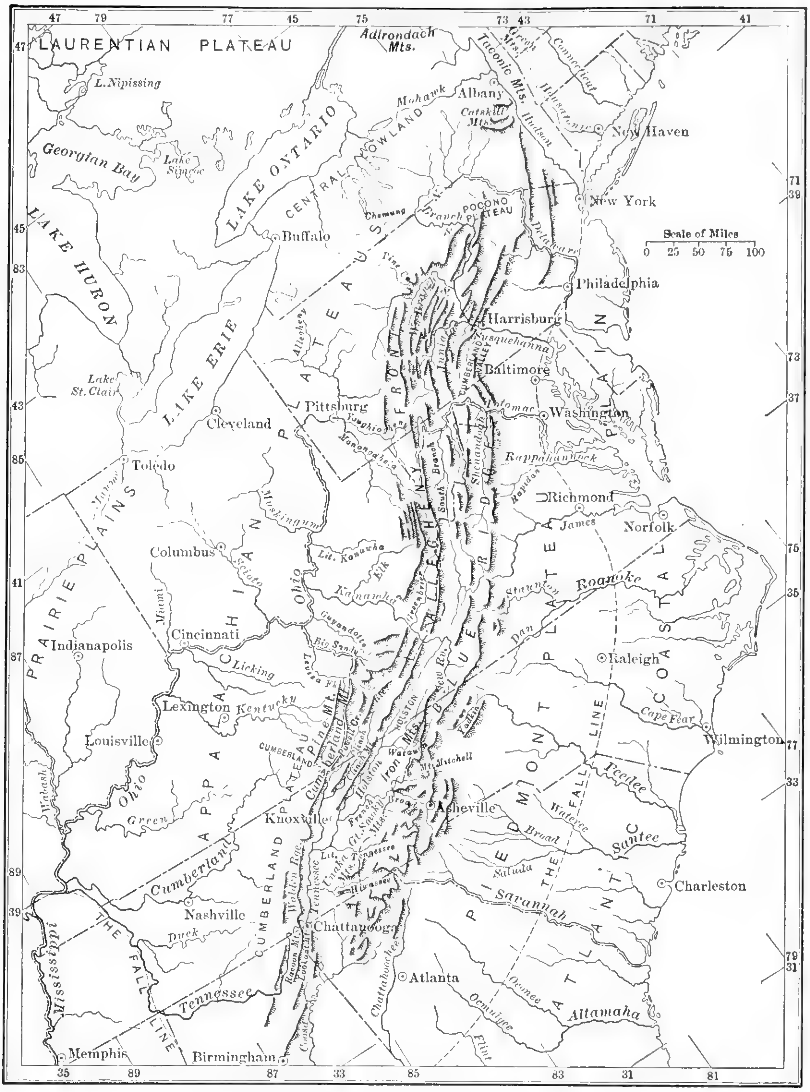

Fig. 235a. — Drainage map of the Appalachian region.

rocks have been folded into long, symmetrical, parallel folds which are among the most notable physiographic features in the world. In the Appalachian Mountains and the Piedmont Plateau the rocks are chiefly schists, gneisses, and granites of extremely complex structure, — ancient crystalline rock deeply decayed and mantled with residual soil. Seaward from the Piedmont Plateau and on both the Atlantic and Gulf slopes of the Appalachian and Ozark districts is a vast coastal lowland, the Atlantic and Gulf Coastal Plain.

The lines of division between these physiographic provinces are everywhere topographically distinct except in the case of the common border of Piedmont Plateau and Coastal Plain. Although the latter is everywhere lower than the former, yet on the common border it is but little lower; and more distinct than the differences in topography are the differences in soils and the steeper descents of the eastward-flowing streams on passing from the Piedmont to the Coastal Plain.

The great Appalachian System includes the four central members of the series of six between the Mississippi and the Atlantic coast. It extends roughly from the Ohio Valley on the northwest to the Atlantic Coastal Plain on the southeast and from the St. Lawrence Valley on the north to central Alabama and Georgia on the south. Its subdivisions and border relations on the north are somewhat different from those on the south. The Coastal Plain terminates at Cape Cod, north of which the Older Appalachians extend to the coast. A narrow upland plain, corresponding to the Piedmont Plateau of the south, borders the southern and eastern margins of the Green Mountains and extends from western Connecticut through Massachusetts and Vermont. The Green Mountains correspond to the Great Smokies, Unakas, etc., and the valleys of the Hudson and the Champlain are the counterparts of the Tennessee and the Coosa respectively at the south. The Catskills and the Cumberland Plateau are also corresponding elements. The White Mountains and bordering uplands are exceptional features in that they have no southern representatives. At the south there is a single mountain and a single plateau element in the Older Appalachians; at the north there are two mountain axes and two bordering upland plains with a great valley — the Connecticut — between them.

In general the Appalachian System includes two great belts composed of broadly different rock types — a southeastern belt composed chiefly of crystalline rock and a northwestern belt composed chiefly of sedimentary rock, Plate V. Both trend northeast and both have their broadest development toward the southwest. The crystalline belt, called the Older Appalachians, includes the Piedmont Plateau and the Appalachian Mountains; the sedimentary belt embraces the Newer Appalachians, including the Great Appalachian Valley (in places so filled with even-topped ridges as to be a mountain and not a lowland belt) and the Appalachian Plateaus, a group name for a number of separate plateaus such as the Cumberland Plateau, Allegheny Plateau, etc., and interrupted by local basins such as the Nashville Basin and the Blue Grass Country. A knowledge of the geographic positions and relations of these members is indispensable for the further discussion of their physiography, Fig. 235a.

The various provinces of the Appalachian System stand in a very interesting geologic relation to each other, a relation that is of physiographic importance chiefly through its effect upon the drainage. While the details of this relation are complex the essentials may be roughly outlined as follows. The southeastern crystalline belt has very irregular structures which were gained during several pre-Paleozoic and Paleozoic mountain-making periods that deformed the strata and elevated the mass of the province. This whole area has been called the Older Appalachians in contradistinction to the Newer Appalachians formed upon the regularly folded strata.[1]

The Older Appalachians existed as a narrow land area of unknown limits eastward but bordered on the western side by an arm of the sea that spread over a large portion of the central lowland of the continent. The erosion of the Older Appalachian land mass gave rise to land waste that was swept into the neighboring seas. On the east the sediments then accumulated have since been buried and are now concealed by Cretaceous and Tertiary strata of later origin; on the west the heavy marine and fresh-water sediments accumulated in great beds which were (1) somewhat regularly folded at the end of the Paleozoic era to form the Newer Appalachians or (2) broadly uplifted to form the Appalachian Plateaus. The folding force was directed westward, so that the folds are in general more compressed, more notably faulted, and the dips steeper on the eastern than on the western margin of the Newer Appalachians. On the western border in fact the folds die out gradually. Cumberland Plateau, Walden Ridge, and other forms are flat synclines, while the Sequatchie Valley occupies an eroded anticline, and low folds of similar nature occur elsewhere within the eastern border of the Appalachian Plateaus, as in the Tioga and Elkland districts of north-central Pennsylvania. On the whole, however, the change from the strongly folded to the gently folded rocks of the

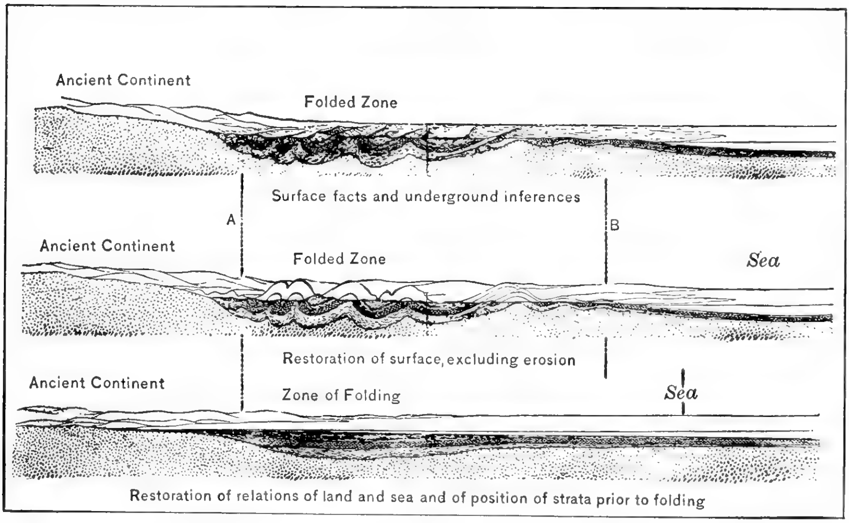

Fig. 236.—Structural Relations of the various parts of the Appalachian System, looking south. (Willis, U. S. Geol. Surv.)

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[1] W. M. Davis, The United States, Mill's International Geography, 1900, pp. 727–729.

northwestern sedimentary belt is rather sharply localized along a line now represented by the eastward-facing escarpments known on the south as the Cumberland Escarpment and on the north as the Allegheny Front.

It must not be supposed that the strata of the Appalachian Plateaus are flat merely because the strongly developed features of the Newer Appalachian belt east of them practically cease along the definite line indicated. They are often sensibly flat, but never absolutely level over considerable areas. Low folds occur here and there and a number of important faults have also been identified.

These distinctions between the various belts of the Appalachian System serve a useful purpose in making physiographically simple what is geologically very complex. While the student may require for very detailed geographic and geologic work a minute knowledge of the geologic history of, for example, the Older Appalachians, the general features of the belt become very simple if the net results of all the complex history and not the details of the history itself are kept in mind. The broad features of the region have been developed with striking uniformity upon a mass of greatly deformed strata; the detailed topography and drainage are minutely irregular and reflect the detailed structural features. The broad features of structure and origin are of chief importance in the present connection, but we shall nevertheless keep in the background of our thought the fact of geologic complexity in order that the more detailed descriptions that follow may be adequately explained.

It is possible to assign all the topographic forms of the Appalachian System to a few simple categories. (1) The uplands and the even crest lines of the ridges are remnants of a Cretaceous peneplain above which are (2) hills and mountains — Unakas and Great Smokies on the south, White and Green mountains on the north, etc. — that have survived as residuals. (3) The third category includes the slopes, valleys, and open lowlands sunk into the Cretaceous lowland after its elevation in early Tertiary time. If the valleys and lowlands were filled up to the level of these remnants and the whole surface depressed to a lower level we should have a representation of the geography of the tract near the end of the Cretaceous period. (4) This category includes those locally base-leveled areas of small extent developed in late Tertiary time. They are much more limited in extent than the early Tertiary lowlands and were developed only upon the softest rocks near the largest streams. (5) The fifth category includes the narrow and young trenches and valleys with their associated terraces below the level of the late Tertiary peneplain.[1]

Physiographic Development

The physiographic development of the great Appalachian System has been complicated by great variations in structure, by pronounced

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[1] W. M. Davis, The Geologic Dates of Origin of Certain Topographic Forms on the Atlantic Slope of the United States, Bull. Geol. Soc. Am., vol. 2, 1891, pp. 578–579. The assignment of the relief forms to categories was first clearly brought out in the paper cited; but the number of the categories is increased here to include the fact of a third local peneplanation later than the early Tertiary, — a local peneplanation resulting in the development of a topographic level identified by Hayes, Campbell, and others in the Chattanooga district as the Coosa peneplain, in the Nashville basin as the Nashville peneplain, in western Pennsylvania as the Worthington peneplain, in northern New Jersey as the Somerville peneplain, etc.

differences in elevation, and by the varying distances of different districts from the sea. Many features of the topography are unified, however, through their association with the most important single fact related to the system, the fact of former peneplanation. This makes it necessary always to keep in mind two groups of facts, those which make for diversity and those which make for uniformity of topographic expression.

On the whole the province has been a land area since the close of the Carboniferous period and in all that time has been a region of erosion. The uplifts which gave rise to erosion were not simple but complex and were probably halted a number of times by depression, so that the present altitude of the region represents the algebraic sum of a number of uplifts and depressions. The uplifts do not appear to have been regular but intermittent, for, as we have just seen, the surface was stable during several periods long enough to allow the formation of either extensive or local peneplains.

A remarkable feature of the province is the unity of expression and origin of a large number of the most prominent topographic forms. Related features are continued over a wide area throughout Alabama, Tennessee, Kentucky, West Virginia, Georgia, North Carolina, South Carolina, Virginia, and Maryland, and indicate that the conditions that produced them must also have been uniform over wide areas.[1]

The most widely distributed feature is the Cretaceous peneplain that constitutes the highest surface of reference in the province. It is also the oldest topographic feature that can be identified with certainty and is a plane of reference for the forms of later origin. The remnants of the Cretaceous peneplain are sufficiently numerous so that a number of important generalizations can be determined. It is the most perfectly base-leveled surface ever developed in the tract and was exceptional for its extent and regularity. It must not be supposed, however, that its surface was perfectly horizontal. It was most nearly level where erosion progressed under highly favorable conditions, as near the sea margin, or along the largest streams, or where the rocks had little power of resistance to weathering and erosion. In favorable localities hard and soft rocks were reduced to a common level and the

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[1] For details see (1) Hayes and Campbell, Geomorphology of the Southern Appalachians, Nat. Geog. Mag., vol. 6, 1894, pp. 63–126; (2) C. W. Hayes, Physiography of the Chattanooga District in Tennessee, Georgia, and Alabama, 19th Ann. Rept. U. S. Geol. Surv., pt. 2, pp. 9–58; (3) Bailey Willis, The Northern Appalachians, Nat. Geog. Mon., 1896, pp. 169–202; (4) W. M. Davis, The Geologic Dates of Origin of Certain Topographic Forms on the Atlantic Slope of the United States, Bull. Geol. Soc. Am., vol. 2, 1891, pp. 545–586.

rivers flowed in meandering courses and with slow currents across the underlying deeply weathered and soil-covered strata.

The outcrops of the harder strata or the originally higher masses were generally developed in relief upon the Cretaceous peneplain, especially in the case of those located on broad divides distant from the sea. In western North Carolina and northern New England, for example, subdued mountains stood at altitudes varying from 3000 to 3600 feet above sea level and somewhat less than this amount above the level of the adjacent portions of the Cretaceous peneplain. The map, Fig. 237, brings out clearly the unreduced portions of the land surface that projected above the general level of the Cretaceous peneplain. Such areas were on the whole relatively small, and although they were not reduced to the general level they were eroded to such a degree as to stand at only moderate elevations. Their present height is due to later uplift and the development of local or partial peneplains as well as deep valleys below and around them. They constitute, for example, the highest portions of the Blue Ridge on the western border of the Piedmont Plateau and the groups of higher mountains, principally in western North Carolina, the Great Smoky Mountains, the Unakas, the Iron Mountains, the Pisgah range, etc.

Among the mountains the forces of erosion were able to reduce local tracts only, thus giving rise to prairie-like country among the mountains, adjacent river basins being separated in many instances by low divides. Such a locally base-leveled surface is found all the way from Roanoke to Cartersville, Virginia, in the heart of the Smoky Mountains. The upper basins of the Coosawattee and Etowah, Georgia, consist of broad undulating plains partly enclosed by mountains; island-like residuals with gentle slopes rise above the level of the plains.

Later erosion has in many instances completely destroyed the Cretaceous peneplain over wide areas, and this is true in general around the margins of the province, but especially in central Tennessee and Kentucky, where the uplift of the peneplain brought about its destruction over wide areas, so that there are only a few widely separated outliers of the Cumberland Plateau whose summits still indicate the surface of the peneplain. A typical outlier of this kind is Short Mountain in central Tennessee, which rises a thousand feet above the surrounding plain. It is 20 miles from the Cumberland Plateau, has the same altitude, and is capped by the same hard sandstone. The low plain intervening is formed upon limestone which was easily eroded upon the removal of the sandstone cap. In eastern Pennsylvania, portions of southern New England, and over the greater portion of the Piedmont

Plateau the Cretaceous peneplain has also been dissected in the formation of local peneplains at lower levels.

That the uplifted Cretaceous peneplain is with certainty recognizable so long after its uplift is due to the fact that interstream surfaces which are in the aggregate of great areal extent waste very slowly. The rivers of a region denude the land surface by relatively small amounts, for most of the land is not occupied by streams. Wasting takes place chiefly through rain-wash, infinite gullying, and slumping, etc., so that the interstream surfaces, less affected by these forces, may carry clear records of denudation cycles long closed.

The uplift of the oldest topographic level, the Cretaceous peneplain, has been accomplished in large part by a series of deformations of true orogenic character affecting comparatively narrow areas along certain well-defined axes. One of the most important of these is that which extends from Cincinnati to Cape Hatteras, a transverse uplift which is believed to have a prominent part in the great projection of Cape Hatteras, on the eastern side of the United States. A second and more

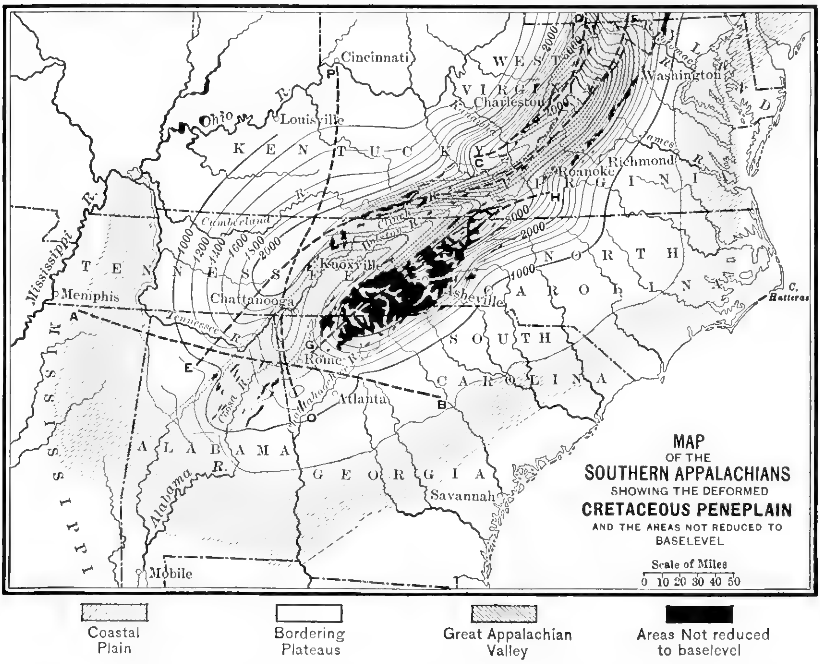

Fig. 237. — Axes of deformation represented by broken lines, AB, CD, EF, GH, and OP. Contours represent elevations of restored surface. (Hayes and Campbell.)

closely defined axis of elevation extends from Chattanooga to Cincinnati. A third prominent axis passes near Atlanta and forms a tangent to the great northwestward bend of the Tennessee. In the northern part of the Appalachian System the restoration of the remnants of the Cretaceous and Tertiary peneplains shows an axis of deformation in western Pennsylvania, as shown in Fig. 238. This deformation was in the nature of a broad bowing up of the earth's crust along a southwest-northeast axis which appears to be parallel to or continuous with the axis that passes through the summit of the Cumberland Plateau. A similar pronounced axis is recognizable in western Massachusetts and Connecticut and corresponds to the structural axis of the Green Mountain range.

The orogenic movements which deformed the surface of the peneplain determined the concentration of erosional energy along certain axial lines indicated on pp. 593 and 688. Where the elevation was slow erosion was moderate; where the elevation was rapid erosion was rapid and the peneplain was here quickly dissected.

The movements which terminated the Cretaceous cycle of erosion inaugurated the succeeding or early Tertiary cycle of erosion. The crust of the earth was maintained at a fairly constant elevation so long that the surface was again reduced to a peneplain in those regions where conditions of erosion were exceptionally favorable. Broad valleys developed upon soft rock belts of the interior portions of the southern Appalachians were reduced to base-level lowlands. The Harrisburg peneplain, standing about 500 feet above the sea, east of Harrisburg, Pennsylvania, is the northern representative of this erosion level. Like the Cretaceous peneplain, the early Tertiary peneplain has been greatly modified by erosion and by uplift, which carried both the Cretaceous and early Tertiary peneplains above their former level. The second uplift introduced a third or late Tertiary cycle of erosion, which had progressed to an even less advanced stage than its immediate predecessor when uplift again intervened and brought the land approximately to its present level. After this level was attained erosion partially destroyed the latest peneplain and continued the destruction of the two higher peneplains.

In a sense it is incorrect to speak of the two Tertiary lowlands as peneplains, for a relatively small portion of the whole region was reduced to base level. They are, strictly, local peneplains, and the durations of the erosion cycles they represent were very short as compared with the duration of the Jurassic-Cretaceous cycle.

The Cretaceous peneplain is called the Cumberland peneplain at the south and the Kittatinny (sometimes Schooley) peneplain at the north

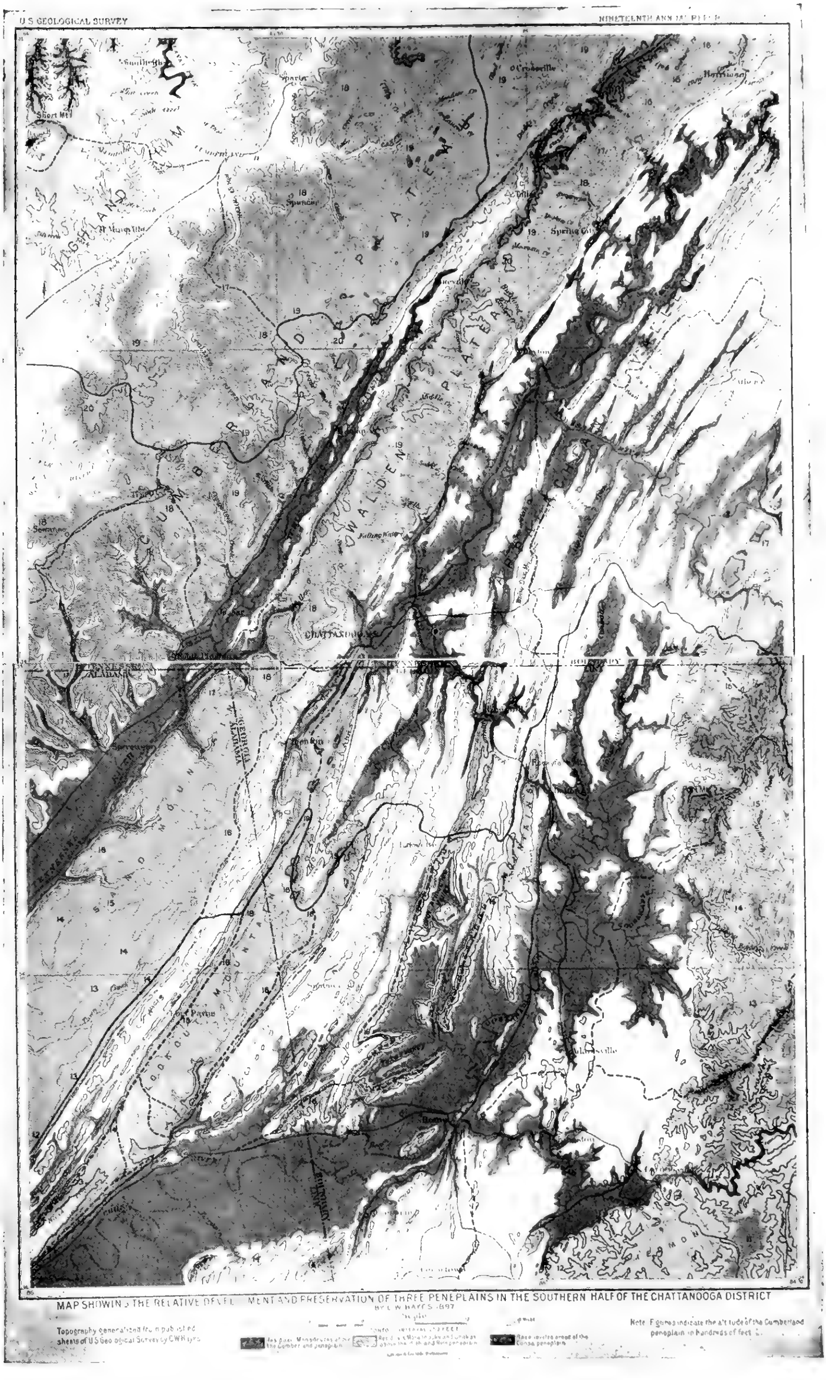

Fig. 238. — Darkest areas, base-leveled areas of the late Tertiary or Coosa peneplain; lightest shade, early Tertiary or Highland Rim peneplain; intermediate shade, remnants of the Cretaceous or Cumberland peneplain. Residuals above the Cumberland peneplain are shown in slightly darker shade. Scale, 20 miles to the inch. (Hayes, U. S. Geol. Surv.)

(Pennsylvania, New Jersey, etc.), in the former case because the summit of the Cumberland Plateau is the best preserved remnant of it, in the latter case because the even crest of the Kittatinny Mountains of northern New Jersey is due to its former development in that district. The early Tertiary peneplain is called the Highland Rim peneplain at the south because well preserved beyond (west of) the edge of the Cumberland Plateau on a surface called the Highland Rim, with respect to the Nashville Basin below it; the same level is called the Harrisburg at the north because well developed east of that city. For comparable reasons the late Tertiary peneplain is called the Coosa at the south and the Somerville and Worthington at the north. We shall generally refer to these three peneplains as Cretaceous, early Tertiary, and late Tertiary, implying their correlation over the whole Appalachian System. The student will find reference to them facilitated by the use of these terms instead of the local names ordinarily employed.

Relation of Topography to Rock Types

Since lithology and rock structure control topographic form to a large degree during the youthful and mature stages of landscape development, it is of fundamental importance in the study of the Appalachian region, where vigorous erosion is now going on, to determine the principal rock types and their degrees of erodibility. In the southern part of the Appalachian System the beds of conglomerate, quartzite, and siliceous shale are composed of nearly insoluble materials that powerfully resist erosion. The outcrops of these rocks are marked by high ridges, as in Beans Mountain, an outlier of the Unakas, and Indian and Weisner mountains south of the Coosa River.

The limestones alternating with more or less calcareous shales are in general easily eroded, a large part of the erosion being by solution. Portions of them have sufficient resistance to erosion to stand as somewhat higher ridges, but both the height and the number of such ridges are nowhere great. One of the members of the limestone group is the Knox dolomite, which contains a large proportion of relatively insoluble chert which, on the removal of the more soluble calcium carbonate, remains behind as a heavy residual mantle that has a protective influence on the remaining portion of the formation, thus giving rise to moderately high hills and irregular ridges.

A third group of rocks (Silurian, Devonian, and Carboniferous) consists of sandstone and chert of great resistance to erosion. These strata therefore stand out in some localities as residuals of superior height, for example, Oak and Chattanooga mountains. Chert beds have also been instrumental in preserving the Highland Rim.

The Coal Measures conglomerates, sandstones, and sandy shales form a group with distinct topographic characteristics. The conglomerate is the most resistant member and constitutes the cap rock of much of the Cumberland Plateau and the most important factor in the long preservation of its base-leveled surface. These various rock groups as a whole show a tendency to grow thicker and less calcareous toward the southeast, so that in a few cases strata of the same age weather into entirely different topographic forms on the two sides of the district.

The igneous and metamorphic rocks of the region contain a large proportion of feldspar and may be designated the feldspathic group. The feldspar which they contain is an element of weakness, for on exposure to the weather it decays quite rapidly, and the rock of which it is a part disintegrates. The Piedmont Plateau is composed largely of such easily weathered feldspathic rock, chiefly igneous, and a number of large valleys in the mountainous portion of the crystalline rock belt, of which Mountaintown and Talking Rock valleys are illustrations, owe their existence to the occurrence of large areas of highly feldspathic rock. It is not uncommon to find granite and diorite with a high percentage of feldspar weathered to depths of 50, 70, or 100 feet from the surface.

On the other hand the slates, graywackes, and conglomerates of the metamorphic terranes are nonfeldspathic and have a high degree of resistance to weathering and erosion. They have as a rule been greatly deformed, standing on edge in much of the mountainous section of the southern Appalachians. The result of combined hardness and vertical or nearly vertical position is shown in long, narrow, steep-sided ridges, or in rather sharp and high peaks with many radiating finger-like spurs separated by narrow, V-shaped valleys, a type of irregular topography seen to good advantage at the southern end of the Unakas on the boundary between North Carolina and Tennessee. The accompanying illustration, Fig. 239, brings out the relation between the topography on the one hand and the composition and erodibility of the rocks on the other. The relative thicknesses of the different groups is indicated by the vertical distances, relative erodibility by the lengths of the horizontal lines.

A similar relation between rock types and topography is exhibited in the northern and central portions of the Appalachian System. In the zigzag ridges of Pennsylvania the hard ridge makers are thick, hence the mountain feature is strongly developed; in the lowlands of the Hudson east of the Catskills the soft formations are thick, the hard forma-

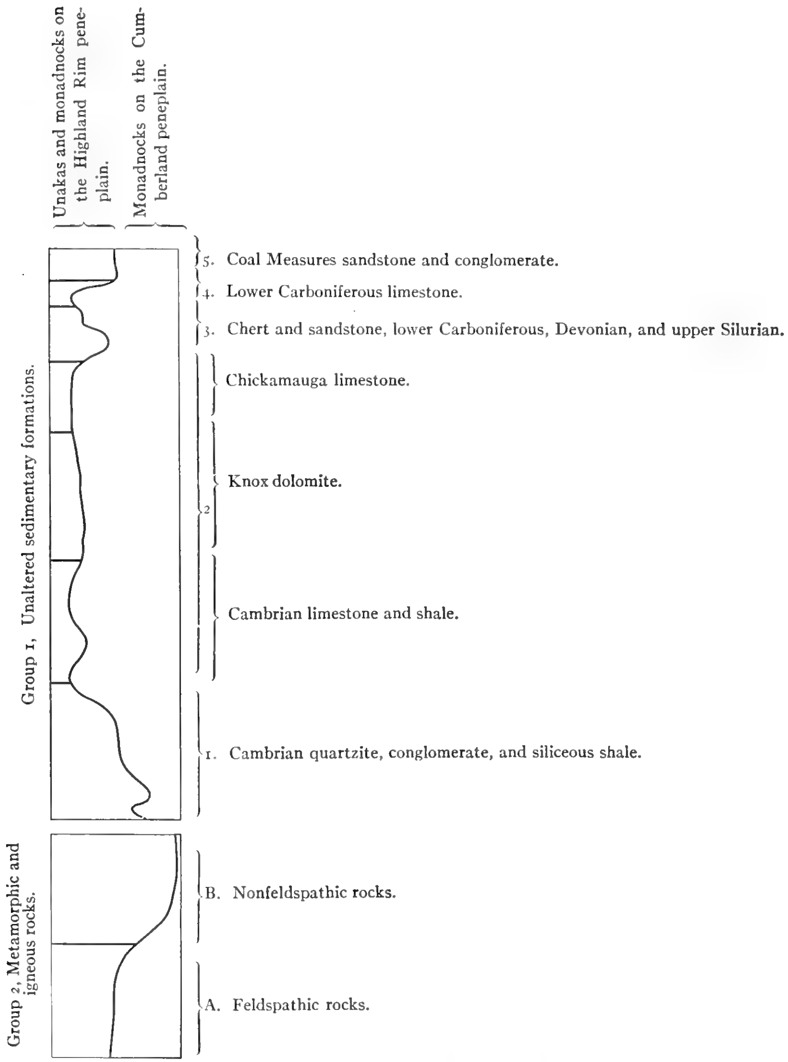

Fig. 239. — Curve illustrating the relation of topographic relief to lithologic composition in the southern part of the Appalachian System. The term *unaka* is applied to a massive residual, *monadnock* to an isolated residual surmounting a peneplain. Each curve toward the left denotes a less resistant rock, each curve toward the right a more resistant rock. (Hayes, U. S. Geol. Surv.)

tions thin, hence the lowland feature is strongly developed. The principal hard formations are the Pocono sandstone, the Oneida-Medina sandstones, and the Pottsville conglomerate; the soft formations are the Hudson River shales, the Mauch Chunk shale, and the Coal Measures. The Pocono sandstone forms Second, Peters, Mahantanago, Line, and Little mountains northeast of Harrisburg in the splendid series of zigzag ridges developed there; the Oneida-Medina sandstone forms Blue Mountain in the same locality; and the Pottsville conglomerate forms Third Mountain and Big Lick Mountain. The intervening valleys are formed upon the soft formations, principally upon the Mauch Chunk shales and the Coal Measures, as in the case of the upper valleys of Mahonay and Shamokin creeks. These soft formations are narrow as compared with their development toward the north, and the valleys formed upon them are likewise narrow for the most part; in eastern New York they are thick and have weathered into broad valley lowlands.

Glacial Effects

Reference to the map, Plate IV, will show that the northern part of the great Appalachian System was glaciated but that the southern and central portions were not covered with ice. It follows that the interpretation of the topography and drainage of the latter districts is much easier than in those regions where glaciation has interfered with the normal development of the landscape or has partially buried the surface underneath a cover of glacial till.

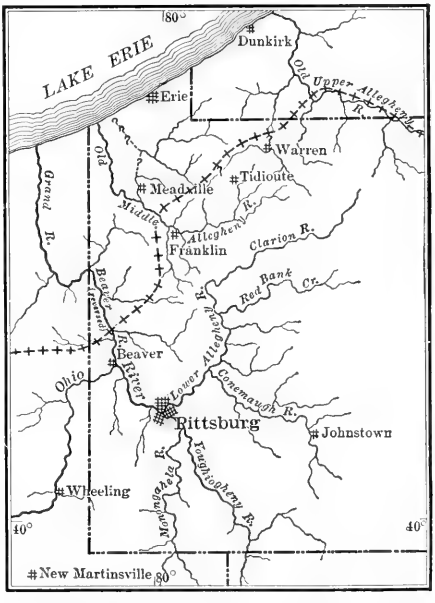

Fig. 240. — Probable preglacial drainage of western Pennsylvania, the limit of glaciation is shown by the broken crossed line. (Modified from Leverett.)

One of the most important effects of glaciation was the changing of river courses either by the bodily diversion of streams, the ice occupying the valleys long enough to enable a new course to be cut by the river in a different situation, or by the blocking of the preglacial channels with glacial drift, causing streams to be deflected into adjacent valleys. One of the most striking instances of glacial diversion is that of the Allegheny, which formerly flowed northward into Lake Erie northwest of Pittsburg, Fig. 240. The continental ice sheet displaced the river and kept it to a southern course so long and so modified the ancient valleys by drift deposits that with the retreat of the ice the streams had established themselves in new channels draining in the opposite direction and forming a system tributary to the Mississippi.[1]

Many other tributaries of the Ohio suffered similar changes of position and direction of flow through glacial action. The Ohio itself was in large part diverted from its preglacial channel. The variation in width of the present channel of the Ohio is the result of the formation of a single channel out of a number of sections of different stream channels. It is significant that the general course of the stream corresponds roughly with the southern limit of glaciation, a condition similar to that found in the course of the Missouri and due to similar causes. Under these conditions it is not surprising that the fall of the Ohio River is not uniform; it varies from 0.2 foot to at least 5 feet to the mile. The greater fall commonly occurs where the river crosses the old rock divides which are not yet reduced to a graded profile. The original courses of the streams of the till-covered country north of the Ohio have now been determined in some detail by borings for oil and gas. Well records are so numerous in the region as to enable faithful restorations of the bedrock surface and the character of the drainage. Those streams which discharged northward toward or against the ice margin also suffered extensive modifications too intricate to examine in detail in this connection.[2]

In at least one locality the ice had an important effect in impounding the drainage of a district and causing the formation of lake clays and marginal deltas now at some height above the drained lake floor. Lake Passaic, an extinct glacial-marginal lake of northern New Jersey, Lake Neponset in eastern Massachusetts, and many other similar lakes in central New York are illustrations in point. Lake Passaic was formed within (west of) the curved Watchung trap ridges and its extinction followed upon the disappearance of the ice and the cutting down of the outlets. The chief importance of such phenomena to the student of forest physiography lies in their relation to the character of the soil;

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[1] Topographic and Geologic Survey of Penn., 1906–1908, pp. 123–124.

[2] For a discussion of both typical and detailed features see W. G. Tight, Drainage Modifications in Southeastern Ohio and Adjacent Parts of West Virginia and Kentucky, Prof. Paper U. S. Geol. Surv. No. 13, 1903, who discusses the changes in the courses of the rivers of the region, reconstructs the old courses, and analyzes the causes that have led to the drainage changes.

an understanding of the distribution of the bottom clays and the gravelly and sandy beach and delta deposits rests upon a knowledge of the existence and extent of a former lake.

While the northern ends of both the Older and the Newer Appalachians were glaciated, Plate IV, the topographic effects of glaciation are of minor importance. The preglacial relief is still prominent in valley and upland while the glacial relief is in the nature of minor irregularities — the detailed features of valley slopes and floors and the drumlins, eskers, sand plains, and low morainic ridges scattered irregularly about.

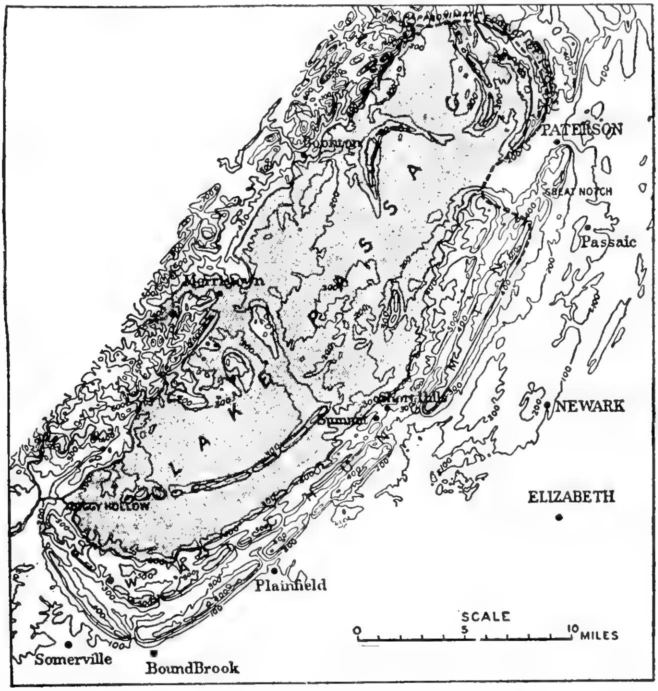

Fig. 241. — Maximum stage of Lake Passaic. All outlets except that at Moggy Hollow were either blocked by ice or filled with drift. (U. S. Geol. Surv.)

The amount of till deposited by the ice sheet in the Appalachian Plateaus is very slight. This is due to the brief period in which the ice overlay the region, to the elevated nature of the country, and to the fact that hard rock yielding little waste constitutes the cap rock of a large part of the province. The valleys received the chief contributions of drift, and many of them are also partially filled with fluvio-glacial deposits now terraced by the streams. The terraces occur without as well as within the southern border of the glaciated country and are among the most conspicuous and persistent elements of the valley forms.

Detailed features of relief and drainage that owe their origin to glaciation will be discussed in connection with the general physiography of the various regions of the Appalachian System.

CHAPTER XXIX

OLDER APPALACHIANS

SOUTHERN APPALACHIANS AND PIEDMONT PLATEAU

Appalachian Mountains

THE southeastern belt of crystallines in the Appalachian System consists of two very unlike portions, a western portion of strong relief, the Appalachian Mountains, and an eastern of low relief, the Piedmont Plateau. The mountain belt is broad at the south and narrow at the north. In western North Carolina, northwestern South Carolina, and eastern Tennessee the Appalachian Mountains are 50 miles wide and are bordered by declivities of the first order; in western Virginia, central Maryland, and south-central Pennsylvania the belt narrows to a single ridge known in its various parts as the Blue Ridge (Virginia), Catoctin Mountain (Maryland), and South Mountain (Pennsylvania). Farther north the Appalachian Mountains are represented by the highlands of New Jersey, the highlands of the Hudson, the Green Mountains, etc. These northern representatives of the system are narrow and their relief is not great as compared with the mountains of North Carolina, yet they have notable relief, for both the crystalline rocks and the limestones, shales, and sandstones of varying structure and age that border them on either hand have been worn to lowlands, valleys, or upland plains of relatively slight relief.

Attention will here be given chiefly to the mountains of the broad southern portion in western North Carolina and eastern Tennessee, whose most notable qualities as compared with other portions of the Appalachian Mountains are (1) their great height and ruggedness, (2) their great areal extent, and (3) their dense and valuable forests. This is by far the most important member of the southern Appalachian district and is here designated the southern Appalachian Mountains.

The southern Appalachian Mountains include the highest point in the eastern half of the United States (Mount Mitchell, N. C., 6711 feet) and are more truly mountainous than any other portion of the country east of the Rockies. So unsettled are they that certain sections have only the merest sprinkling of population; and in general one finds

PLATE III

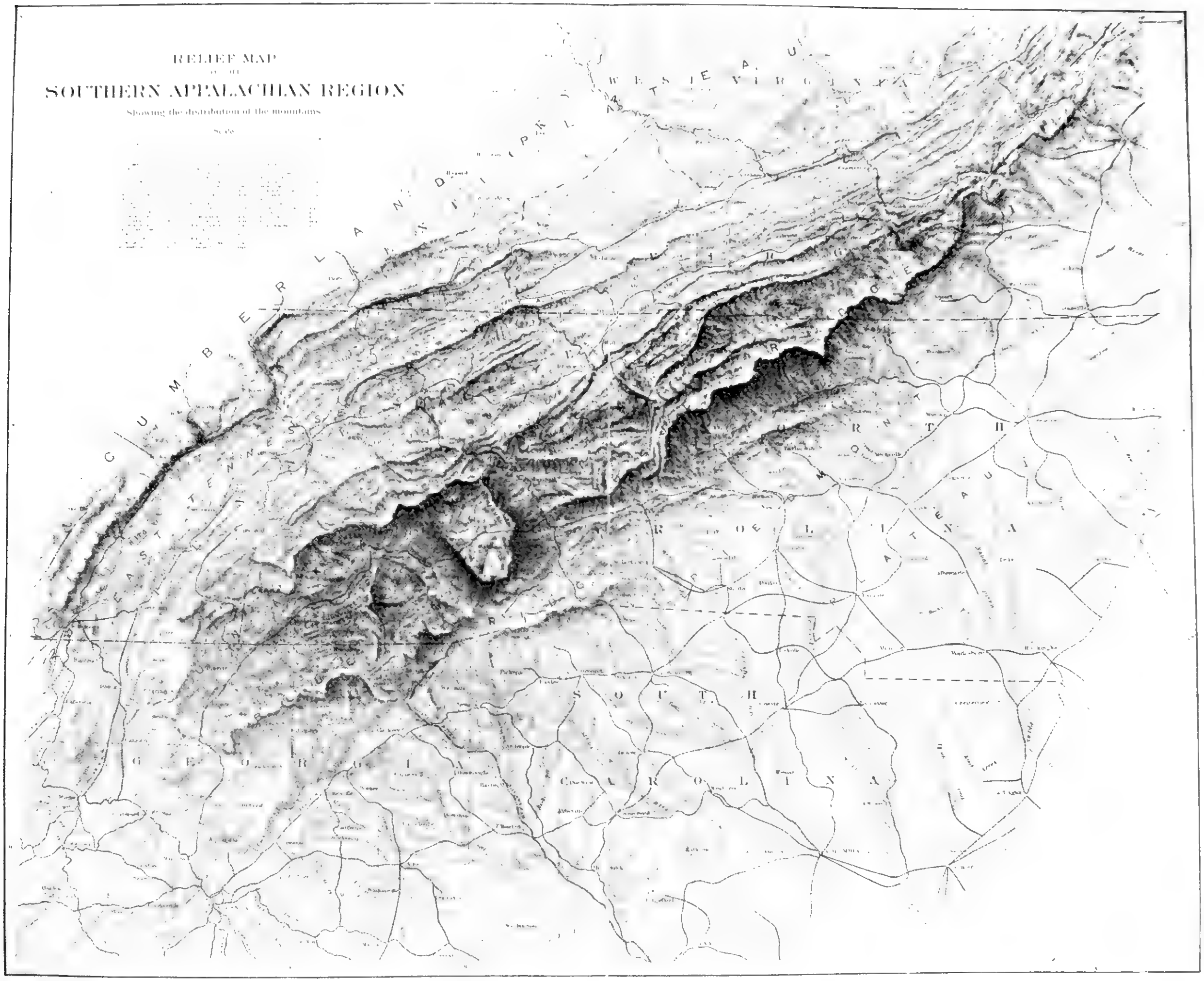

Plate III. — Southern Appalachians.

Interest in the southern Appalachians is heightened by the fact that they contain one of the largest bodies of fine timber to be found on the Atlantic slope of the country and are of almost supreme interest to the eastern forester, who sees in them one of the country's greatest forestry possibilities. Nowhere else in the United States, not even excepting the arid and untimbered West, do the correlated problems of drainage, soil maintenance, forestry, and agriculture have a larger immediate importance or their solution a more far-reaching effect. In a region made up chiefly of steep mountain slopes each man's acts must be in a high degree adjusted to the welfare of his neighbor if both have interest in the productions of the soil; each man must become his brother's keeper as a matter of economic as well as of moral necessity.

Fig. 242. — Pisgah Mountains from Eagles Nest near Waynesville, N. C., looking S. 70° E. Cold Mountain (6000 feet) and Big Pisgah Mountain (5749 feet) are on the sky line. Beatty Knob in the middle distance shows characteristic details of spurs and ridges. (U. S. Geol. Surv.)

The distinctly greater elevation of the southern Appalachians above the surrounding country gives them a notably cooler climate. The temperature is that of south-central Pennsylvania or New Jersey. Above 5000 feet it ranges usually from 45° to 75° in summer and from −10° to 45° in winter. The low temperature is expressed among other ways in the presence of red and black spruce, northern birch, white pine, and fir, while the magnolia, mulberry, papaw, and persimmon trees are representative southern species which occur at lower elevations and have reproductive associations with large areas of such species in the surrounding plains and valleys.

Because of greater elevation, the degree of cloudiness and the rainfall are both much greater than on the surrounding plains and plateaus. This being the case we should expect also to find differences in the distribution of these climatic conditions within the mountain area, on account of the rather wide topographic differences. The most important generalization of this kind is in the distribution of heat and rainfall. The southeastern slopes, with a declivity of 10° to 30°, are almost exactly normal to the sun's rays for several summer months and receive almost as much heat from the sun as do equatorial lands during the same period. The northwestern slopes depart from the normal by an equal amount but in the other direction, and may be said to receive an amount of direct insolation no greater than that received by Newfoundland or southern Norway, though in each case the net result is nowhere near such extreme temperatures as these comparisons would seem to show on account of the mitigating effects of the wind, which tends constantly to equalize the distribution of the heat. Nevertheless the southeastern slopes are notably warmer than the northwestern slopes, and being warmer are also drier on account of the greater evaporation.

A second and more important cause for the comparative dryness of the southeastern slopes is the effect of the prevailing westerly winds which precipitate about 60 or 70 inches of rain on the windward (northwest) slopes and but 40 or 50 inches on the leeward (eastern) slopes. This climatic contrast is sufficiently marked to affect the distribution of forest fires, which are found to be much more frequent, or at least do the greatest amount of damage, on the drier southeastern slopes than on the moister northwestern slopes. About 80% of the total area, or 4,500,000 acres, have been burned over, the greater number of the fires being on the ridges, where they are often set to improve the pastures, or to effect partial clearings.

Besides these differences in rainfall and temperature on the two slopes of the southern Appalachians there are important differences dependent upon altitude. These are roughly expressed on the accompanying map showing the rainfall of the United States, but a larger number of observations would undoubtedly show even greater differences, as have been shown by the refined observations of late years in the Alps of Europe and the mountains of Wales.

PHYSIOGRAPHIC DEVELOPMENT

The southern Appalachians have a very complicated structure. The rocks are chiefly crystalline and are in part igneous, in part metamorphic. The igneous rocks occur in the form of ancient dikes, sheets, etc. The metamorphic rocks consist of altered sedimentary strata which were deformed in several periods of mountain making but chiefly in the Ordovician period when there was formed a very complex structure, the folds due to compression being arranged in all directions, though the northeast-southwest direction predominates. So complicated is the structure, and so diverse is the rock character within short distances, that great irregularity of drainage direction and of topographic form is the consequence.

While irregularity of structure thus prevails there is a marked predominance of trend toward the northeast and it is in a northeast-southwest direction that the principal stream courses, valleys, and ridges lie. Structural irregularities are expressed in the many cross ranges, the highly irregular trend of mountain and range spurs, and the minute irregularities in the slopes and crests of individual mountain ranges. The character of the rock also has been an important factor in making the slopes irregular in detail. The areas of softer rock such as the feldspathic Cranberry granite, extensively exposed about Asheville and in smaller areas in many other localities, weather down much more rapidly than less feldspathic rock, and as the outcrops of the former are extremely irregular, the dependent erosion forms are correspondingly irregular. It is therefore only in a broad view that the mountains appear to possess any system whatever, and even in such a view there are large tracts in which no general arrangement can be discovered. The larger members of the group, such as the Unakas, the Great Smoky Mountains, the Black Mountains, the Iron Mountains, the Pisgah range, and many others, all run in a northeasterly direction, Plate III, but this feature is less clearly seen in the details of the mountain slopes than in a general view of the ranges such as a group map affords.

Fig. 243. — Geologic structure of the Appalachian region where extreme faulting has occurred. Length of section, 8½ miles. (Keith, U. S. Geol. Surv.)

The smoothest contours in the southern Appalachians are in the southeastern portion, occupied almost exclusively by igneous rocks which have given rise to broad and massive domes; the northwestern portion is carved out of metamorphic rock of greater resistance to erosion, and in contrast to the subdued mountain forms west of the Blue Ridge are the Unakas and Great Smoky mountains, whose peaks are prevailingly rather sharp and rise to greater heights. The summits of the Unakas are capped for the most part by hard quartzite; the mountains close to the Blue Ridge are carved out of massive granite. This adjustment of topography to the hardness of the rock is illustrated everywhere and is one of the features indicative of the great geologic age of the region, though, had the topographic cycle been carried farther, these adjustments would in their turn have given way to peneplanation in which rocks of varying hardness all but cease to have topographic expression, as is the case in the Piedmont Plateau on the east or the Cumberland Plateau on the west.

Fig. 244. — Roan Mountain, Tenn. Hills in foreground are composed of granite; the broad rounded summits of the mountains are characteristic of the Roan gneiss. (U. S. Geol. Surv.)

The absence of adjustments to structure is exhibited in the courses of the westward-flowing streams which in some instances cross the main mountains of to-day, the Unakas and Great Smokies, in deep gorges and canyons that divide these ranges into a number of more or less separate units. A certain degree of this transection is, however, to be attributed to upheaval of the mountains in the paths of the streams, an upheaval that continued during the two Tertiary uplifts that followed the development of the Cretaceous peneplain in the Appalachian region. As already described, these uplifts were sharply localized along the present mountain axes and were orogenic in nature, thus giving a certain antecedent quality to the westward-flowing streams.

In the southern Appalachians the Cretaceous peneplain was developed only upon the highly feldspathic rocks and the less altered slates, while the nonfeldspathic conglomerates and the harder slates formed considerable elevations above the peneplain. These elevations were sometimes of mountainous proportions, and were of such size and such degree of resistance to erosion and so favorably placed at the headwaters of the dissecting streams as to have suffered relatively little erosion since the uplift of the Cretaceous peneplain. The best-preserved residuals are the Great Smoky Mountains, the Unakas, and a dozen or more neighboring groups.[1]

The largest and best-preserved remnants of the Cretaceous plain formed within the southern Appalachians are those about Asheville, where a local peneplain was developed upon the feldspathic Cranberry granite, and east and south of James Mountain and south of the Unakas in Mountaintown and Talking Rock basins. Over a large part of the southern Appalachians the Cretaceous level is expressed only in dissected remnants of a former plateau surface at the heads of the main streams as in the plateau immediately west of the Blue Ridge. Many smaller remnants of such a leveled surface are to be found here and there among the mountains, for example in the plateau of the French Broad River from 2200 to 2300 feet above the sea, and similar cases are to be found in a number of other river systems at comparable but slightly different altitudes.

The plateau bordering Pisgah River near Waynesville and Sonoma is between 2700 and 2800 feet above the sea; that of French Broad River is about 2200 feet. Remnants of the plateau west of the Blue Ridge pass entirely around the head of French Broad Valley and along the heads of the minor streams and continue southwestward across the headwaters of Toxaway and Horse Pasture rivers, which are tributary to the Atlantic.

The valleys intervening between the mountain ranges of the Pisgah region are sharp, narrow, and V-shaped at their heads but widen out at lower levels where they are bordered by rounded, plateau-like tracts only slightly varied by shallow valleys. They are alike in form and origin but vary considerably in altitude, rising gradually toward the heads of the rivers, so that each main stream has its own particular set of altitudes. All of these basins, but the larger ones more conspicuously than the smaller ones, are now being dissected by the streams which drain them. In the case of the largest and most interesting of them all, the Asheville basin, the main stream has intrenched itself well below its former level and the tributaries are intrenched by smaller amounts. The former plain has been carved into hills and valleys with thoroughly organized and graded waste slopes. But the dissection of the former plain has not yet reached the point where the earlier flatness can not be safely inferred, for some areas of flat land can still

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[1] The term "monadnock" is applied to a single isolated residual such as Mount Monadnock in New Hampshire, which stands alone. More massive residuals of greater size and height would seem to require a different name, and the term "unaka" has been proposed for such large residuals as the Unaka Mountains which illustrate the type.

be made out here and there and the hilltops still reach accordant elevations, though the structure and to a lesser degree the rock character vary from point to point. East of the Black Mountains, in the valley of the South Toe River, is a basin smaller than that of the French Broad at Asheville but made in a similar manner and now in process of dissection similar to that exhibited about Asheville, the river being intrenched about 200 or 300 feet below the general level of a comparatively even upland. A third basin of this kind is that of the Caney River west of Mount Mitchell, but it is much smaller than the other two.[1]

A topographic and drainage feature of the southern Appalachians that has a dominating influence in the distribution of the population and a direct relation to the growth and development of the forests is the distribution and character of the basins, gorges, and coves. The basins have already been defined in terms of topographic cycles and rock character as the result of local peneplanation of areas of more feldspathic rock. They vary in size from the many small, even tiny, flat or gently rolling areas such as those found along the courses of the minor rivers to such large tracts as those on the Nolichucky and the Holston and the Asheville basin in the valley of the French Broad.

Less important than the basins just described are the small plains that frequently occur at the headwaters of the streams. They are perched well up on the mountain slopes and reëntrants, where the brooks or "branches" unite to form creeks. They appear upon irregular areas of softer rock, at stream junctions, and where land waste has been washed into the hollows of the mountain slopes. These basins are a common feature of the whole southern Appalachian mountain region. Between the high coves and the basins at an intermediate level and also between the basins and the great valleys and plains that border the southern Appalachians the streams descend through gorges or steep valleys. Thus between the Asheville basin and the Great Appalachian Valley the French Broad leaves the wide valley in which it flows above Asheville and enters a gorge at Hot Springs, Tennessee; the Linnville flows through a broad valley above the falls at the Blue Ridge, then plunges down in a reversed curve to the quieter stretch of the Piedmont; to the same class belong the gorges of the New River above Ivanhoe, the Doe River above Elizabethtown, Tennessee, the Nolichucky above Unaka Springs, Tennessee, the Tallulah at Tallulah Falls, Georgia, and the Nantahala, Little Tennessee, and Hiwassee at the points where they make their steepest descents. In like manner the streams descend from the high-level coves to the level of the larger intermontane basins through gorges and canyons often rather steep-walled though seldom precipitous.

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[1] For an interesting discussion of the Stream Contest along the Blue Ridge see a paper with that title by W. M. Davis, Bull. Geog. Soc. Phil., vol. 3, 1903, pp. 213–244. The paper also contains a short discussion of the general character of the southern Appalachians and the Piedmont Plateau.

In these two features of plains and gorges one has a large part of the physiography of the southern Appalachians that enters directly into relationship with man, for it is in the coves, basins, and plains that the 350,000 people of the region are chiefly found and it is through these to a large extent that the development of the forest must proceed. Since the total area of the basin and valley lands is small, the population is small and as scattered as the relatively flat lands they occupy. Only one-fourth of the tract is under cultivation of any kind, the wagon roads are chiefly ruts, and but one railway crosses the entire mountain region from east to west, though there are a score of feeders that enter it for considerable distances. It is largely to these features that the backward condition of the region is to be ascribed. Its life is but an eddy of the life of the surrounding plains; the mountaineer of the southern Appalachians is almost as crude as his somewhat more isolated brother in eastern Kentucky in what are locally known as the Kentucky Mountains. In both cases life is largely a struggle against space, whose vertical and horizontal elements are both discouragingly large.

Fig. 245. — The uplifted and dissected local peneplain known as the Asheville Basin. (Keith, U. S. Geol. Surv.)

The succession of basins and gorges with falls and rapids is not ideal for the agricultural development of the southern Appalachians, but it has positive advantages for the mineral and forestry interests, since it affords an unrivaled source of energy. More than 6400 acres of land along the Blue Ridge, Unakas, and intermediate highlands have an elevation over 6000 feet, and about 54,000 acres are more than 5000 feet above the sea. The Piedmont Plateau on the east is from 1000 to 2000 feet high and the Great Appalachian Valley on the west from 1500 to 2000 feet high. Under these conditions the gradients of the streams are necessarily very steep; they fall from 2000 to 4000 feet within the mountains. It is estimated that about 1,000,000 horse power could be developed on the principal streams — the New, Kanawha, Holston, French Broad, Nolichucky, Little Tennessee, Coosa, Chattahoochee, Catawba, and a dozen others. At present water power is used in almost every settlement for grinding and sawing, and the larger towns are becoming to an increasing degree dependent upon it, but as a whole the greater part of this splendid resource is unused.

In the development of the timber resources of the region two advantages are required that will not be long delayed — a denser population for labor supply and for markets. Already the manufacturing South is a reality. North Carolina cotton mills require more cotton than is grown in the state, those of South Carolina consume nearly three-fourths of the home-grown cotton,[1] and the concentration of population to which these industries lead will greatly enlarge the demand for cheap lumber. At present some of the finest wood in the country is being sold for astonishingly low prices. For example, oak, cherry, walnut, and hickory commonly sell for $5 to $10 per thousand feet, and in scores of localities the difficulties of marketing the forest products limit the development of the timber to that required for local use.[2]

SOILS AND VEGETATION

The soils of the southern Appalachians reflect the variations in rock character quite as faithfully as do the slopes of the mountains, the trends of the ranges, or the courses of the streams. Not only are the siliceous gneisses and the quartzites prominent topographically but they also have the thinnest soils; the feldspathic granites have the deepest soils and underlie the largest basins, as the Asheville basin in the valley of the French Broad.[3] The soils of the upper part of the Little Tennessee River basin are sandy, being derived from granite. On Little Tennessee River around and above Franklin most of the good farms

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[1] E. R. Johnson, Sources of American Railway Freight Traffic, Bull. Am. Geog. Soc., vol. 42, 1910, p. 246.

[2] Ayres and Ashe, The Southern Appalachian Forests, Prof. Paper U. S. Geol. Surv. No. 37, 1905.

[3] Hall and Bolster, Surface Water Supply of the United States, Water-Supply Paper U. S. Geol. Surv. No. 243, 1910, p. 165.

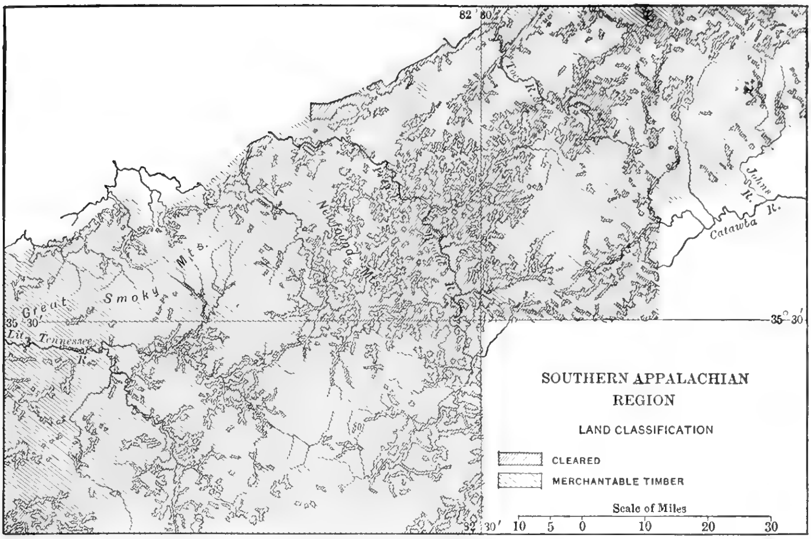

Fig. 246.—The large cleared areas lie chiefly in local basins such as the Asheville basin and the valley basins of the Little Tennessee. The smaller isolated areas are largely upon the hillslopes and in the upper and smaller basins or coves.

Fig. 247.—Grassy "bald" and border of spruce forest, White Top Mountain, Virginia. (U. S. Geol. Surv.)

are located on deep fertile red loams derived from schists. In the narrow valleys among the high mountains, where sandstones, quartzite, and conglomerate prevail, the soils are generally thin and sandy and have little agricultural value; but on the north slopes and hollows they bear well-developed forests. In the Hiwassee River basin deep valleys extend from the rivers far into the mountains between spurs five to twenty miles long. The mountain sides are steep and in many places rocky, while the creek valleys have considerable areas of alluvial flats and rolling foothills. The foothill soils are almost entirely clay and the alluvial flats along the river and creeks have a large percentage of clay. The soils of the mountain slopes are loamy and moderately fertile; the ridges are covered with a light and stony soil that precludes agriculture.[1]

The distribution of the timber of the area is in general sympathetic with the major natural features. The principal timber is the oak of several varieties, found chiefly on the ridges, and the pines, found chiefly on the plains. The hemlock is found in strips or bands along the shaded ravines and on the better-watered northern or northwestern slopes between 3000 and 5000 feet. The northerly exposures also support beech, maple, birch, etc. Shortleaf and pitch pine and hickory are found chiefly along the lower slopes of the Blue Ridge. Individual oaks reach their best development in the coves, though as a whole the stands are there too dense for the best reproduction. The soils of the ridge crests are generally too stony and thin for the best stands, though the conditions are very favorable for reproduction. Northerly exposures at the higher altitudes have the added difficulty of being too cold, a condition that limits the productive power of the soils. Finally, on the higher summits of the Great Smoky, Pisgah, and Balsam mountains are a few thousand acres of black spruce occupying a habitat similar to that of the spruce forests of New England but very strictly limited in range because of the small proportion of land located at the requisite elevation for favorable conditions of temperature and humidity.

The higher coves of the region have singular value and interest. In them the forest litter and leaf mold are generally thick, being washed down from the surrounding slopes. The soil of such localities is rarely ever wanting in humus, unless it has been recently reburned, as is sometimes the case with those coves located on the southern slopes, where there are less rainfall and a higher temperature and consequently more frequent and more destructive forest fires.

Great havoc is being wrought in the region by the pursuit of cultural

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[1] Hall and Bolster, Surface Water Supply of the United States, Water-Supply Paper U. S Geol. Surv. No. 243, 1910, p. 190.

and forestry methods which permit the too rapid wastage of the soils. At first the clearings were all located on the basin and valley floors, but as the population gradually increased and the old fields became depleted the clearings extended farther and farther up the valley sides beyond the point where natural fertility is long maintained in the soil and where the land yields so poor a return that it ought always to remain in forest. As the cleared farms became unproductive the clearings were extended farther into the forest and the old fields allowed to revert to natural growth. Widespread erosion of hill and mountain slopes resulted, and great areas have in this way been rendered worthless, either through gullying or through the growing of useless brush. This is the rule within the mountain area, but along the western border of the Unakas and the eastern border of the Blue Ridge young quick-growing pines are the pioneers and cover the mountain slopes before gullying becomes too far advanced. Only the highest state of cultivation and the maintenance of brush dams and stone and earth terraces will preserve the soil upon the mountains and valley slopes once the natural forest cover is removed. So vigorous is erosion on the unprotected areas that the streams from them are often nearly half earth. Tending to the same destructive results is the overgrazing of considerable areas of the forest. As a result the young growth is checked or prevented altogether, the humus is depleted, the roots broken and bruised, and a rapid run-off ensues, which accumulates in effect and soon gains on the forest beyond the point of natural control.

About 74% of the total area is still forested. Even this amount, however, is considered too small. Under the given conditions of slope gradient, soil texture, rainfall, etc., it is considered unsafe to have more than 18% to 20% of the surface cleared. Recent studies[1] have supplied clear-cut illustrations of soil erosion in a variety of situations: (1) on sodded "balds" where overgrazing and trampling by cattle have broken the turf and started landslides that quickly developed into gullies; (2) on all slopes where lumbering has removed the original protective covering and hastened the action of rain-wash; (3) on cleared and abandoned slopes once used for agriculture. In the last-named case the harm has been underestimated in the past. Undercutting and caving, once started in a cleared area, often extend upward into forested tracts and the débris derived in this manner is washed downward into the forest below. Some porous soils are erosion-resisting but their aggregate area is not relatively great. The allowable limit of steepness for cleared lands,

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[1] L. C. Glenn, Denudation and Erosion in the Southern Appalachian Region, Prof. Paper U. S. Geol. Surv. No. 72, 1911, p. 137.

15°, is almost everywhere exceeded, and in many places greatly exceeded. Terracing is practiced on a wholly inadequate scale. There is increased silting on the flood plains and in the stream channels, a conclusion applied to all streams draining catchment areas that have been extensively cleared.

A great deal has been written concerning the evil effects of deforestation upon soils and stream flow upon the assumption that the removal of a forest cover will inevitably and under all circumstances cause vigorous soil washing and floods. That some damage results upon the removal of a forest is axiomatic, but superlative terms can not be applied to all regions. Upon large areas of the sandy plains of the northern part of the southern peninsula of Michigan the removal of the white-pine forests has indeed affected the régime of the streams to a large though not a disastrous degree; the sandy soil imbibes the rainfall as readily as forest litter and retains it, without washing, almost as effectively as the roots and ground litter of a forest. In general it may be said that the deforestation of a plains area with a sandy soil produces minimum effects upon stream flow.

The vital feature of the forest physiography of a mountain region is the balance of power which the forest holds in the contest between soils and run-off. If in the run-off of a mountain region we grant any retarding effect at all, it follows that in those mountain regions in which the waste slopes are delicately organized and supply and demand sensitively balanced, the presence of the forest throws the advantage to the side of the soils and moderate and normal soil removal takes place at a rate compensated by the decay of the rock and soil formation. If on the other hand the forests be removed, their influence is withdrawn from the contest and run-off gains upon soil formation and disastrous soil wastage results.

The primeval forests have a peculiarly sensitive relation to these processes. In such regions the forest influence is expressed in the fashioning of the slopes, in the depth of decay of the rock, the rate of run-off, the amount of rain beating to which the soil is exposed, etc. Grant any degree of influence at all, however small, and the conclusion must follow that upon the removal of this influence — the forest — readjustment of relations must take place. The rain beats directly upon the soil, the retarding influence of the ground litter and tree roots and trunks is withdrawn, and more rapid soil removal occurs.

When once these evil effects have been allowed to take place mankind is deprived practically for thousands and even millions of years of the favorable conditions that preceded the epoch of destruction. In

Fig. 248. — Protection against erosion by parallel ditches. (Ayres and Ashe, U. S. Geol. Surv.)

Fig. 249. — Erosion checked by covering gulleys with brush, Longcreek, Va. (Ayres and Ashe, U. S. Geol. Surv.)

a hundred years man may achieve such baneful results as nature will compensate only during a geologic period of hundreds of thousands of years. Soil is a resource of priceless value. On resistant rocks its formation is excessively slow. The mills of the gods grind nowhere with more exceeding slowness than here. Many glacial striæ formed on resistant rock during the last glacial epoch, roughly 60,000 to 75,000 years ago, are still preserved as fresh as if they were made but yesterday. In that time man has come up from the cave and the stone hammer. Seventy thousand years is a very short time for the development of a soil cover; for man it means a period so great that his mind can hardly appreciate it. The earth as we find it in the geologic to-day must be treated with care if the human race is to have a fair distribution of its wealth in time. To the geologic mind there is something shocking in the thought that a single lumber merchant may in 50 years deprive the human race of soil that required 10,000 years to form.

Fig. 250.— Erosion checked by brush dams, Walnut Run, N. C. (Ayres and Ashe, U. S. Geol. Surv.)

These considerations apply with peculiar force to the southern Appalachians, which are in a subdued state of topographic development.

Bare rock ledges are the exception; waste slopes are the rule. The eye may roam over hundreds and thousands of square miles of country and see only well-graded waste slopes, delicately organized waste removal. This means that rock decay has gained on soil removal, that the interior forces of the earth are relatively feeble, and that weathering has gained on uplift. In this interplay of forces the forests have had a prominent part and have contributed to the formation and holding in place of the soil cover, an effect reciprocally helpful to the forest. The forest cover removed, the waste slopes are dissected, soil removal gains on soil formation, and the effect is of such magnitude as to deserve the name "geologic." Nor is the effect mitigated by systems of lakes such as occur in the glaciated mountains of the northern Appalachian region, the White and the Green mountains of New England.

Lakes act as strainers and deprive the waters that flow from them of their cutting tools, so that erosion by lake-fed streams is generally far less vigorous than in the case of a lakeless land. A region of lakes is also commonly a glaciated region, and if the topography is mountainous the soil is often largely removed on the mountain slopes. It is patchy in distribution and alternates with areas of rock outcrop and ledge. Such a composition — lakes, clear streams, rock outcrops abundant, and soil patchy in development — means that the removal of the forest cover is not expressed in widespread denudation such as takes place under other conditions.

Blue Ridge

The Blue Ridge, so-called, forms the eastern escarpment of the southern Appalachians and extends northward from their northern extremity as far as Pennsylvania. At the north it is a true ridge; at the south it is a great scarp that descends steeply from the upper level of the mountains to the lower level of the Piedmont Plateau. The gradients of the streams that flow eastward from it are excessively steep; descents of 2000 feet are in many places made in 3 miles. So vigorous is the assault of these streams upon the divide between them and the long roundabout streams that flow westward to the Tennessee and the Mississippi that the Blue Ridge divide is rapidly retreating westward.

The Linnville River of western North Carolina has pushed its headwaters so far westward as to invade the valley of a stream flowing southwest to the Nolichucky. The valley side has been broken down and the feebler westward-flowing stream diverted to the Linnville and the Atlantic by a course about 2000 miles shorter than its former one. The profile of the Linnville shows a reversed curve at the point where it crosses the Blue Ridge, an indication that the capture has taken place so recently in a geologic sense that the gradient has not yet been worn down to normal form. In a good many other instances, as near Rutherford, North Carolina, where the South Fork of the New River is being endangered by Elk Creek, a headwater tributary of the Yadkin, capture of a similar sort is imminent, and, as the earth counts time, to-morrow will see similar diversions take place at these localities. So strong is the contrast between the gentler descents of the westward-flowing streams and the torrential descents of the eastward-flowing streams that steep headwater alcoves are often separated from well-developed meanders by only 2 or 3 miles, or less, of low divide. This great wall-like scarp has been an effective barrier to the works of man, and only one railroad, that through the valley of the French Broad, via Asheville, crosses it. Elsewhere and in a large number of places the railroads run to the foot of the scarp, where they end abruptly.

Eastward for several miles from the Blue Ridge escarpment, Fig. 251, the country is exceedingly broken and forms a wilderness of hills and long trailing spurs that enclose headwater coves where many rural population groups are found. Villages and individual farms are numerous, while the "mountains" between the coves or the streams that head in the coves are wholly without inhabitants. To the people in the coves the Blue Ridge and the mountains beyond them are the "Land of the Sky." The escarpment is not a straight line nor a straight wall but consists of a labyrinth of coves, hills, and spurs that represent strong differential erosion of a mass of highly irregular rock. Formerly the highland west of the ridge extended much farther east, but the shorter eastward-flowing streams have been rapidly extending their headwaters westward since the uplift that followed or marked the close of the Cretaceous cycle, and the spur and hill crests are but the reduced remnants of the eastern border of the upland.

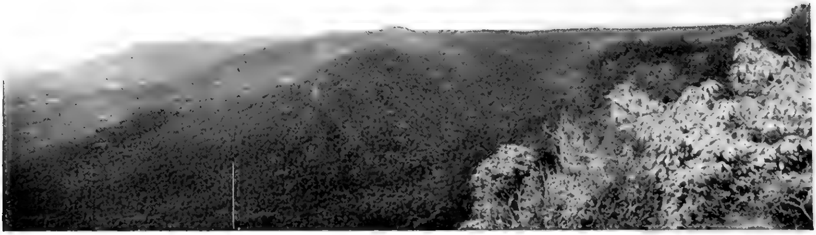

Fig. 251. — Plateau and escarpment of the Blue Ridge, looking southwest from Cæsar's Head, S. C. (U. S. Geol. Surv.)

Typical spurs of this sort are Haines' Eyebrow and Singecat Ridge, and among the isolated hills a typical occurrence is Pilot Mountain, whose top is covered or protected by a remnant of quartzite from which fragments are constantly breaking off and cluttering the slopes and aiding in their resistance to erosion.

North of the southern Appalachians the Blue Ridge changes its character completely. In western Virginia and in its northern extensions in Maryland and south-central Pennsylvania it is a true ridge, but its topographic aspects are gentle and it is characterized by rounded spurs and knobs. It is soil covered throughout and bears forests, or cultivated fields, or pastures, up to the summit.

The highest portion of the Blue Ridge north of North Carolina is about 65 miles south of the Potomac, where Stony Man and Hawk's Bill opposite Luray are 4031 and 4066 feet respectively above sea level. This is also the widest portion of the Blue Ridge, 10 to 16 miles. Northward the ridge crests are lower, and from Mount Marshall to the Potomac (50 miles) there are three deep gaps cut down to about 1000 feet — Snickers, Ashby, and Manassas gaps. Southward from Mount Marshall (3150 feet) 100 miles to the James there are numerous smaller gaps, but they are all at higher elevations, about 2300 feet above the sea.

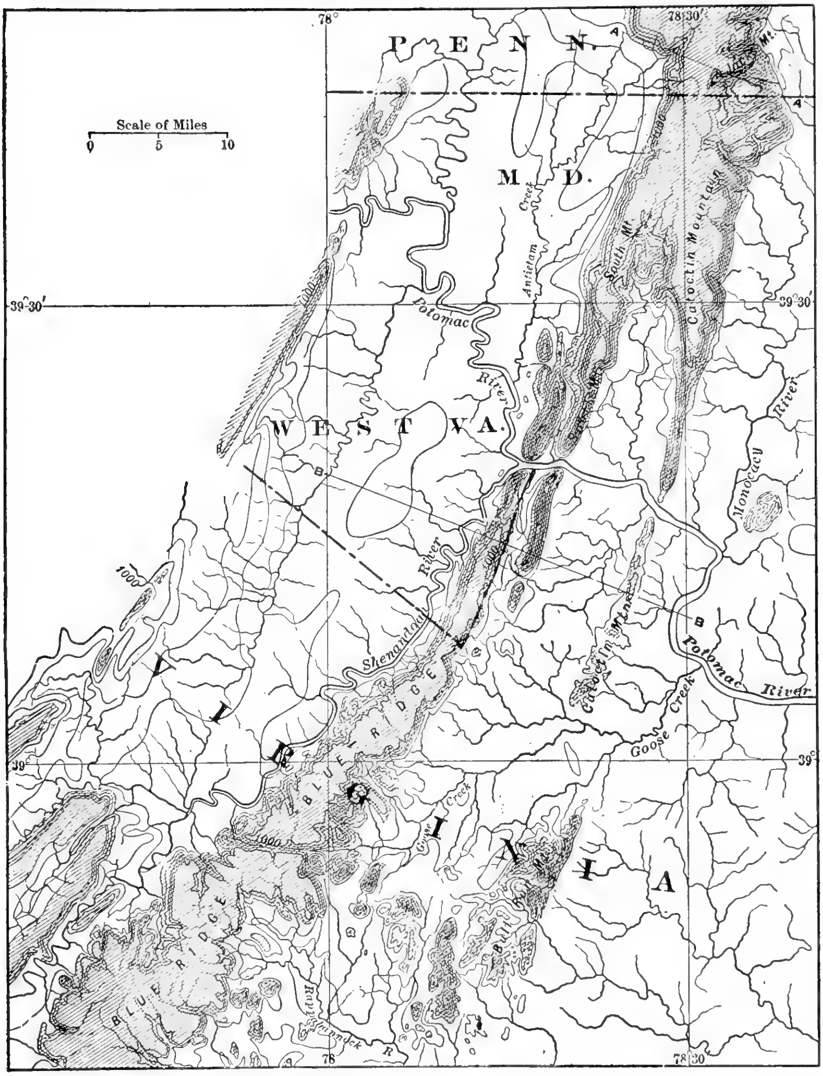

Fig. 252. — Blue Ridge, Catoctin Mountain and Bull Run Mountain in Virginia. Blank areas represent Tertiary peneplain; shaded areas represent remnants of Cretaceous peneplain now appearing as residuals above the Tertiary level. (Keith, U. S. Geol. Surv.)

The Blue Ridge extends northward from the Potomac still as a quartzite ridge of rounded contour known as Catoctin Mountain in Maryland and finally into south-central Pennsylvania near Carlisle, where it is known as South Mountain, reaching an elevation of 2000 feet, or about 1000 to 1200 feet above the Cumberland Valley which here borders it on the west. In New Jersey the Blue Ridge is represented by the highlands above Morristown, and the Highlands of the Hudson are really the northward continuation and expansion of the Blue Ridge. The latter form a narrow upland belt 1200 feet high and 12 miles wide that crosses the Hudson between Fishkill and Peekskill and continues east, merging finally with the upland of western New England.

The Blue Ridge owes its ridge-like quality in Virginia, Maryland, and south-central Pennsylvania to the harder rocks of which it is composed and to their superior resistance to erosion. These rocks are not everywhere uniform in character, and variations in altitude, breadth, and shape, of the Blue Ridge, occur in response to variations in rock character. Across Maryland and into Virginia as far as Berryville the Blue Ridge is formed upon resistant sandstones (Lower Cambrian), and over this portion its summit is rough and rocky and usually sharp-crested. South of Berryville the main crest is formed of an epidotic schist (Catoctin) and to some ex-

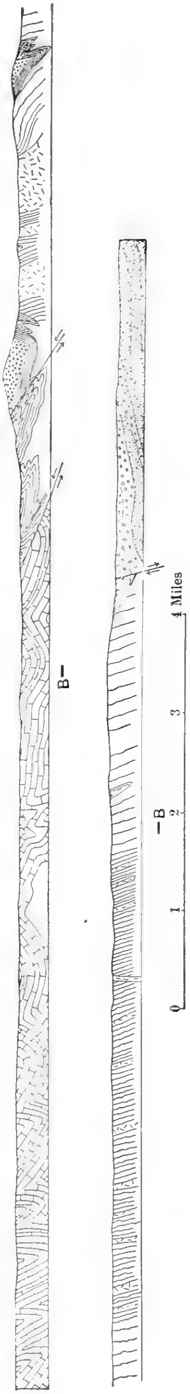

Fig. 252 a. — Cross section of the Catoctin Belt, western border of Virginia. (Keith, U. S. Geol. Surv.)

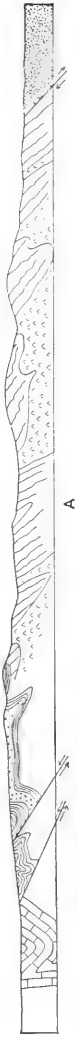

Fig. 253. — Cross sections of the Catoctin Belt, western part of Virginia. (Keith, U. S. Geol. Surv.) For location see Fig. 252.

tent of granite. The portion formed by the Catoctin schist is broad and has no very definite linear arrangement, as shown on the map, Fig. 252, so that the Blue Ridge through an expanse in breadth loses its simplicity and becomes markedly irregular in form.

East of the Blue Ridge in western Virginia and central Maryland and parallel with it is a similar ridge of resistant material known as Catoctin Mountain and Bull Run Mountain, formed for the most part of hard sandstones (Lower Cambrian), with the exception of a small part of the southern end of Catoctin Mountain, where a schist (Catoctin) makes the summit of the range. Bull Run Mountain has crests developed upon resistant sandstone.[1]

The structure of both Blue Ridge and Catoctin Mountain is synclinal, complicated by many faults; while the valley between them is anticlinal, and a similar structure is found in the Shenandoah Valley west of the Blue Ridge; so that while the Shenandoah Valley is at a lower elevation than the adjacent ridges, it is composed of younger rocks (Siluro-Cambrian limestone with occasional troughs of Lower Silurian shale). East of Catoctin Mountain the Piedmont Plateau is developed in the main on Newark strata composed of red sandstone and conglomerate.

PIEDMONT PLATEAU

The Piedmont Plateau extends southwestward from northern New Jersey and eastern Pennsylvania, its width gradually increasing from 50 miles in Maryland to a maximum of about 125 miles in North Carolina. Beyond this point it narrows and in central Alabama finally passes beneath the sediments of the Coastal Plain. Its surface dips gently eastward at the rate of about 20 feet per mile from an altitude of 1000 to 1200 feet on the west to 400 or 500 on the east.

The Piedmont Plateau is named from its position at the foot of the mountains that lie upon and beyond its western border. The name does not signify, however, that it has any of the characteristics of a piedmont alluvial plain, for its soils, topography, drainage, and physiographic development are in contrast to these features as developed on a foreland plain subject to alluviation.

The Piedmont province is a plateau only by reference to the low and flat Coastal Plain on the east, from which it rises by low bluffs or more strongly marked slopes than those developed upon the Coastal Plain. This border is marked by steepened stream descents and low falls and rapids. It is commonly designated the fall line, or fall zone. It probably marks a simple monoclinal flexure or a series of slight faults whose down-throws are toward the east.[2] The fall line is at variable distances from the coast; it is several hundred miles inland in Georgia and at the head of tidewater in the Chesapeake Bay region. Were the province otherwise situated it might never have received the name of plateau,

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[1] A. Keith, Geology of the Catoctin Belt, 14th Ann. Rept. U. S. Geol. Surv., pt. 2, 1892–93, pp. 285–395.

[2] C. Abbe, Jr., A General Report on the Physiography of Maryland, Including the Development of the Streams of the Piedmont Plateau, Maryland Weather Service, vol. 1, pt. 2, pp. 115 et seq.

for its absolute elevations are but little above those of the great plains of the earth. Indeed, as seen from the crest of the Blue Ridge (looking east) it appears as a low rolling plain. From the coastal side it appears essentially as an upland tract between a lower plains region and a region of mountainous relief.

The western border of the Piedmont Plateau is more varied than its eastern border. On the south it extends to the outliers of, or to the foot of, the strongly developed eastward-facing escarpment of the Blue Ridge. The ascent to the higher province is here from 1000 to 2000 feet in short distances. Northward the Blue Ridge becomes a true ridge and not only the eastern border of a mountainous country, a character which it retains as far as South Mountain, Pennsylvania. Farther north the whole Piedmont province changes in character as described in later paragraphs (p. 629).

From any commanding point within the Piedmont Plateau the province appears not as a smooth plain but as a broadly undulating surface extending in every direction as far as the eye can reach; upon this general surface are low knobs and ridges rising above the general level of the plateau, while below the general level are numerous rather deep and narrow stream valleys and channels. The most striking feature of the piedmont topography is the even sky line formed by the rounded hilltops which fall almost into a common plane that is not dependent upon or the result of the structural features of the region. The highly inclined and folded crystalline rocks of which it is chiefly composed and the softer Triassic sediments that occur in its central portion are both beveled off or truncated by the surface of the upland. It is inferred that the region has been subjected to long-continued and active erosion involving the reduction of lofty mountain ranges that once existed here. In this respect the Piedmont Plateau is but the seaward portion of a broad, gently rolling surface that once extended westward across the Blue Ridge, north along the Appalachians into New York and New England, and south across the Cumberland Plateau of Tennessee. Since its development the surface of this lowland has been elevated and much dissected; the present higher mountain crests are the residuals which were never reduced to a lowland because of (*a*) their greater initial height, or (*b*) their greater hardness, or (*c*) their favorable position on stream divides, or (*d*) a combination of two or all of these conditions.

The even contour of the surface of the Piedmont Plateau is not due to the underlying rock formations, for their structures are so diverse and complex as to produce a complex topography. The plain surface is due to peneplanation. An interesting survival of drainage conditions since peneplanation is shown in the courses of the larger streams, which are quite independent of the structure and character of the rock floor, while many of the tributary streams show adjustment to the character of the rock floor. The heterogeneity of the rock and the complexity of its structure are reflected in the indirect courses of the tributary streams and in the complex character of their valleys; but these structures are without expression in the case of the master streams.

The Tertiary cycle of erosion in which the peneplain of the piedmont region was formed was closed by uplift and in consequence the gradients of all the streams were steepened and their erosive powers increased. Down-cutting was the immediate result, and since this has been accomplished a certain amount of lateral swinging also has been accomplished, so that many of the larger streams have limited flood plains and the smaller ones have graded waste slopes. The piedmont has been well dissected by the erosion of the present cycle, but dissection has not yet gone far enough to destroy the accordance of the hilltops, whose approach to a common altitude in a region of disordered rocks is the strongest evidence of the former existence of a base-leveled plain throughout the region. In harmony with this condition is the deeply weathered character of the rock which mantles all the hill slopes and even the hilltops, and under the influence of gravity and rain wash is slowly creeping down to the streams.

So deeply decomposed was the rock of the Piedmont Plateau during the last stages of the long erosion cycle which resulted in its peneplanation that in spite of its later uplift and dissection many of the streams have not yet cut down to fresh rock.[1]

The middle and lower courses of the piedmont streams are gorge-like; the headwater tributaries commonly flow in broad shallow valleys separated by low rounded divides.[2] With the gradual deepening and widening of the lower courses more marked dissection will take place along the headwater streams and their drainage basins will be roughened accordingly.

The rocks of the Piedmont Plateau consist of a number of types each of which has had an important influence on the topography. They are chiefly crystalline and are derived in part from original sediments and in part from original igneous masses. They include crystalline gneisses and schists associated with crystalline limestones, quartzites, and phyllites intruded by granite, and a large variety of other types.

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[1] L. C. Grafton, Reconnaissance of Some Gold and Tin Deposits of the Southern Appalachians, Bull. U. S. Geol. Surv. No. 293, 1906, p. 13.

[2] N. H. Darton, Washington Folio U. S. Geol. Surv. No. 70, 1901, p. 1.

The gneisses, granites, and gabbros all offer about the same resistance and form by far the greater part of the general surface of the plateau. They are developed in the form of rounded hills and gentle slopes on the upland surfaces. Bands of varying resistance are distributed through these rocks, but they are very irregular in size and position and are therefore expressed in the topography by alternate softening and intensification of the contours of the valley walls and in expansions and contractions of the gorge floors. The phyllites, somewhat softer than the gneisses, form more rounded hills, gentler slopes, and valleys of broader proportions. Lenses of limestone and marble in the phyllite, with a high degree of solubility, have resulted in the development of broad flat-bottomed valleys. These limestone and marble bands are the weakest topographic factors among the piedmont rocks.

The more resistant rocks and those most prominent topographically are serpentines, slates, quartz-schists, and quartzites, which stand out as ridges or rounded knolls above the surrounding gneiss. The serpentine is most striking topographically where it is crossed by streams; at such points, steep, bowlder-strewn, rocky gorges and rough channels have been developed. While the form and size of the piedmont valleys have a relation to the geologic structure, the courses of the streams on the whole have not been strongly influenced by the arrangement of the bed-rock, and this is true particularly among the larger streams, which flow markedly independent of the structure.

TRIASSIC OF THE ATLANTIC SLOPE

From the Minas Basin in the Bay of Fundy to the northern boundary of South Carolina there occurs at intervals a geologic formation of great physiographic importance, for its topography, soils, and vegetation are to a large degree exceptionally developed and are unlike the topography, soils, and vegetation of the bordering crystalline rock. The formation is of Triassic age and is commonly known as the Triassic formation of the Newark system of rocks, and occupies about 10,000 square miles of territory. The general distribution of the formation is shown in Fig. 254, from which it will be observed that it does not occur as a continuous body of rock but as a series of elongated and detached areas occupying local basins of sedimentation. The longer axis of each area is roughly parallel to the main trend of the formation as a whole. There are in all thirteen major areas besides a group of smaller areas. As a whole the belt is about 1200 miles long and always less than 100 miles wide.

The principal rock members of the Newark system are sandstones, shales, and conglomerates, with local beds of slate and limestone and a certain marginal development of arkose and breccia. Almost all the areas of Newark rocks have associated sheets and dikes of basic rock, chiefly basalt and diabase known under the collective name of trap. The dikes trend as a rule from northeast to southwest, cross indifferently from sedimentaries to crystallines, and are narrower in the crystalline rocks bordering the area than they are in the sedimentary rock.

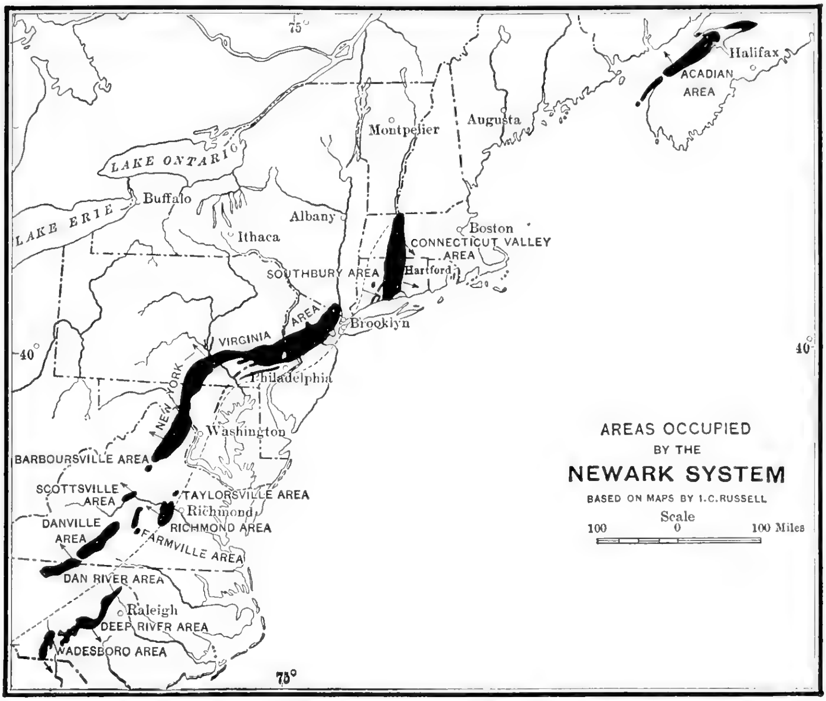

Fig. 254. — Local development of Triassic rock in the older Appalachians. The arrows indicate the direction in which the strata dip.

In part the trap sheets are extrusive and in part intrusive. The trap of Nova Scotia is extrusive in origin; most of that in the Connecticut Valley is extrusive, with important intrusives along West Rock Ridge and the Barndoor Hills north of the Ridge; along the eastern edge of the New Jersey Triassic are the Palisades, also of intrusive origin. In the Richmond and Catoctin areas the igneous rocks are of intrusive origin and usually occur in the form of sheets or sills, and dikes.

The widespread occurrence of faults of all degrees of displacement from a few inches to several hundred feet has caused the repeated outcrop of individual strata. The faulting has almost everywhere resulted in either westward or eastward dips, roughly at right angles to the trend of the basins in which the formation lies. The larger faults are believed to affect the underlying crystalline rock as well as the sandstone and the trap.

In general the Triassic rocks have a monoclinal structure throughout and all have marginal faults; in some cases this is pronounced along one border and in all cases it is developed to some degree. Some of the faults are large enough to bring to the surface the crystalline rock floor on which the sediments were deposited; others expose the basal conglomerate; and still others expose only the lower trap sheets or the intermediate finer shales and sandstones. In addition to faults, broad undulations occur, but no true folds have been observed. The faults in many notable instances pass directly into the crystallines, where they produce marginal features of importance, although within the crystal-

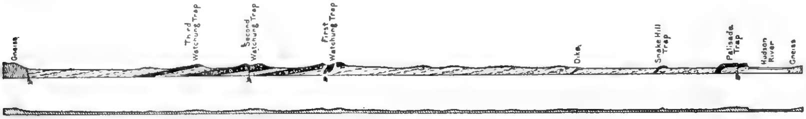

Fig. 255. — Relations of the igneous rocks to the sedimentary strata (Newark) in New Jersey, Paterson quadrangle. Vertical scale three times the horizontal. True profile in lower section. (U. S. Geol. Surv.)

Fig. 256. — Palisades of the Hudson from the Jersey side, looking south. The vertical cliff of diabase and the sloping talus are characteristic. (U. S. Geol. Surv.)

lines the structural and textural differences are not sufficiently marked to give rise to a type of topography as distinctive as that formed in the areas of Triassic rock where uniform structures prevail over wide areas and where strong and sudden alternations in hardness are the rule.

The topographic expression of these belts of Triassic rock is not everywhere the same, but depends upon the nature of the surrounding country rock and the elevation. In the Connecticut Valley the Triassic rock rests upon and is bordered by crystalline rock which is very much harder than the sandstone. The elevation of the region above the sea is in the main from several hundred (near the sea) to 2000 feet and less (in the interior), and erosion has therefore been sufficiently active to degrade the soft rocks to a lowland, while making so little impression upon the hard rocks as to leave them in the form of uplands. On the other hand the Richmond basin of Virginia is a plain continuous with the plain developed upon the surrounding rock. In this case it is not possible, except in a few localities, to infer any geologic change from a change in the topographic level,[1] a condition due not to the character of the surrounding rock, which is crystalline as in New England, but to the absence of pronounced elevation. The Richmond Triassic is on the eastern edge of the Piedmont Plateau and only a few hundred feet above sea level.

The characteristic features of the Piedmont Plateau as developed in Georgia, South Carolina, etc., are modified to an important degree or wanting altogether over large portions of northern New Jersey, eastern Pennsylvania, and central Maryland, Virginia, and North Carolina because of the occurrence of Triassic sandstone, the largest body of which occurs in New Jersey and Pennsylvania, Fig. 254.

In New Jersey and Pennsylvania the Triassic is a gently rolling plain from 100 to 400 feet above the sea. It is lowest along its southeastern margin. The hills for the most part show a distinct northeast-southwest trend, which coincides with the strike of the underlying strata, and in general reflects the slight variations in texture in the different sandstone layers. The relief is uniformly slight. Practically all the slopes are long and gentle and covered in most places with a thick, fertile soil. The general continuity of the plain is interrupted by valleys cut below the general level and by hills, ridges, and plateaus of harder rock that surmount the plain. The region was reduced to a peneplain during the Tertiary, and it is this that accounts for the general plain-like character of the region, but the reduction was only partial and the hard outcrops

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[1] Shaler and Woodworth, Geology of the Richmond Basin, 19th Ann. Rept. U. S. Geol. Surv., pt. 2, 1897–98, p. 393.

of the included trap were in this cycle but little reduced below the level to which they were brought during the Jurassic-Cretaceous cycle of erosion. The crystalline rocks of the Piedmont are overlain and concealed by the Triassic sandstones and shales except, so to speak, on the four corners of the depression in which the Triassic rocks were deposited. Here the crystallines run down into long tapering bodies of rock upon which is developed a topography of a type far different from that developed upon the Triassic strata.

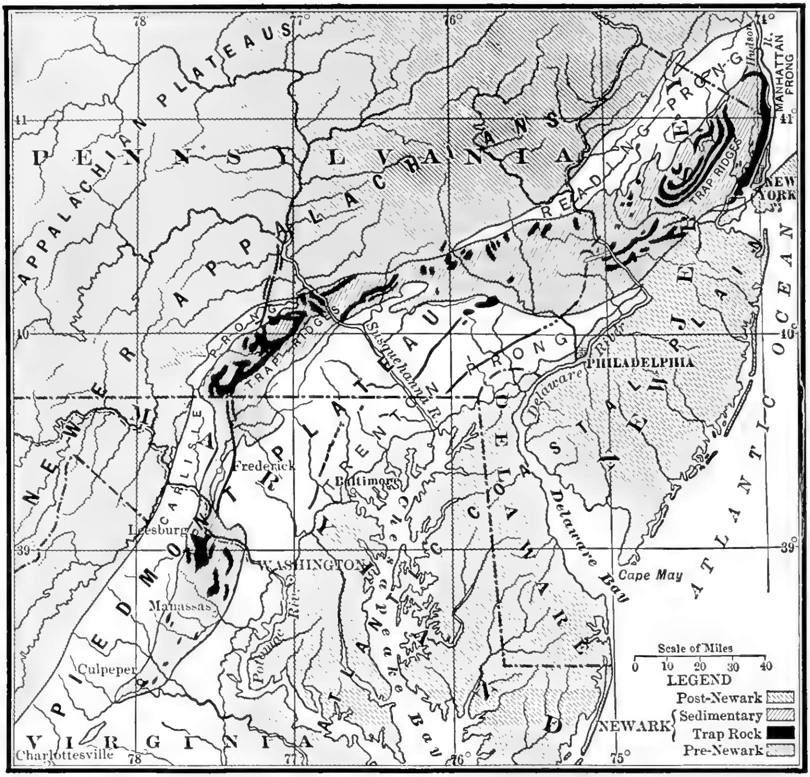

Fig. 257. — The four crystalline prongs of the older Appalachians which enclose the New York-Virginia area of Newark rocks. (Adapted from Russell, U. S. Geol. Surv.)

To these four narrow, tapering tracts the name *prong* has been applied by Professor Davis and each has been given a distinguishing name after the name of the town near its terminus. The prong that extends across southeastern Pennsylvania to Trenton is called the Trenton prong; the prong whose local name is South Mountain and which terminates near Carlisle, Pennsylvania, is the Carlisle prong; the narrow upland of crystalline rock which crosses northwestern New Jersey and terminates near Reading on the Schuylkill is the Reading prong; and the prong that includes and terminates Manhattan Island is called the Manhattan prong. Each prong has certain distinctive features which will now be described.

The Highlands of New Jersey, the Reading prong, are made up of long, parallel, continuous ridges, separated by limestone valleys.

> "The side slopes are often steep and the soil on them is generally thin, rocky, and poor. Between the ridge hills lie secluded vales of rich farming lands, opened out on soft limestones, more or less hilly on a small scale, and directly comparable to the larger valleys of New Jersey. Similar valleys, though less numerous, are also found in other parts of the range, as Saucon Valley, occupied by the creek of the same name, and Oley Valley, near Reading." [1]

Toward the west the Reading prong consists of short, rounded, semi-detached hills, often stony and rugged, ranging roughly northeast and southwest. Although the hills over the greater part of the area are generally rounded, the southern slopes are in most cases somewhat steeper, due to the inclination of hard strata at a high angle toward the south. The rather level summits of the highest hills reach a fairly uniform elevation between 900 and 1000 feet; occasional crests rising 100 or more feet higher represent residuals on the old peneplain surface of which all the summits were a part.[2]

The Carlisle prong (South Mountain, Penn.) extends south from opposite Carlisle, in Cumberland County, has a greater altitude and a more marked development of the ridge and valley type of surface than the Reading prong, and merges southward into the distinct single crest of the Blue Ridge. The general elevation is not less than 1000 feet throughout the range, though it increases toward the south, until along the Maryland line it reaches 2100 feet. As a result of greater elevation the hills toward the south appear less subdued than in the Reading prong, though there are no rocky peaks and few bare cliffs. The uniformity of upland level is also less marked over the area in general than in the case of the Reading prong, though from a distance it presents a smooth, even sky line.[3] The prong rises steeply from the surrounding valley plains and exposes a core of ancient volcanic rock and quartzite. The general structure is that of a broad uplift with minor folds on its surface which produce offsets of considerable magnitude.

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[1] W. S. Tower, Regional and Economic Geography of Pennsylvania (Physiography), Bull. Geog. Soc. Phil., vol. 4, 1906, p. 21.

[2] Idem.

[3] Idem.

From its narrow northeastern extremity at the rapids of the Delaware just above Trenton, where the hills are very low, the Trenton prong extends southwestward, widening gradually. The general elevation of the upland level slowly rises from about 400 feet to 600 feet on the south, and the surface has an eastward slope to the Delaware River; the streams have cut many tortuous valleys and shallow ravines below the general level to depths of 100 or 200 feet. The area may be described as a rolling country of rather even-topped hills and shallow dales. The hills are generally low. They are flat, to rounded or dome-shaped, with summits at a generally uniform level, expressive of the former base-leveling, and have gentle slopes coated with a thick layer of soil.[1]

The Manhattan prong descends from the level of the rugged uplands east and south of the Highlands of the Hudson to sea level at New York. The submergence of its outer border is marked and has made the lower Hudson a tidal estuary, broadened and deepened the East River, and given the coast an embayed character similar to that exhibited along the whole coast of New England.

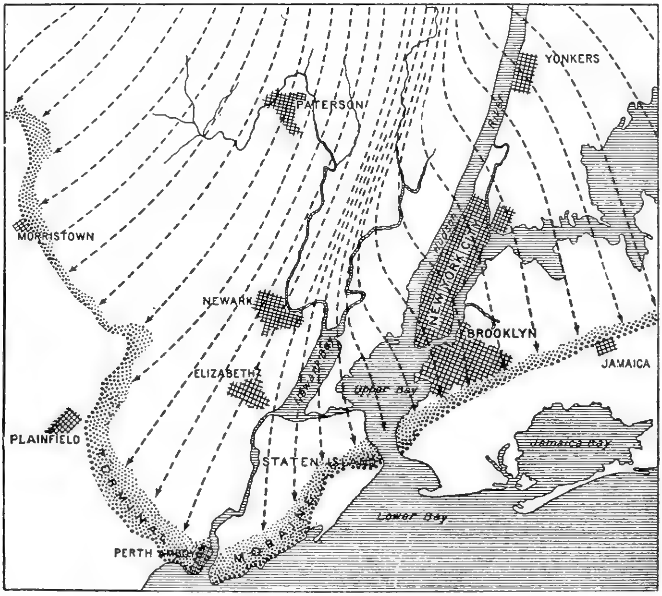

Fig. 258. — Terminal moraine and direction of ice movement in the vicinity of New York. (U. S. Geol. Surv.)

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[1] W. S. Tower, Regional and Economic Geography of Pennsylvania (Physiography), Bull. Geog. Soc. Phil., vol. 4, 1906, p. 19.

In northern New Jersey lakes and ponds were formed in the glaciated belt by the irregular disposition of the glacial drift in such a manner as to make basins; while glaciation also gave rise to minor topographic features in marked contrast to those produced by erosion. The drift in northern New Jersey is thin, its average thickness being probably not over 15 feet, while the general relief is measured in terms of several hundred feet. Had the drift been disposed uniformly over the surface it would have had small effect on the topography. But in some places the rock was left bare, while in others the drift was accumulated to a depth of scores of feet. In general the valleys received a heavier drift covering than the uplands, a covering which consists not only of glacial deposits themselves but of fluvio-glacial deposits related to them. The result of the filling of the valleys and the erosion of the intervalley ridges and uplands was to diminish the relief, though such diminution is nowhere marked.[1]

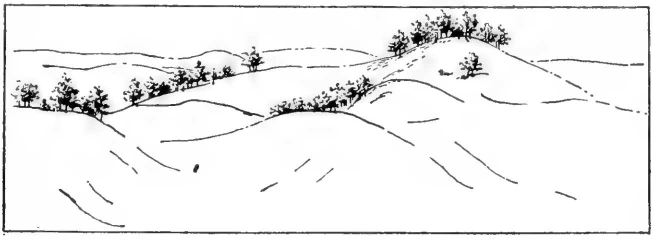

Fig. 259. — Characteristic terminal-moraine topography. (U. S. Geol. Surv.)

SOILS OF THE PIEDMONT PLATEAU [2]

The soils of the extreme northern part of the Piedmont region, in New Jersey, are glacial, but elsewhere they are purely residual in origin, and have been derived almost exclusively from the weathering of igneous and metamorphic rocks. The chief exceptions are the detached areas of Triassic sandstones and shales. Marked differences in the character of the rock and in the methods of formation have given rise to a number of soil types, those derived from crystalline rocks being the most numerous and widely distributed.

The most important and widely distributed soils of the Piedmont Plateau are known as the "red-clay lands" and are characterized by red clay subsoils, with gray to red soils ranging in texture from sand to

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[1] R. D. Salisbury, The Physical Geography of New Jersey, Final Report of the Geol. Surv. of New Jersey, 1895, pp. 155–156.

[2] Data chiefly from Soil Survey Field Book, U. S. Bur. Soils, 1906.

clay, the lighter colors prevailing with the sandy members. The red-clay soils are of residual origin, derived from the degradation of igneous and metamorphic rocks which have been weathered generally to great depths, so that outcrops are rare. Fragments and bowlders of the parent rocks are, however, found on the surface to a variable extent.

An important type of red clay soils is a gravelly loam which has been derived from the breaking down of granites chiefly of a coarse-grained variety; it represents a less complete weathering of the rocks than some of the other types. The soil is a brown sandy loam about 7 inches deep, carrying variable quantities of feldspathic or quartz gravel. The subsoil is a heavy, micaceous, red loam or clay loam containing considerable gravel. Outcrops of granite appear in many places. A prominent feature of this type is a lack of tenacity in both soil and subsoil, as a result of which the land erodes and gullies in a serious manner. As a rule it occupies high broken uplands and the drainage is good. The characteristic timber growth is hickory, shortleaf pine, and some cedar.

The fine sandy loam type of red sand soils is formed chiefly from the weathering of talcose schists and slates. It is light gray to pale yellow in color. Hickory, oak, and pine are the growths found on the better-drained areas, while gums are characteristic of its poorly drained phases. The Indian or purplish red soils derived from the weathering of red sandstones and shales (Triassic) are developed in detached areas in shallow basins in the Piedmont from New England to South Carolina.

The occurrence of a large number of fragments of shale (from 10% to 40%) in those soils derived from Triassic shales is characteristic, whence the local name "red gravel land" for the shale loams. The Triassic sandstones weather into gravelly and sandy loam types where they are coarse and into pure loams and silt loams where they are fine. A stony loam type consists of very stony land, hilly to mountainous in character, generally covered with a natural forest of chestnut and oak. The soil consists of a rather heavy red loam, 8 to 10 inches deep, containing from 30% to 60% of red or brown sandstone fragments. The subsoil is of much the same character to a great depth. This type is derived from the more siliceous or hardened phase of the Triassic sandstone. It is well adapted to forestry and orcharding, and the more level areas, when the stones are removed, to general farm crops.

The soils of residual origin, derived principally from mica schists, have yellow or only slightly reddish subsoils and gray or brown surface soils. They are also micaceous and subject to erosion. Locally they are known as "gray lands," to distinguish them from the "red lands" derived from the Triassic sandstones. The topography is in general not so rough, being rolling to moderately hilly. They are not deeply weathered, and the underlying rock is often encountered within 2 feet of the surface on slopes where erosion is pronounced and rarely more than 10 to 15 feet below the surface.

The gneisses and schists of Maryland, Pennsylvania, and Virginia weather into a stony loam containing from 30% to 60% of stony material. The type occurs on the summits of hills and ridges and on steep slopes where the drainage is good.

CHAPTER XXX

OLDER APPALACHIANS (*Continued*)

NORTHERN OR NEW ENGLAND DIVISION

THE New England physiographic province is continuous with New Brunswick and Nova Scotia and that part of Quebec lying south of the St. Lawrence River. To a large degree it has shared in the physiographic history of these districts, the Laurentian Plateau of Canada, and the great Appalachian province of the United States of which it forms a large division. Like the adjacent regions a large part of the New England province was peneplaned (Jurassic and Cretaceous time), then uplifted, extensively dissected, and glaciated. In general terms it may be described as an upland, for it possesses a somewhat uniform upper surface which extends from an elevation of several hundred to two thousand feet above the sea. But this term can scarcely be applied to its outer margin. Recent depression has submerged the border of the region, and the upland character is not therefore conspicuous on the immediate shore. The word upland or plateau, often applied to the New England province, also requires important modification when applied to certain interior portions of the New England region; for while most of the southern half of New England is accurately described as a dissected upland plain or plateau, the northern portion of New England bears important mountain groups, the White Mountains of New Hampshire, the Green Mountains of Vermont, and other groups of lesser height and size, besides a number of isolated mountain peaks such as Mount Katahdin in central Maine and Mount Monadnock in southern New Hampshire. Indeed, so mountainous are large parts of New Hampshire and Vermont that the mountain feature and not the plateau feature is conspicuous, and over large areas the plateau feature is not expressed at all.

The western portions of Massachusetts and Connecticut are also more rugged than the central and eastern portions. The principal elevations are the Hoosac Mountains, the southern extension of the Green Mountains. Even in southern New England almost every general view embraces one or more residuals of former lofty mountains. As elevations they are scarcely ever of notable scenic interest, though in a moderate way they are attractive with their forest-clad summits and slopes, drained by a large number of cool, spring-fed, torrential brooks. They are but the unimpressive remnants of a once more mountainous country. In place of these trifling elevations were mountain peaks and ranges of alpine height bearing upon their flanks snow fields and perhaps glaciers.[1]

Upland Plain of New England

The detailed topographic forms of the *southern* New England region have been carved in the Cretaceous peneplain since its elevation; for this reason a knowledge of the peneplain feature is of great importance in the study of the present topography. The argument for peneplanation is sustained by the striking accordance of level between different portions of the old peneplain developed alike on the crystalline rocks of the eastern and western uplands and the tilted lava sheets of the Triassic area of Massachusetts and Connecticut. Furthermore, no other process but peneplanation would give so uniform a slope to the surface southward toward Long Island Sound.[2] An imaginary plane passed through the hill summits of the region would slope southeastward gently and would rest on nearly all the summits of both the eastern and western uplands.

CRETACEOUS AND TERTIARY PENEPLAINS

During the Jurassic and early Cretaceous periods the New England region, of rugged aspect because of displacements at the end of the

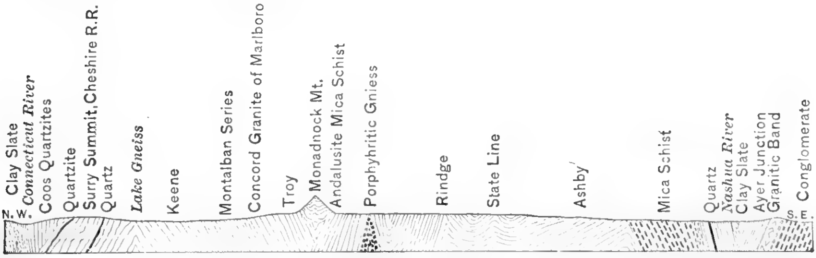

Fig. 260.—Profile across central New England, showing uplifted peneplain and the Mt. Monadnock residual. (Hitchcock.)

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[1] Among the isolated residual elevations of New England Mount Monadnock in southern New Hampshire is typical. The name of the mountain is therefore applied to any isolated residual. Mount Monadnock rises 3866 feet above mean sea level and about 2000 feet above the surrounding plateau of southern New England. The peak does not stand alone, but is one of a family of monadnocks which includes Wachusett, Watatic, Asnebumskit, and others. All of them are believed to owe their survival to their position on the divides between the major streams rather than to the greater resistance of the rocks composing them. See J. H. Perry, Geology of Monadnock Mountain, New Hampshire, Jour. Geol., vol. 12, 1904, pp. 1–14.

[2] W. M. Davis, The Geological Dates of Origin of Certain Topographic Forms on the Atlantic Slope of the United States, Bull. Geol. Soc. Am., vol. 2, 1891, p. 557.

Triassic, was eroded practically to sea level. Topographic irregularities disappeared, hills melted under the forces of erosion until only their roots remained. A slight depression then occurred which submerged the outer border upon which were deposited Cretaceous sediments of considerable depth and horizontal extent. At the beginning of the Tertiary period New England was again uplifted, but the uplift was of a broad regional variety. During uplift a slight tilt was given the land surface in the direction of the sea, so that the interior valleys were cut far below the general level. Dissection followed upon the uplift of early Tertiary time, the overlapping Cretaceous sediments of the southern border of the region were entirely removed, and the limestones of the Housatonic Valley, less resistant than the crystalline rocks in which they were enclosed, were reduced to a narrow lowland. The soft Triassic shales and sandstones of the Connecticut Valley were also worn down, forming a local peneplain bordered by crystalline uplands and surmounted by resistant trap ridges and hills.

Again uplift occurred, which invigorated the streams and led not only to the deeper dissection of the remnants of the uplifted Cretaceous peneplain but also to the dissection of the lower (Triassic) and more local lowland. The dissection of both the Cretaceous and Tertiary peneplains has everywhere brought into relief areas of softer and harder rock, even among the prevailingly hard crystallines where a relatively small degree of variability in resistance is the rule. Since the period of maximum uplift and dissection of southern New England there appears to have been a depression, for the outer border of the region is now drowned, as shown by the estuarine bays at the mouths of all the coastal streams and by Long Island Sound, which now occupies the inner lowland of the Coastal Plain, whose remnants are Long Island, Martha's Vineyard, Nantucket, and Cape Cod.

Geologic Features

The chief structural features of New England are (1) a western mountain axis extending through Vermont and western Massachusetts into Connecticut, (2) an eastern mountain axis extending through Maine and New Hampshire southward to the Sound, (3) a long, narrow, structural depression between these axes — the Connecticut Valley, and (4) two ancient basins on the eastern border of the province, the Boston and Narragansett basins. Each mountain axis is a line of topographic elevation on the north but has been worn to a lowland plain on the south, and, more recently, raised to form an upland. Since dissection accompanied and followed uplift the plain has become a dissected upland.

Thus the Green Mountains extend through Vermont as a prominent mountain range but change from a range-like elevation to a plateau near the northern boundary of western Massachusetts. In a similar way the White Mountains terminate near the northern border of Massachusetts. The Connecticut Valley is everywhere a structural as well as a topographic depression, but it too has a northern and a southern section of unlike characteristics. On the common border of Vermont and New Hampshire it is a great synclinorium[1] of crystalline Paleozoic rocks whose valley character has been emphasized by the predominance of rather easily denuded mica schists[2]; its southern continuation across Massachusetts and Connecticut is developed upon a block-faulted and much dissected mass of sandstones, shales, and conglomerates (Triassic) and intercalated trap sheets.

The mountains and uplands east and west of the Connecticut Valley are composed mainly of crystalline rock — schists, gneisses, and granites of many varieties. In the western part of the province a considerable body of limestone occurs, a fact of physiographic importance since the limestones are characterized by topographic depressions and deep soils. The schists, gneisses, and granites are of variable composition and have been variously affected by the weather. The granite gneiss of Lighthouse Point, New Haven, is a very resistant rock and is but little weathered; the chlorite schist west of that city and on the eastern edge of the western upland is more deeply decayed, the planes of schistosity offering relatively easy means for the penetration of weathering agencies. In general the north-south trend of the structure is brought out rather clearly by the differences in resistance among the various rock types. The main valleys have been carved on north-south lines and the intervening ridges trend in the same direction. Railway construction on north-south lines is comparatively easy; construction on east-west lines is almost as difficult as in a mountainous country.

Differences in rock character are largely responsible for differences in the valley widths in both the western and eastern uplands. The upper Housatonic and the Deerfield illustrate this relation admirably. The one flows southward in western Connecticut through a limestone belt and has developed a broad, deep valley of exceptional size; the other traverses a belt of resistant gneiss and its valley has a canyon-like aspect. The limestone is so soft relatively that good exposures of it are rare in individual stretches of a mile or more; many of the schist

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[1] Pumpelly, Wolff, and Dale, Geology of the Green Mountains in Massachusetts, Mon. U. S. Geol. Surv., vol. 23, 1894.

[2] C. H. Hitchcock, Geology of the Hanover Quadrangle, Rept. State Geol. Vt., 1905.

and gneiss outcrops are so resistant that the striæ of the glacial period are still clearly defined upon them.

Effects of Glaciation

TOPOGRAPHIC AND DRAINAGE MODIFICATIONS

The last geologic event of topographic importance was the invasion of New England by the continental ice sheet which covered the northern portion of America. The ice removed the deep soils of the peneplain from the interstream areas where they probably persisted even after preglacial uplift and dissection had removed large portions of them. The bed-rock was scoured and its weathered upper portion largely removed and fresh rock exposed. Rock ledges were commonly grooved, scratched, polished, and rounded by the land waste which clogged the lower portions of the ice, and minute irregularities of form and drainage were thus imposed upon the landscape. Glacial action produced a characteristic roughening of the surface, areas of soft rock were excavated to a greater depth than surrounding areas of hard rock, and reversed slopes were formed not only in the localities of glacial scour but also in those of glacial accumulation. A rearrangement of stream channels resulted in the filling of many depressions, and the formation of lakes and ponds and numberless falls and rapids.

TILL DEPOSITS

Of great interest in any glacial region is the distribution and extent of the glacial débris. New England was neither covered with heavy sheets of till as was the case with Illinois, Indiana, and other central-western states, nor so denuded of soils as Labrador and portions of Newfoundland. Although rock outcrops are common and even abundant in southern New England, the surface consists in the main of a thin sheet of glacial material largely of local origin and of very complex composition. A part of this material was brought into place by the glacial ice as subglacial drift, but the larger part is probably englacial material that was dropped in a confused and irregular manner upon the country as the ice sheet gradually melted away and disposed in large part regardless of the underlying topography. The lower few hundred feet of ice must have been heavily clogged with drift after the manner of the Greenland ice sheet to-day; and during the last stages of melting the stagnant ice must have dropped its enclosed material upon the surface in the most irregular manner and largely without regard to the form of the surface upon which the ice rested. The relative absence of a drift cover on the higher elevations, as on the trap ridges of the Connecticut Valley, is probably owing (1) to the greater freedom of the ice at this elevation from drift, and (2) to postglacial erosion. The lower hilltops and many of the hill slopes bear quantities of glacial material. Hillside and hilltop farms are common, and their soils, when cleared of bowlders, are not sterile and easily impoverished, as is so often stated, but include some of the most naturally productive lands of the region. Their chief defects are an excessive amount of bowlders and a tendency to erosion when kept cleared of the native vegetation. Locally there exist extensive areas of glacial till, as in Aroostook County, Maine, and in all the valley lowlands, especially the Connecticut Valley lowland. Such areas are as a rule intensively farmed, whether they are of large or of small extent. They and the drained swamps and valley floors of the coastal regions represent the chief basis of the agricultural interests of New England.

The more rugged northern portion of New England bears a smaller quantity of glacially derived land waste. Its more northerly position subjected it to more intense erosion because the southward-flowing ice was there thicker and hence more powerful, while the greater relief of the section gave abundant opportunity for the thorough scouring of the more exposed and higher masses against which the ice impinged. Its hilltops and sides are bare or the rock is thinly veiled with a bowldery till. The most notable accumulations of material are in the valleys and especially at the point of convergence of several valleys where englacial material, often in large amounts, was dropped at the time of the disappearance of the continental ice sheet.

ESKERS, DELTA PLAINS, AND SAND PLAINS

Eskers occur in greatest abundance in southern Maine, where they were formed during the waning stages of the glacial invasion. They represent channel deposits of subglacial and englacial streams that discharged across the zone of wastage of the continental ice sheet. They form a not inconsiderable part of the total area and are conspicuous relief features, often extending for a score of miles without a break of any sort and with even summits, again crossing hills and valleys, the level undulating in sympathy with the general topography. Their composition is rather uniformly of sand, gravel, and stones of medium size, the whole with various degrees of stratification but always somewhat sorted. Their slopes are commonly so steep as to be uncultivated and wooded. The tops are so narrow that although flat they are not of sufficient area to make cultivation worth while. In the other New

England states they are found here and there, but they do not generally form important elements of the relief nor have that great length that marks the eskers of Maine.

In a flat region glacial sand plains are often inconspicuous topographic features, but in so rough a country as New England every flat tract, be it sand plain, salt marsh, or valley floor, introduces into the landscape an unusual element that catches the eye and enhances the view. The general roughness of the surface of New England is responsible for the formation of a large number of sand plains, glacial deltas, and allied forms that are important topographic features. During the period of deglaciation a large number of small water bodies developed in front of the ice as the ice impounded the drainage of some local basin draining toward it, and into these water bodies streams were discharged and deltas were accumulated. Later drainage of such lakes by the disappearance of the ice exposed the deltas and allowed their dissection.

Where alluvial material was accumulated in front of the ice and not in a body of standing water it commonly formed a sand plain or valley train, the one if deposition took place upon a rather flat plain, the other if deposition took place in a narrow valley. Locally sand plains are sometimes found along the borders of valleys where deposition took place at the mouth of some tributary while the main valley was still filled with ice. Such plains are commonly associated with rude terraces of which they themselves form a part. The terraced effect was gained by the disappearance of the ice, which left the outer edge of the accumulated material unsupported.

STREAM TERRACES

The influence of glaciation is also expressed in stream terraces built during a period of stream aggradation associated with the retreat of the ice. It now seems probable that aggradation was enforced as much by the lower gradient of the valleys during the waning of the ice sheet as by the abundance of land waste contributed to them. In this view the change from aggradation to that degradation which resulted in the terracing of the aggraded material was invoked by both decreased waste supply and tilting of the land. The tilting is common in a very large region including at least the Great Lake district, New England, and the Laurentian Plateau.

The Connecticut and Merrimac valleys on the New Hampshire boundary have been to some extent mapped and leveled and the terraces identified. The highest terraces and deltas of tributaries represent the remnants of an ancient flood plain; they stand quite uniformly about 200 feet above the Connecticut River, except where a tributary enters.[1]

Farther south the attitude of the Connecticut Valley was such as to favor the formation of a succession of lakes. There were three main bodies of water — Montague, Hadley, and Springfield lakes — separated from each other by the central trap ridges. Tributaries accumulated sand and gravel deltas on the lake margin, fine laminated clays (in which arctic leaves have been found) were spread over the lake floors, and shore lines were formed. On the northern border of Massachusetts these accumulations are now 380 feet above the sea, at Northampton they are at 300 feet, on the southern border of the state they are at 180 feet, and at New Haven correlative deposits are near sea level. The southward tilting of the land which these southward-diminishing elevations imply, drained the lakes, gave the Connecticut greater erosive power, and resulted in the formation of the great terraces that now border that stream and enhance its scenery as well as the productivity of the valley.[2]

While the New England terraces are everywhere the product of either the tilting of the land or decreased waste supply or both, their disposition, size, and field relations offer a great variety of conditions. In the Connecticut Valley they seem in the main to have been controlled in their size and shape by natural unrestrained meander growth and stream deflection. In the Westfield Valley, and presumably in a large number of others not yet examined, their development appears to be guided largely by the rock sides of the preglacial valley.[3]

LAKES

Lakes are among the most characteristic features of a glaciated surface and are of special interest in connection with forests and stream flow. They are very abundant in New England, Connecticut alone including more than 1000, and together with swamps and marshes they occupy 145 square miles, or about 3% of the surface of that state. In Maine the proportion of surface occupied by lake is greater than in any other state in New England; 5% to 10% of the total area of the larger catchment basins is the rule. The lakes have a very beneficial effect upon both the climate and the run-off. They act as great reservoirs, and though they rise and fall with the seasons, they do so over larger areas

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[1] C. H. Hitchcock, The Geology of New Hampshire, Jour. Geol., vol. 4, 1896, p. 61.

[2] B. K. Emerson, Holyoke Folio U. S. Geol. Surv. No. 50, 1898, p. 3, col. 4.

[3] W. M. Davis, River Terraces in New England, Bull. Mus. Comp. Zoöl., vol. 38, 1902, pp. 281–346.

than the rivers and therefore by smaller vertical amounts. They steady the river discharges by holding large volumes of water but little above the level of the outlet both in time of flood and in time of drought.

It is perhaps the general conception that of two groups of streams occurring in regions of equal rainfall and comparable relief, that group that has the larger number of lakes will have the more even flow through the year. In this view the rivers of New England should have fluctuations of lesser value than the lakeless streams of the broken portions of the Middle Atlantic States. To test this generalization the author made some computations of the average discharge of 30 New England streams from the St. John to the Connecticut during the months of May and November, 1908, the months which appear by rough estimation to represent the greatest departures in opposite directions from the normal discharge for 1908.[1] It was found that the ratio of discharge in the month (November) showing least discharge to the month (May) showing the greatest discharge is 1 : 11.6. Similar computations for the 14 streams between the Susquehanna and the Rappahannock, almost wholly outside the glaciated area and the region of the lakes, is 1 : 7. The influence of the lakes would seem theoretically to throw these ratios in the other direction. The cause for this curious condition is probably found in the facts (1) that the northern streams are fed by the rapidly melting snows of spring, the discharge lagging behind the time of maximum melting, and (2) that the thinner soil of New England enforces a more rapid run-off.

A partial test of this explanation would be the examination of two stream systems in the glaciated area, one in the region of no snow or of early melting snows and the other in the region of late snows.

Were it not for the lakes the fluctuations of stream discharge would be still greater in the lake region than they now are, for the effect of the rapid melting of the snows would not then be mitigated. A thorough test of this conclusion would require an examination of streams throughout whose catchment areas the forest cover is in the same state of preservation and the topography is of the same quality but whose drainage systems contained widely different percentages of lake basin. A partial test is the contrast afforded by the St. Croix and the Penobscot. The St. Croix basin is well covered with forest, the Penobscot is about two-thirds covered with forest; the former has about 10% of lake and pond surface, the latter about 6%. In harmony with these figures are the ratios of discharge for May and November, 1908, which are 1 : 5 for the St. Croix and 1 : 8 for the Penobscot. The Merrimac basin has about 3.6% of lake and pond surface, and the ratios of discharge for May and November are also 1 : 8 respectively for this river.

These figures clearly show the influence of the lakes in retarding the flow and also how disastrous the floods of New England would be if

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[1] The basis of these computations is the summary table by Barrows and Bolster, The Surface Water Supply of the United States, 1907–8, pt. I, North Atlantic Coast, Water-Supply Paper No. 241, 1910, pp. 342–344.

the lakes did not exist. Though New England is a lake country, its forests are needed to help equalize stream flow to an even greater degree than more rugged southern districts where snows are absent or light or melt at more regular intervals and where the soils are deep.

SUBREGIONS OF THE NEW ENGLAND PROVINCE

Having examined the general physiographic features of the New England province we shall now consider the special features of the topography, drainage, and soil of a number of exceptional subregions.

The largest of these subregions are:

(1) White Mountains and bordering uplands.
(2) Green Mountains and bordering uplands.
(3) Connecticut Valley lowland and associated trap ridges.

WHITE MOUNTAINS AND BORDERING UPLANDS

The most interesting and important mountains in New England are the White Mountains of New Hampshire. Their highest summit, Mount Washington, is 6290 feet above the sea and is the nearest New England rival of Mount Mitchell, N. C. (6711 feet), the highest peak in the eastern part of the United States. The most important single feature of the White Mountains is the Presidential Range, which besides Mount Washington includes Mount Jefferson, 5725 feet, Mount Adams, 5805 feet, Mount Madison, 5380 feet, Mount Monroe, 5390 feet, and a number of other peaks of comparable altitude. This range extends roughly north and south, which is the prevailing trend of the other ranges that constitute the group, although there are many departures in detail from the general condition, such as the northeast trend of the Dartmouth Range, the northwest trend of the Belknap Range, the great curve from east-west to north-south in the Randolph Range, etc. The valleys about and among the White Mountains lie at elevations ranging from 500 to 1000 feet, and the plateau remnants that lie about their bases are from 1000 to 2000 feet above the sea. Their relative elevations are therefore but little less than their absolute elevations and their influence as cloud gatherers and rain condensers is conspicuous. The average precipitation of the mountains is perhaps from 10 to 15 inches more than that of the surrounding valleys and plateaus, although no accurate observations of this condition for a period of years have yet been made.[1]

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[1] For incomplete data as to the rainfall and the snowfall of the White Mountains consult A. J. Henry, Climatology of the United States, U. S. Weather Bureau, Bull. Q, 1906, p. 120; and S. A. Nelson, The Meteorology of Mount Washington, Geological Survey of New Hampshire, 1871; Water-Supply Paper U. S. Geol. Surv. No. 234, 1909, pp. 7–76 et al, map, Plate 1.

The White Mountains constitute the most important part of the eastern mountain axis in New England, which has two points of difference when compared with the western or Green Mountains axis: (1) it is composed largely of igneous rocks while the western range consists largely of metamorphic rocks, and (2) it has no southern representative in the Older Appalachians. Like the western range the eastern is bordered on one side by sedimentary rocks; the Carboniferous conglomerates, sandstones, and shales of the Boston and Narragansett basins lie on the eastern flanks of the New Hampshire-Maine axis, just as limestones, sandstones, and grits lie on the western flanks of the Green Mountains axis. The geosynclinal structure combined with the lesser resistance of the basin sediments as compared with the bordering igneous rocks have resulted in the development of lowlands, and the drowning of portions of the lowlands thus developed has given rise to Boston Bay and Narragansett Bay.

The eastern mountain axis of New England extends northward and northeastward through New Hampshire and northern Maine where it forms a belt of rough country, Plate V. Mount Katahdin, Maine, is a part of the White Mountain district. The White Mountains are the only part of this mountain axis that have not been reduced to a lowland, then uplifted, dissected, and glaciated. Elsewhere the surface has been so completely base-leveled that only isolated residuals occur, such as Mount Katahdin in Maine, Mount Monadnock in New Hampshire, Mount Wachusett in Massachusetts, and other monadnocks of less importance.

The whole of Maine southeastward of the White Mountains axis is a gently inclined upland sloping with marked regularity toward the sea. The degree of base-leveling which it reached at the end of a previous erosion cycle is indicated in Fig. 261. It must of course be remembered that isolated unreduced masses occur even here where the general reduction of the rough topography appropriate to a disordered mass of rock such as the figure indicates is so complete. Mount Desert Island is perhaps the best-known residual of this sort. Its highest peaks are but little over 1000 feet above the sea.

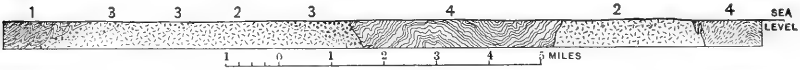

Fig. 261. — Section south of Blue Hill, Maine, showing the base-leveled surface of the uplands bordering the White Mountains on the east. 2, granite; 3, diorite, diabase, and gabbro; 4, schist. (Emmons, U. S. Geol. Surv.)

In so far as the geology of the White Mountains has been deciphered there is warrant for the conclusion that the general structure of the main or Presidential Range is that of a great overturned anticline.[1] The subsidiary ranges are in general also anticlinal, while the main valleys or depressions are considered as synclinal in structure. If these interpretations are correct, the White Mountains as a whole may be described as a geanticline or an anticlinorium.[2]

The general mountainous condition in so far as it depends upon elevation may then be assigned to uplift of the rocks of the White Mountains in the form of an anticlinorium; this is to be regarded as the net result of a long series of very complex mountain-making movements. During the long erosion interval which in southern New England produced a peneplain, the White Mountains were worn lower than previously but not completely reduced. The White Mountains of to-day should therefore be regarded as but the remnants of far higher mountains worn down to moderate elevation. With the uplift of the peneplain in late Cretaceous and early and late Tertiary times the White Mountains were also broadly uplifted, and from the gradual rise of the peneplain in their direction we may reasonably infer that the uplift was more pronounced in the mountain belt than elsewhere. It may have amounted to 2000 feet.

Following uplift, vigorous erosion set in, with the result that the profiles were steepened and the relief developed on bolder lines than before. Still further variety was given the relief by glacial action. It is noteworthy that in general the relief is steeper along the main lines of glacial flow, as if from more pronounced scour of the preglacial valley borders. The combined effects of preglacial and glacial scour and erosion were the fashioning of the slopes on bolder lines, so that the relief in places becomes almost alpine. The degree of steepness is suggested by the destructive landslides that have occurred in the past and may occur in places again.[3]

Details of slopes in the White Mountains are as complicated as the structure upon which in most cases they have a certain dependence. General statements are of little value in this connection. The wedge-shaped mass of granite in the White Mountain Notch is more easily weathered than the flinty rock of anticlinal structure and high dip in Mount Willey and Mount Webster on either side, so that it has been excavated as a deep valley bordered by excessively steep walls, and is one of the most notable scenic features of the region. Granite seems

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[1] C. H. Hitchcock, Geological Survey of New Hampshire, 1871, p. 8; also the same author's Geology of the White Mountains, Appalachia, vol. 1, 1879, pp. 72–74.

[2] For definition see Chamberlain and Salisbury, Geology, vol. 1, p. 485.

[3] C. H. Hitchcock, The Recent Landslide in the White Mountains, Science, vol. 6, 1885, pp. 84–87.

everywhere to be the least resistant rock and to underlie the valleys.[1] Where it occurs as a narrow band the valleys are steep-sided, being bordered by more resistant schists, etc.; where it occurs in broad bands the valleys are wide.

During the closing stages (Champlain) of glaciation a climate sufficiently Arctic existed, to produce local glaciers upon the Laurentides and the Green and the White mountains.[2] From each central *mer de glace* alpine glaciers moved radially outward, into the intermediate tracts which may have been submerged.[3] The detailed occurrence of transported bowlders and lateral and terminal moraines upon which these conclusions rest is indicated in the two last-named references. In one stretch of about two miles north of Bethlehem village sixteen terminal moraines have been identified.

Agassiz notes that the number of the moraines is here greater than in the case of a spot long regarded as particularly favorable for such phenomena, the valley of the Rhone below the Rhone glacier; and he believes that no one who had studied similar phenomena in connection with living glaciers could doubt the glacial explanation of these forms. Besides these evidences there have been found by numerous observers glacial cirques of subperfect development which must be assigned to the action of local glaciers such as those that have occurred in the Mount Toby district, Massachusetts, and on Mount Katahdin, Maine. The chief valleys affected by the local glaciers, which in one instance attained a length of 12 miles, are the Peabody, Ellis, Saco, Ammonoosuc, Pemigewasset, and others. With the removal of the mountain forests and the more detailed observations of the topography which this makes possible, many more evidences of a similar nature will probably be found.

Green Mountains and Bordering Uplands

Vermont, the Green Mountain State, contains the largest portion of the Green Mountains, which extend across it from north to south as a rugged chain of ridges and hills. Save for the alluvial terraces and patches of till on the western border of the Connecticut Valley, and for the so-called valley of Vermont on the western border of the state, there is little arable land. The total length of the Green Mountains is about 250 miles; their width varies from 25 to 50 miles. The range extends from central-western Connecticut through western Massachusetts, northward across Vermont, then turns northeastward, and terminates in eastern Quebec and northern New Brunswick on the southern border of the St. Lawrence

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[1] C. H. Hitchcock, The Geology and Topography of the White Mountains, Am. Nat., vol. 4, 1871, p. 568.

[2] A. S. Packard, Evidences of the Existence of Ancient Local Glaciers in the White Mountain Valleys, Am. Jour. Sci., 2d ser., vol. 43, 1867, pp. 42–43; Louis Agassiz, The Former Existence of Local Glaciers in the White Mountains, Am. Nat., vol. 4, 1871, pp. 550–558; C. H. Hitchcock, Glacial Markings among the White Mountains, Appalachia, vol. 1, 1879, pp. 243–246.

[3] C. H. Hitchcock, The Geology of New Hampshire, Jour. Geol., vol. 4, 1896, pp. 60–62.

Valley in Quebec near the meridian of 70° west longitude. The northern termination has a strong northeastward trend parallel with the bordering St. Lawrence Valley.

The Green Mountains are the northernmost representatives of the mountainous western border of the older Appalachians and correspond in position with the Great Smokies of western North Carolina, South Mountain, Pennsylvania, and the Highlands of New Jersey. The axis as developed in the United States consists of three distinctly unlike parts: (1) a northern, discontinuous section, (2) a continuous range section extending through the southern two-thirds of Vermont, (3) a plateau section in western Connecticut and Massachusetts.

The northern section of the Green Mountains in the United States contains the highest peaks of the range and might therefore be thought the most rugged and difficult to cross. On the contrary, four valleys cross it, and dissection along them has been so pronounced that roads are obliged to ascend to an elevation of only 500 feet.

The four valleys, named in order from north to south, are: the St. Francis, in Canada; the Missisico, near the international boundary; the Lamoille, near Mount Mansfield; and the Winooski at Bolton; and in them all the drainage is from the eastern border of the mountains toward the west and northwest, unlike the drainage of the southern end of the Green Mountains axis, which is from the western border eastward. The highest peak in the Green Mountains is Mount Mansfield, 4430 feet, and Mount Killington is but a little less at 4380 feet.[1]

The second section of the Green Mountains extends from Hoosac Mountain northward for about 100 miles with an absence of passes and considerable uniformity of summit level, so that roads crossing this section not infrequently rise to an altitude of 2000 feet above the sea. The highest peaks of this section are under 4000 feet high and in general range between 2500 and 3500, with the larger number reaching to a little over 3000 feet.

In Vermont the main axis of the Green Mountains consists of a series of sharply compressed folds striking approximately north and south in sympathy with the general trend of the range. The series is overturned to the west in most localities. Steep westerly slopes are characteristic and occur in the form of terrace scarps on a large scale or as mountain brows of precipitous quality. The eastern slopes are characteristically formed on the dip of the planes of the schistosity or the dip of the planes of stratification and are steep or gentle as the dips vary between these extremes, although in general they may be called

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[1] C. H. Hitchcock, Glaciation of the Green Mountain Range, Rept. of the State Geologist of Vermont, 1904, pp. 69–71; A. D. Hager, Physical Geography and Scenery, Geology of Vermont, pt. 2, 1862, pp. 144–145.

relatively gentle. West of the Green Mountain range is a great limestone valley with island-like ridges of folded schist with synclinal structure, the remnants of former more extensive formations largely removed by erosion.[1]

That portion of the Green Mountains in the northwestern corner of Massachusetts and near the Vermont boundary is called the Hoosac Mountains and forms the divide between the Hoosac and Deerfield rivers, branches of the Hudson and the Connecticut respectively.[2]

The Green Mountains extend into Massachusetts and Connecticut, but their form undergoes a radical change south of Hoosac Mountain, Massachusetts, where they are developed as a broad plateau extending from the Connecticut Valley on the east to the upper valleys of the Hoosic and Housatonic rivers on the western border of Massachusetts and Connecticut. Its western border is a bold continuous scarp about 2000 feet high, which forms the eastern border of the Berkshire Hills country and is a divide between the tributaries of the Connecticut and the Housatonic; eastward the plateau descends by a more gradual and undulating slope as far as the western border of the Connecticut Valley lowland, where it descends from the 1000-foot level to the 400-foot level of the lowland floor in distances of a half mile to a mile.

The Green Mountains of western Massachusetts and northwestern Connecticut (the Green Mountain Plateau) are mountains of the second generation. Their original mountain forms were obliterated by the peneplanation which affected the region in Jurassic and Cretaceous times. Whatever of mountain form they possess to-day has been derived by uplift and erosion since peneplanation. Occasional residuals rising above the ancient peneplain as low eminences are now the highest points of the region, affording fine panoramas over a broad expanse of upland.

The Tertiary lowlands developed upon the softer limestones of western Connecticut and Massachusetts and the sandstones of the Connecticut Valley establish a surface which is of flatter gradient than the surface of the Green Mountain Plateau (a portion of the old Cretaceous peneplain) and appears to indicate that the uplift of the region after peneplanation was not uniform throughout but that it was somewhat sharply localized along the old mountain axis, after the manner of the uplifts that have been determined in the southern Appalachians (p. 593). When this is combined with the fact that most of the residual elevations on the divide between the Connecticut and the Housatonic lie upon the Green Mountains axis it will be readily understood that dissection since uplift has acted with unusual vigor here and given the region a rugged and mountainous appearance.

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[1] Pumpelly, Wolff, and Dale, Geology of the Green Mountains in Massachusetts, Mon. U. S. Geol. Surv., vol. 23, 1894.

[2] Idem.

Between the Green Mountains axis in western Connecticut, Massachusetts, and Vermont on the one hand, and the Connecticut Valley on the other, is a plateau or upland fringe bearing the same relation to the bordering mountains as the Piedmont Plateau of the southern Appalachians bears to the mountainous western border in Georgia and North and South Carolina. It is an upland composed in part of somewhat metamorphosed granite and diorite, in larger part of slates, schists, etc., derived by metamorphism from sedimentary rocks. Although much narrower than its southern representative it maintains continuously its identity as a border feature and possesses a well-marked physiographic character. It forms a transition upland between the eastern flanks of the Green Mountains and the lowland of the Connecticut Valley in Connecticut, Massachusetts, and Vermont, and throughout its whole extent is much dissected by transverse southeastward-trending valleys such as the Farmington in Connecticut, the Westfield in Massachusetts, and the White and the Williams rivers in Vermont. The uplands rise from a low southern margin on the shore of Long Island Sound to an elevation of 1000 feet at the northern boundary of Connecticut and to 1400 or 1600 feet at the northern boundary of Massachusetts. For the first score of miles the average rate is 20 feet per mile and is maintained with tolerable regularity. The ascent of the upland in Massachusetts is somewhat more gentle, from 10 to 12 feet per mile.

Lying well within the border of the glaciated country of North America and constituting one of the two principal lines of elevations in New England it is natural that the Green Mountains should bear the marks of heavy glaciation. Striæ and rounded knobs and bosses of rock, erratic bowlders and sheets and patches of till are the common features, while many of the lakes of Vermont within and without the Green Mountains are due either to glacial overdeepening of preglacial valleys or irregular deposition of drift or to both.

The mountain summits are often bare rock ledges; the mountain flanks, especially on the west, are steep slopes with abundant rock outcrops and naked precipitous cliffs. Rarely are the mountain flanks soil-covered up to their summits, although a few such cases occur. Mount Stratton, one of the two highest peaks in southern Vermont, is completely covered with glacial débris even to its summit.[1]

The eastern slopes of the Green Mountains are the gentler and it is natural that we should find them more heavily cloaked with glacial

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[1] C. H. Hitchcock, Glaciation of the Green Mountain Range, Rept. State Geologist of Vermont, 1904, p. 75.

material. Especially do they have a covering on the lower slopes, which are cleared and farmed and form a pleasing contrast to the western slopes of the White Mountains on the opposite side of the Connecticut Valley. The narrow fringe of upland between the Green Mountains and the Connecticut Valley, the northern representative of the Piedmont Plateau, is also blanketed with glacial waste and both hills and valleys are dotted with homesteads.

The abundant rainfall of the Green Mountains, a condition which they share with the rest of New England, offsets to some degree the disadvantages of a thin soil, and though the forest growth is never luxuriant, it is, or was, in the main continuous. The lower valley slopes offer the deepest soil and the most sheltered positions and hence are most heavily timbered. The soil of the higher exposed situations supports a relatively thin forest of spruce and birch. The most favorable situations

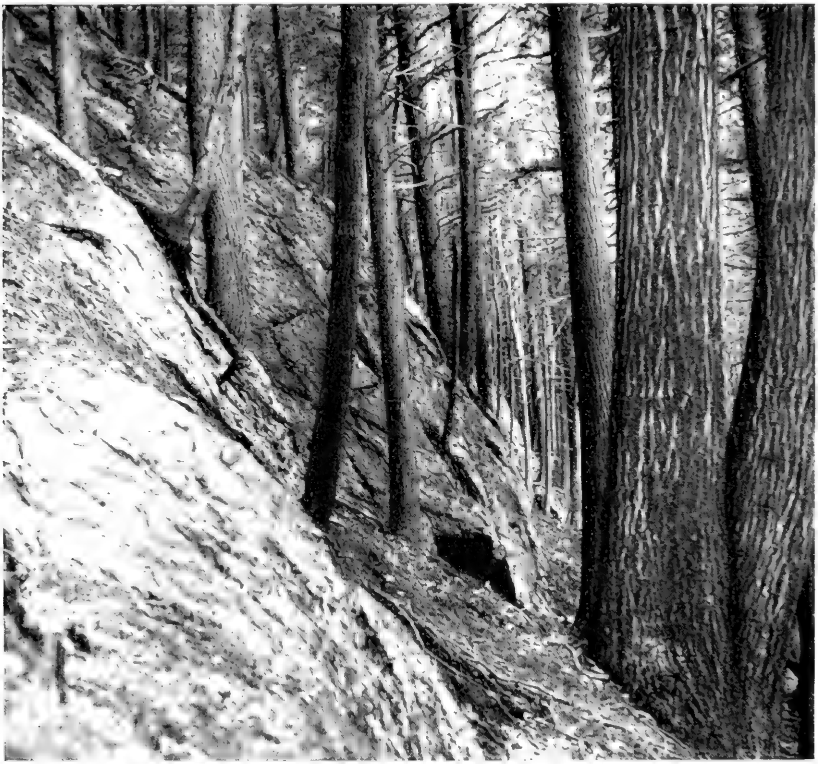


Fig. 262. — Forest growth on a steep and rocky New England hillside, Jamaica Plain, Mass.

for tree growth are the coves developed upon the older granites of the range, where the decayed rock is heavily cloaked with glacial till.

Both the White and the Green mountains, as well as many other portions of New England, have great tracts of ultimate forest land, that is to say, land which will bear trees more profitably than anything else and hence will be kept timbered when man's purposes become well adjusted to the soil. Indeed much of their surface will yield nothing but timber. It is surprising how healthy a growth will sometimes be developed upon a steep and almost barren hillside, Fig. 262. The clearing of such a situation rarely does great damage to the soil because the soil is so thin and stony (see p. 6), though if kept cleared it is subject to harmful erosion. Vigorous soil erosion is not, however, common on the unforested mountain slopes of New England. On the other hand, the effects of the forests on stream flow are clearly apparent. The slopes of the surface are sufficiently steep to enforce a dangerously heavy and rapid run-off were the timber cover and lake systems less extensive.

Connecticut Valley Lowland

GENERAL FEATURES

The Connecticut Valley, or valley lowland, as it is sometimes called, is about 95 miles long. Its width varies from 5 miles at each end to 15 or 18 miles in the middle. Its area is about 1000 square miles; a third of this is in Massachusetts, the rest in Connecticut. A slight uplift since Cretaceous peneplanation and the general occurrence of soft sandstones and shales have led to the development of a lowland (Tertiary) between an eastern and a western upland of crystalline rock of sufficient resistance to preserve traces of the peneplain. The greater part of the lowland is drained by the Connecticut River, although large portions are drained also by the Quinnipiac and the Farmington.

GEOLOGIC STRUCTURE

The lowermost rocks which constitute the Triassic formation of the Connecticut Valley consist of a series of 5000 to 6500 feet of coarse sandstone and conglomerate and a limited amount of shale. The material consists of the waste of granite and other crystalline rocks similar to those upon which the deposits lie. Intruded in these and generally not more than 200 to 300 feet above the base of the formation are the trap sheets of West Rock Ridge in the south and of the Barndoor Hills in the north. The sheets are from 500 to 600 feet thick in

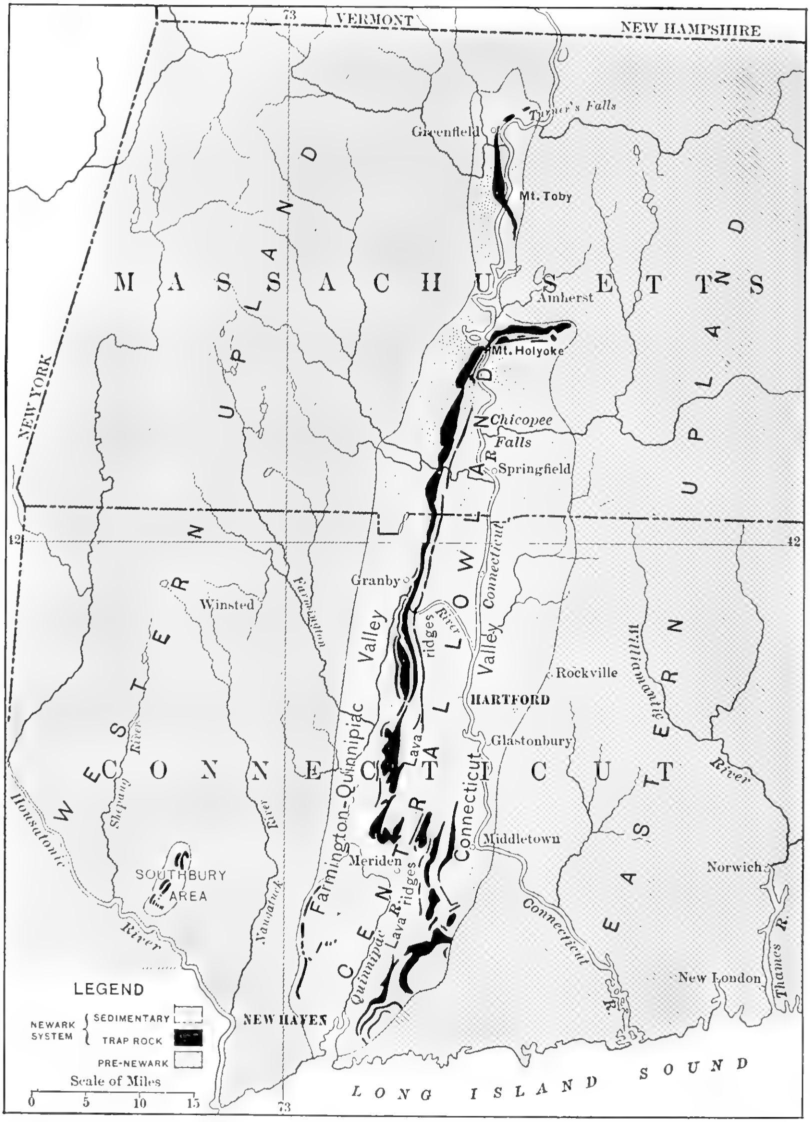


Fig. 263. — Relation of the Connecticut Valley lowland to the bordering uplands, the extent of the lowland, principal relief features, and drainage systems. (Russell, Davis, and others, U. S. Geol. Surv.)

places, but generally somewhat less. Succeeding the lower members with their intruded trap sheet is a series of sandstones, shales, impure limestones, intercalated with a series of three trap sheets. The lower trap sheet is called the anterior sheet and is generally about 250 feet thick, but thins out and disappears before reaching the northern boundary of Connecticut. Above the anterior sheet are shales and sandstones

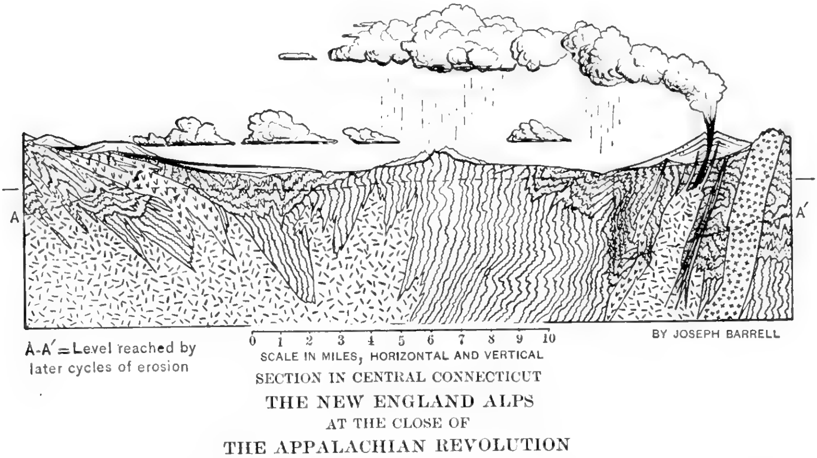
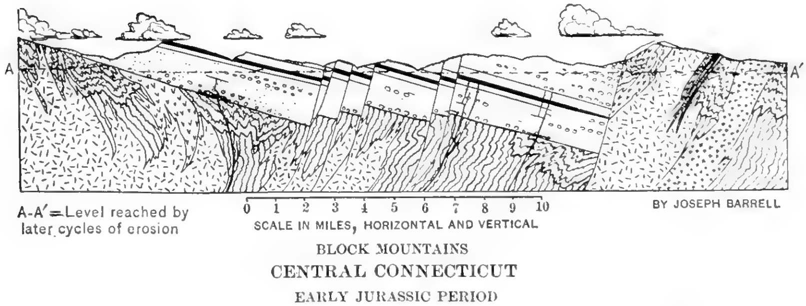
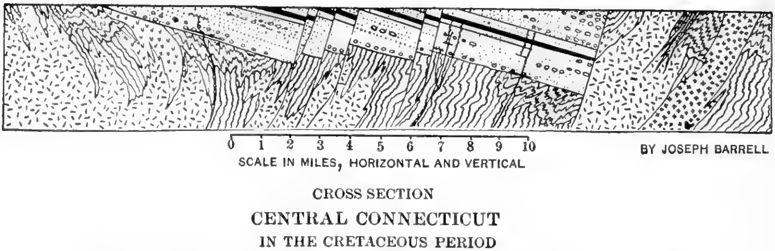


Fig. 264. — The geologic and physiographic history of the Connecticut Valley lowland and adjacent portions of the bordering uplands. Vertical and horizontal distances to same scale.

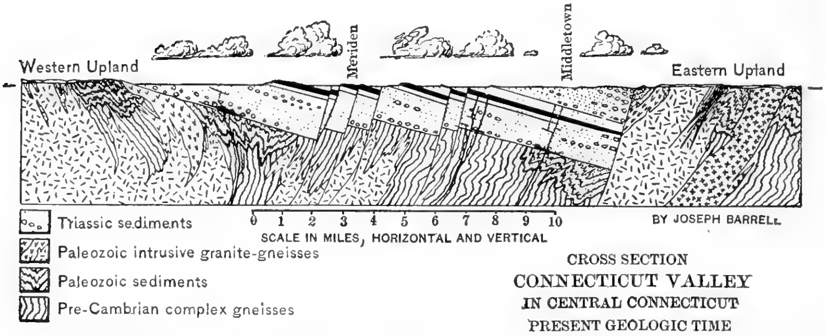
A. A time of great regional metamorphism and inferred volcanic activity.



B. After sedimentation had filled a structural depression and the strata had been block-faulted. Contemporaneous lavas are shown as black bands conformable with the strata.



C. Appearance of the surface at the end of the Jurassic-Cretaceous cycle of erosion.



D. Following uplift there was more vigorous dissection of the softer sandstones, leaving the trap ridges and crystalline uplands in relief.

from 300 to 1000 feet thick. Then comes the thickest and main trap sheet, 400 to 500 feet thick, another series of shales 1200 feet thick, and an uppermost or posterior trap sheet 100 to 150 feet thick.

Originally the sediments were deposited in a nearly horizontal position, and had this position been maintained up to the present, the topography and drainage of the region would be far more simple than is the case to-day. It was while the sandstones were being deposited that the lava flows of the eastern trap sheets took place, and after they had been deposited that the igneous intrusions of the western trap sheets took place. There followed a period of deformation in which both sandstones and trap sheets were extensively faulted and tilted, thus exposing the basset edges of both.

FAULTS AND ASSOCIATED OVERLAPS

The western range of trap ridges including West Rock Ridge and the Barndoor Hills of northern Connecticut have their successive members arranged *en échelon*. The southern ridges are arranged in advancing order, each northern ridge standing to the west of the next southern ridge, the ends overlapping by a moderate amount. In the northern group the arrangement is reversed; the order is receding and each northern ridge in succession stands farther east than the next southern ridge; and instead of the overlapping feature of the southern ridges there are gaps between the different members of the northern ridges, Fig. 265.

The eastern trap ridges are greatly diversified as to form, size, and arrangement on account of differences in the thickness of the trap sheets and their greater number. Two features predominate. In the southern section two ridges are curved into the form of an irregular crescent convex to the northwest, the horns of the crescent extending almost to the eastern crystalline area. The other ridges, about 20 in number, are arranged in the same advancing and receding order that is exhibited in the western range, the advancing order being displayed exceptionally well near Meriden, the retreating order about Tariffville, and the change from one to the other may be noted west of Hartford. Along the eastern ridges the main or middle trap ridge is of greater topographic prominence because of its greater thickness, 400 to 500 feet.

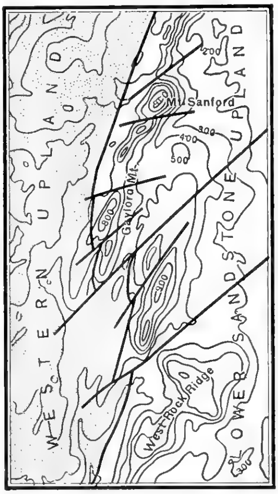


Fig. 265. — Displacement of trap ridges near northern end of West Rock Ridge and corresponding displacement in the crystallines of the bordering uplands. (Davis.)

The advancing and retreating order of the trap ridges is explained by displacement along the faults that cross the Triassic formation diagonally from northeast to southwest. The ridge overlaps on the south and the gaps on the north are both the expression of a movement on the fault planes. In the one case (overlapping ridges) displacement resulted in *offset with overlap*, in the other case (gaps between ridges) displacement resulted in *offset with gap*. The movements in the two cases were in parallel lines but in opposite directions. The application of this simple principle explains all the more prominent outlines of the topography of the district. The transverse diagonal faults just described are not confined to the Connecticut Valley. Just as they cross sandstones and traps, lowland and ridges, so they pass from the valley to the upland, into which they may in a few cases be traced. Upon the border of the upland they produce important indentations, the chief ones being from South Glastonbury to South Manchester and from Vernon to Rockville, where the border of the eastern crystallines strikingly corresponds in northeast trend with the direction of the lines of major faulting in the Triassic. On the western border the faults of the lowland pass into the crystalline upland in a much less distinct manner, causing slight offsets and overlaps in the western boundary, Fig. 265.

CRETACEOUS PENEPLAIN

Except on the trap ridges the Cretaceous peneplain is now completely destroyed in the Connecticut Valley. Upon the peneplain at the time of its full development the streams must have flowed in courses that were within certain wide limits independent of rock structure and therefore of belts of hard and soft rock. The whole region was blanketed with a cover of residual soil upon which the streams were free to meander, perhaps only slightly controlled by the harder trap which may have persisted in the form of low flat-topped divides even during the time of most complete denudation.

SUPERPOSED COURSE OF THE LOWER CONNECTICUT

The Connecticut River, after flowing in a rather direct manner from north to south through the Connecticut Valley lowland, turns almost at right angles at Middletown and cuts through the crystalline rocks of the eastern upland as far as the point of discharge near Saybrook. Such a course could not have been gained during the period of adjustment of streams to structures before the formation of a peneplaned surface.

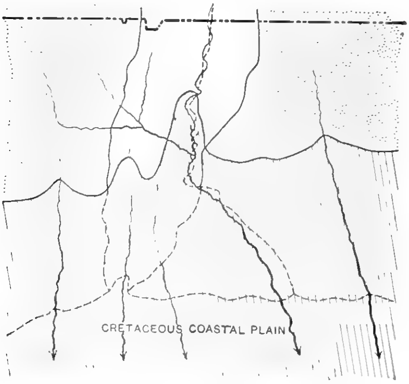


Fig. 266. — Inferred Cretaceous overlap on the southern shore of Connecticut. (Davis.)

The most reasonable explanation applied to the lower Connecticut is as follows. The Cretaceous clays and sands outcropping upon the northern shore of Long Island formerly extended farther north, overlapping the southern border of the Cretaceous peneplain, Fig. 266. It is probable that they formerly overlapped the southern border of New England as far as Hartford.

The retreat of the shore line after the deposition of the Cretaceous overlap would allow an extension of all the streams down the slope of the coastal plain thus formed. The general slope of the plain would determine the general direction of the extended streams and the more detailed courses would be determined by the local irregularities of the surface. The stripping off of the overlapping Cretaceous cover would result in the gradual superposition of the lower courses of all the streams upon the underlying floor. It is clear that the lower courses might be directed across points of hard rock, across ridges, and from crystallines to sandstones and vice versa, in a manner only visible when the cover causing these complexities was extensively removed. After uplift and while the lower Connecticut was developing a narrow valley in the resistant crystallines, its tributaries developed a broad valley in the soft sandstones.

It need not be supposed that the Cretaceous overlap was of great thickness to cause a complete turning aside of the streams from a course coincident with that which they formerly had upon the peneplain beneath the Cretaceous cover. The base-leveling was so nearly completed that a cover of a hundred feet thickness, perhaps fifty feet, would conceal all but a very few of the low rounded hills that appeared as residuals above the general level of the peneplain. It is even conceivable that the master stream of the region, the Connecticut, might have accumulated an exceptional amount of material upon the sea floor at its mouth and that when uplift occurred it would flow down the steepest slope of a broad fan, a course which might be on any radius. Conceiving the radius most favored as that directed most nearly to the east, the river would be turned from its former direction to one that would cause it later to be incised in the crystallines.

TERTIARY PENEPLAIN

The uplift of the Cretaceous peneplain and of the overlapping border of Cretaceous sediments enabled erosive agencies completely to remove the overlap and everywhere to dissect the uplifted peneplain. The uplift was accomplished not in one period of deformation but in two periods; for between the old Cretaceous level of the trap ridges and the present level of erosion one finds an intermediate level, a local Tertiary peneplain developed upon Triassic sandstones. It stands out conspicuously in certain views, being well developed north and northeast of Hartford, south of Mount Carmel, west of Mount Tom, and in many other localities. During the time in which the Tertiary lowland was being formed the resistant trap rocks of the valley lowland and the only slightly less resistant crystallines of the uplands maintained approximately their old positions.

FORMS DUE TO SECOND UPLIFT AND TO GLACIATION

The short Tertiary cycle was terminated by a second uplift which brought the land approximately to its present level and enabled the dissection of the uplands to be invigorated and that of the Tertiary plain to be begun. The last geologic event of importance in the region was glaciation, which, however, did not markedly affect the principal topographic and drainage outlines. The slopes of the hills and valleys were more or less thinly cloaked with rock waste, the débris of the continental ice sheet. The tops of the ridges were in many cases notably rounded, smoothed, and striated, although they were presumably but little reduced in height. The lowland plain and the river valleys were everywhere made more irregular, and in many cases reversed slopes were produced back of which lake waters now lie.

The most conspicuous drainage change was in the case of the Farmington River, which formerly ran south from Round Hill and Farmington through the present valley of the Pequabuck, through Plainville and Southington, and thence through the present Quinnipiac Valley to the Sound. But a low dam of glacial material at Plainville diverted the water of the river northward, with the result that from Farmington the river runs almost due north for about 12 to 15 miles to Tariffville, where it makes a sharp turn to the east and southeast, crosses the three trap sheets of the valley and pursues a more or less irregular course toward the southeast to the Connecticut at Windsor.[1]

SOILS AND VEGETATION

The soils of the Connecticut Valley are of many kinds, depending in part upon the many differences in rock character from place to place and in part upon different modes of origin. To understand the first cause of difference it is necessary to recall that though we commonly speak of a glacial soil as composed of foreign material, this is true only within certain rather narrow limits. Analyses made by Leverett and by Alden show that about 85% of the till of the Great Lake region is derived from the underlying sedimentary rock. An even higher proportion of locally derived material is found in the Connecticut Valley.

Such glacial forms as drumlins, eskers, sand plains, moraines, etc., have distinctive soil characters that are easy of identification. On account of their flatness and areal extent the sand plains of the Connecticut Valley deserve special consideration. The material of the sand plains is commonly loose and porous, varies in texture from fine to coarse but is always prevailingly sandy, may have moderate natural fertility but is generally decidedly infertile as compared with the more

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[1] Rice and Gregory, Manual of Connecticut Geol. Bull. Conn. Geol. and Nat. Hist. Surv. No. 6, 1906, pp. 251–253.

clayey soils of the till plains, and has a high absorptive capacity because of its flatness and porosity. Its loose nature, however, prevents it from retaining the absorbed water in large enough quantities and for long enough periods as a rule to allow a maximum or even a favorable plant growth, and sand plains are commonly local semi-arid tracts in the midst of more fertile areas.

Fig. 267. — The North Haven sand plain, or "desert," five miles south of Wallingford, Conn. See the New Haven quadrangle, U. S. Geol. Surv. Part of Mt. Carmel in the background. Note the tufted grass (*Andropogon scoparius*) and the extent of bare surface. (Photograph by Beede.)

One of the best illustrations of these features found in New England is the North Haven sand plain which stretches from Montowese (New Haven topographic sheet) to Wallingford, Connecticut, and beyond. It is about 15 miles long, with an average width of 1 to 2 or more miles. Its surface is in general flat or gently sloping; its soils vary in texture from a fine to a coarse sandy loam, with large areas of pure sand without a loamy admixture. The yellow sand shows distinctly through the thin cover of vegetation and gives such tracts a strikingly desert-like appearance. The water table stands from about 10 feet to 20 feet below the surface in spite of proximity to the river (Quinnipiac) and the fact that it receives the drainage from the adjacent upland portions of the drainage basin in which it occurs. Even after a heavy rain one can find little water in the soil except in the most favored portions. In places the scanty vegetation has a prosperous appearance, but in general distinctly xerophilous characteristics are displayed. Certain tracts support only grasses (chiefly Andropogon) which grow in scattered bunches. An elaborate botanical study of the vegetation of this area has been made with some interesting results.[1] It has been found that while the lack of water is pronounced it is not this lack but the burning heat of the sun on the bare sand that enables only xerophytes to exist. Other plants perish soon after their seeds germinate. Among the perennial grasses, *Andropogon furcatus* has thickened root nodes in which food and moisture are stored up and carried through the winter. *Andropogon scoparius* is present in tufts, is the most abundant, and has a leaf whose upper surface is composed of an epidermis made up of water cells that constitute about one-third the total thickness. Similar or comparable adaptations have been found on nearly a dozen other annuals found within the area.

On certain areas there is a regular order of occupation of the bare sand. The reindeer moss (*Cladonia rangiferina*) covers the bare sand, and where this lichen becomes established other plants spring up because the moss prevents the sand from shifting and entangles the seeds blown across it. Upon this undisturbed surface there accumulates in time a layer of leaf and vegetable mold that retards evaporation and enriches the soil, enabling, through these more fortunate conditions, the germination and development of other more delicate plants. Sweet fern (*Comptonia peregrina*) may possibly follow the reindeer moss as the next stage in the development of a vegetal cover. The black cherry, with a tendency to form colonies by root sprouting; the common milkweed, also grows in colonies; and scrubby black oaks widely scattered throughout the area are common forms of larger growth. The prosperous condition of the larger trees and especially the oaks is noteworthy and appears to be due in the case of the oaks to the length of the characteristic taproot.

Each tree forms a sort of anchorage ground about which and under which acorns, grasses, mosses, and lichens grow or accumulate in some numbers. In time a mold is formed even at some distance from the parent tree, and in it acorns may sprout and thus gradually extend the vegetal covering. Once started the long taproot quickly reaches the ground water, and once in touch with this source of supply the life of the tree is assured barring accident. The normal development of vegetation thus outlined is interfered with by fires, which burn the leaves and grasses and even burn out the mold from the surface soil, the element most needed for the reclamation of the area. One sample of the sand-plain soil at Montowese was found to contain but .09 of 1% of nitrogen, and it is probably to the nitrogen deficiency to which this points as much as to the dryness of the area that the absence of plant growth is due at any one time, though the more fundamental cause in the long run must be the relative dryness of the area and the shifting character of the surface.

The soils of the Connecticut Valley (between Springfield and Hartford) are of many varieties and are most irregularly disposed. The so-called Suffield clay (glacial and interglacial), the Triassic stony loam, and the Holyoke stony loam (strictly glacial) are distributed in the most hit-and-miss manner imaginable. The fine sandy loams are com-

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[1] W. E. Britton, Vegetation of the North Haven Sand Plain, Bull. Torrey Bot. Club, vol. 30, 1903, pp. 571–620

monly found along the stream courses and in terraces and valley flats, while the larger areas of undrained or poorly drained meadow land are found along the valley floors. Among the strictly glacial soils the Triassic stony loam is the most important. It is generally a fine sandy loam mixed with gravel and bowlders, the whole derived chiefly from the underlying Triassic sandstones. The amount of gravel and undecomposed rock in it exceeds 5% in all cases and in some cases exceeds 50%. The stoniest loams of the Connecticut Valley sometimes contain from 10% to 50% of bowlders ranging in size from 1 inch to 15 inches in diameter. They are relatively infertile and are but little farmed, being given up mainly to stony pastures, wood lots, and orchards, with occasional patches of corn, oats, and rye.

The exposed floor of the old glacial lake and river terraces in the Connecticut Valley are composed of yellowish-red or brown sand that contains less than 5% of clay. About 5% of the soil consists of coarse gravel and is inclined to be leachy and dry, though it is valuable for truck farming. The surface of the area is level or gently rolling in Connecticut; in Massachusetts it is much more rolling. The type is not very extensively cultivated, and in Connecticut there are but few houses upon it, the roads are deep and sandy, and along them are many old and unsuccessful fruit farms. Many areas of Windsor sand which were formerly cultivated are now grown up to a characteristic forest growth of pine. The soil is open and porous, offers little resistance to rains, and is so flat and so little washed that there are old well-preserved corn rows running through a forest in which the trees must be at least 50 to 80 years old.[1]

On either side of the Connecticut River from Holyoke south to Longmeadow, Massachusetts, and from Warehouse Point to South Glastonbury, Connecticut, are the Connecticut meadows or the present flood plain of the Connecticut River and its tributaries. The lower portions are frequently wet and swampy and subject to overflow, but in spite of this condition there is considerable farming on them at some risk. The character of the material is very uniform; it is a fine sand and silt 16 to 18 inches deep, containing a large amount of organic matter. Below Merrick the meadows are diked to keep out the high water and to insure against overflow. The Connecticut meadows are among the most extensive and most important soils in the valley, with marked differences in texture, water-holding capacity, and warmth, and an equally marked difference in the quality of the products.

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[1] Dorsey and Bonsteel, Soil Survey in the Connecticut Valley, Rept. U. S. Bur. Soils No. 64, 1900, p. 133.

Scattered over the entire Connecticut Valley are considerable areas of swamp land and wet meadow. They generally occur along the scarps between the valley flats and upland where the ground water appears. The degree of swampiness precludes cultivation except where special drainage conditions are maintained.

CHAPTER XXXI

NEWER APPALACHIANS

INTRODUCTORY

THE Newer Appalachians are the most striking member of the Appalachian group of physiographic provinces. The subdivision includes rather regularly folded strata and long narrow valleys separated by nearly parallel ridges. It is marked by the presence of a great valley which extends with but local and minor interruptions from end to end of the long province. This is not a single river valley but a composite of many valleys to which the name Great Appalachian Valley has been applied. The Coosa, Tennessee, Shenandoah, Cumberland, Middle Hudson, and Champlain valleys are its chief members. The Newer Appalachians province is bordered on the east by the Unaka Moun-

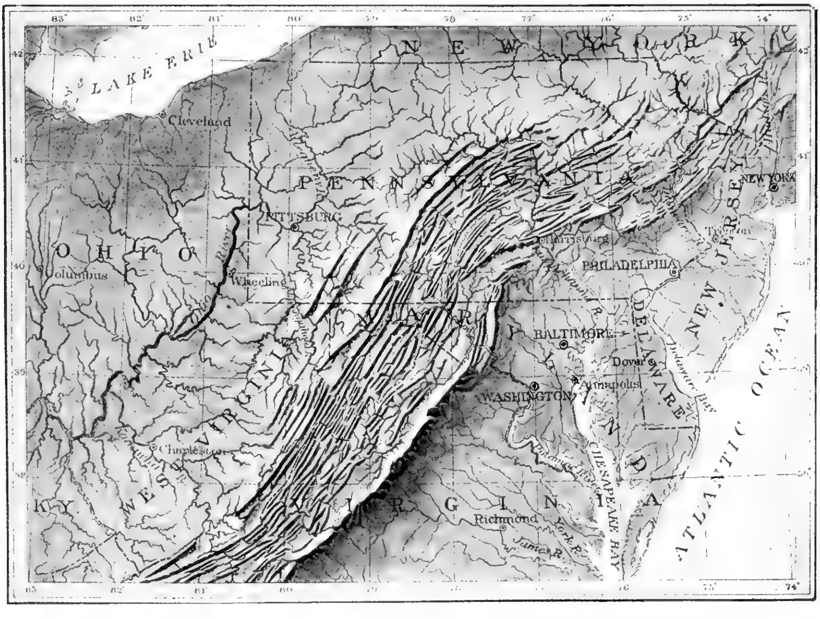

Fig. 268. — Relief map of the central part of the Appalachian System. (U. S. Geol. Surv.)

tains, the Great Smoky Mountains and the Blue Ridge at the south, and by the Highlands of New Jersey and the Green Mountains at the north; on the west it is bordered by the Cumberland Escarpment, the Allegheny Front, the Catskills, and the Adirondacks.

The southern portion of the Great Appalachian Valley is limited on the west by the eastern edge of the Appalachian Plateaus, whose various sections are here designated Walden Ridge, Lookout Mountain, and Sands Mountain. These plateau remnants have a heavy sandstone cap and their margins are defended by heavy and extremely resistant beds of sandstone and conglomerate. They are commonly from 800 to 1000 feet high and on the east overlook the Great Appalachian Valley as a bold scarp — the Cumberland Escarpment — which forms as definite a border to the Great Valley on the west as the southern Appalachians do on the east.

In a broad view the Newer Appalachians consist more largely of valleys and valley lowlands than of ridges in the Chattanooga region on the south and the Champlain-Hudson region on the north. In the central portion of the province the mountain and not the valley feature is on the whole the more prominent, Fig. 268; only the eastern side of the central district is marked by broad valleys, as the Shenandoah Valley of Virginia, developed on less resistant limestones, the Cumberland Valley of Maryland and Pennsylvania, and the Lebanon Valley of eastern Pennsylvania. On the basis of these topographic differences it will be convenient to subdivide the Newer Appalachians into three districts, a southern, a central, and a northern district.

The rock formations change from point to point somewhat, but their most striking characteristics are their continuity and lack of variation through long distances. In general they are more limey at the south and sandy and conglomeratic at the north. There are also important differences of structure such as the presence of great overthrust faults in the Chattanooga district and the general absence of these structural features and related topographic forms in the Pennsylvania ridges. In the former district the presence of great thicknesses of easily eroded strata such as limestone and shale, structurally deformed so as to expose on erosion the edges of the strata, has resulted in profound denudation and the carrying away of at least 10,000 feet of rock.

SOUTHERN DISTRICT

A prominent feature of the southern district of the Newer Appalachians is the number of ridges that follow exactly in line with the topographic level maintained by Walden Ridge and Cumberland Plateau,

Fig. 238. These ridge summits constitute, however, but a small portion of the entire area, for since the uplift of the Cretaceous (Cumberland) peneplain the greater part of it has been removed by erosion. This is due both to the relatively soft rock of the district and to the compressed nature of the folds, which reveal the beds in nearly vertical attitudes and so permit greater erosion. Such ridges as occur are, however, very even-crested in spite of considerable diversity in rock character, and are unquestionably the remnants of a former more extensive plain.

In places the ridges depart somewhat from the general type and seem to rise above the level of the peneplain. In such cases the wind gaps probably represent the old base level, for they have a constant altitude, whereas the intervening portions of the ridges rise irregularly from 100 to 300 feet above them, and were probably a series of knobs projecting above the peneplain level. In contrast to these exceptional features are the ridges composed of less resistant rock or occupying more exposed positions. These have been so reduced by erosion following upon the uplift of the Cretaceous peneplain that no point along their crests attains the altitude of the peneplain. On the whole, however, the ridges are surprisingly accordant in altitude and their level is nearly always harmonious with that of adjacent, better preserved portions of the plain.

The early Tertiary (Highland Rim) peneplain was not developed so extensively as the Cretaceous peneplain within the borders of this district. Its chief development was along the larger valleys where narrow belts of rock were planed to a more or less level expression. Remnants of it may still be seen at altitudes above 1000 feet, where the great majority of hills and ridges may be seen to reach nearly to a common level. Standing above this topographic level are a number of residuals among which White Oak Mountain, Tenn., is the most prominent. Like the Cretaceous cycle the early Tertiary cycle was closed by irregular uplift, the first result of which was to invigorate the streams and cause them to incise valleys below the general level. Gradually the valleys were widened to form local lowlands upon areas of softer rock. The result was a partial planation of a region distinctly smaller than that peneplaned during the early Tertiary cycle and only a fraction as large as the great area peneplaned during the Cretaceous cycle. This local lowland has been called the Coosa peneplain because of its excellent development along Coosa River (see Fig. 235).

The Coosa "Flat Woods" are the largest unit of this peneplain. They form a belt 10 to 12 miles wide and but little above the narrow flood plain of the river though never reached by the present floods. The peneplain is developed upon soft or soluble rocks, limestones, and limey shales; where the Coosa flows upon more resistant formations the valley is comparatively narrow. The altitude of the Coosa peneplain is more than 700 feet at the southern margin of the Chattanooga district and about 800 feet at the northern margin. The slope is little more than the normal grade of a base-leveled surface, which shows that but slight local deformation has occurred, although when examined in detail considerable variation in altitude is expressed in the various portions of the peneplain.

Stream Types

The topographic changes outlined above took place during immensely long intervals of time, and if we recall the physiographic principles of stream adjustment, the constant shifting of stream courses through the more rapid development of those which flow upon belts of softer rock, we shall be prepared to appreciate the fact that very extensive stream changes have occurred in the Appalachian region. These have been conditioned by (1) the exposure of softer beds by the erosion of harder beds overlying them and (2) crustal warping which terminated each cycle and deformed the successive peneplains.

A number of types of streams may be identified; the characteristics of these we shall sketch here only in the briefest manner. The first type is that represented by the Hiwassee, the New-Kanawha, and other streams which flow westward from the southern Appalachian mountains. The most striking member of this group is the New-Kanawha, which drains portions of all three physiographic provinces in succession from the Appalachian Mountains to the Appalachian Plateaus, Fig. 235. It appears to be an antecedent stream in that it has maintained its course westward against all the deformations which have been produced in its path. Its age must be measured in millions of years, for it probably dates from the great Appalachian revolution of Permian time, and though it has suffered many slight vicissitudes and its course has been opposed by mountain-making movements, the river has been victorious in all its contests and still pursues its ancient northwestward course.

The present course of Tennessee River has topographic relations of equal interest. After flowing southwest for several hundred miles, as far as Chattanooga, it turns sharply west, crosses the high plateau known as Walden Ridge, then turns sharply southwestward again, and flows in another straight stretch for over 200 miles before turning north to join the Ohio. Its course across Walden Ridge corresponds to the course of the river upon the Cretaceous peneplain. It is very strikingly meandering, and under other circumstances the meanders would be accepted without question as inheritances from a low-gradient strongly meandering stream later incised in a formation so hard as to preserve them in somewhat their original form or a derived form not departing much from the original pattern. When taken with the other evidence these meanders may be regarded as safely referable to this mode of origin. That they have been preserved for such a long period as all of Cretaceous time does not seem unreasonable when it is recalled that only the lower 100 to 200 feet of the 1000-foot gorge across Walden Ridge is composed of soft limestone, while all the rest of this great section exposes extremely resistant sandstone.[1] The great thickness of the resistant strata has prevented the river from widening its valley in precisely the manner in which the hard strata of the Kittatinny anticline in New Jersey have restrained valley development along the Delaware and made possible the formation of the Delaware water gap. During the time that the Delaware River was cutting the gorge at the water gap the tributaries and their auxiliary streams were widening the soft formations on either side and developing them into the form of a broad valley lowland. The strong differences in rock character between the Sequatchie anticline and the Appalachian Valley on the one hand, and the Walden and Cumberland plateaus on the other, are not less than the differences among the valley widths of the streams or portions of streams flowing through these formations.

A second type of drainage is that which represents the effects of wandering during the later stages of an erosion cycle. This is considered to be an explanation of the course of the Ocoee where it crosses or is superimposed upon the point of Bean Mountain.

A third class of stream is that found in the longitudinal valleys of the Newer Appalachians. It requires little explanation, for it is obvious that it belongs to the type known as subsequent rivers. When the Cretaceous peneplain was uplifted erosion went forward rapidly along belts of weak rock, and tributary streams originating in such belts rapidly extended their valleys headward. Those streams which crossed harder strata were prevented from lowering their channels at the same rate and eventually numbers of them were beheaded and made tributaries of their more powerful rivals. The abandoned channels across the hard ridge makers stood at higher and higher levels as the softer rocks were lowered on both sides; they now appear as wind gaps. Many streams are made up of sections which belong to different types. Their headwaters descend the western slopes of the southern Appalachians as originally, their middle courses occupy subsequent valleys arranged longitudinally, and their lower courses are superposed upon structures across which the streams flowed while working at the level of the Cretaceous peneplain.

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[1] The data for this paragraph are chiefly from the admirable discussion of the Tennessee problem in a paper by D. W. Johnson, The Tertiary History of the Tennessee River, Jour. Geol., vol. 13, 1905, pp. 194–231. The paper also contains a bibliography of the literature bearing on the Tennessee problem.

Central District

The eastern boundary of the central district of the Newer Appalachians is the Blue Ridge; the Allegheny Front forms the western boundary. The latter is rugged and bold and faces southeast. It is the eastern edge of the Appalachian Plateaus and extends from the northern end of the Cumberland Plateau through West Virginia, Maryland, and Pennsylvania, and is continued northeastward more irregularly as far as the Catskill Mountains.

Prominent points upon it are Dans Mountain, Maryland, 2100 feet above the sea; the Pinnacle, West Virginia, 3400 feet; Roaring Plains, 4400 feet; the Big Black Mountains of Virginia and Kentucky, 4000 feet; southward the summit becomes lower and at Cumberland Gap is but 1600 feet high.

It is crossed by many streams such as the New, the Potomac, etc., but not enough dissection has taken place to destroy its wall-like character throughout most of its extent. Narrow thousand-foot canyons are cut in it here and there, and between them are straight stretches of precipice often crowned by a resistant sandstone that stands out under weathering and erosion as a steep brow.[1]

From the Maryland line northward a distance of about 50 miles the crest of the Front is rather broad and flat and nearly straight, at a fairly uniform elevation of between 2500 and 2700 feet. Above this level occasional knobs rise to heights of 3000 or more feet, as Blue Knob, 15 miles south of Gallitzin, 3136 feet, the highest point in the state.

From above or from a distance the lower part of the Allegheny Front in Pennsylvania appears as a grand terrace, made by the even tops of a series of projecting spurs that break the descent of the scarp. They are due to the presence of a second resistant formation, and as the crest of the Front becomes lower toward the northeast the terrace is entirely absent. This feature is nowhere better shown than near Altoona. The lower plain in that locality stands at 1200 feet, from which there is a moderately steep ascent to 1600 or 1700 feet, over a terrace belt from 1 mile to 1½ miles wide. From the terrace there is an abrupt rise to the crest of the escarpment 2400 to 2700 feet high.

The Allegheny Front crosses Pennsylvania in a sweeping curve toward the northeast for a distance of 230 miles, until it merges obscurely with the zigzags of the anthracite region in the northeastern corner of the state. The escarpment is broken only by narrow ravines through which flow the northern branches of the Susquehanna, the North Branch, Muncy, Loyalsock, Lycoming and Pine creeks, the West

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[1] Bailey Willis, The Northern Appalachians, Nat. Geog. Mon., 1896, pp. 172–173.

Branch, and Beech Creek. South of the gorge of Beech Creek the Front is unbroken by any large stream, though many steep ravines notch its crest and offer practicable routes of communication with the regions beyond.

The larger main streams have cut narrow and steep-sided valleys 500 or more feet deep, as well shown by the transverse course of the Youghiogheny. The smaller tributaries, especially in their upper portions west and north of the escarpment, have wider valley floors, and flow in relatively shallow valleys, often not more than 100 feet deep.[1]

The western part of the central district of the Newer Appalachians consists of closely folded strata that outcrop in the form of ridges with alternating narrow valleys, and the mountain, not the valley, feature is most prominent. Furthermore, the ridge crests almost everywhere reach to the level of the plateau on the west and exceed the elevation of the Blue Ridge on the east.

The most persistent characteristic of the Appalachian ridges of the central district is the even character of the sky line as determined by the level-topped ridges and the accordant altitudes of the hilltops. Only here and there are the ridges interrupted by gaps where superposed streams have maintained their courses across the ridges as they were gradually brought out to a strong topographic expression by differential erosion. A commanding point such as the summit of a residual surmounting the general level of the country affords a fine view out over a broad landscape. If the valleys and lowlands, now sunk below the general level, were filled up, the country would appear as a vast gently rolling plain of slight relief — an approximation to the condition that existed at the end of the Jurassic-Cretaceous cycle of erosion when the mountains formed during the great Appalachian Revolution were reduced to the condition of an almost featureless plain. This fact forms the starting point in all the physiographic considerations that follow concerning the Appalachian region as a whole, for it is in the erosion cycles that have followed and out of the peneplain that existed at the beginning of the Tertiary periods of degradation that all the later forms have been carved and the drainage features developed.

The distinctive features of Appalachian topography in Pennsylvania, Maryland, and Virginia are long, parallel, sharp-crested ridges, often with zigzag pattern, Fig. 268, and with narrow valleys intervening. Adjoining ridges are often markedly parallel. They are in places developed upon anticlines that expose resistant strata, in places upon

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[1] W. S. Tower, Regional and Economic Geography of Pennsylvania (Physiography), Bull. Geog. Soc. Phil., vol. 4, 1906, pp. 205–206.

synclines, and in others upon strata with a more complex internal structure. All the larger valleys have their positions and directions determined by the more yielding rocks and have been developed subsequent to both the deformation of the strata and the base-leveling that is responsible for the even-topped character of the ridges.[1]

Eleven principal mountain folds occur between the Blue Ridge on the southeast and the Allegheny Front on the northwest, in a distance of 49 miles. Claypole suggested that the amount of crustal shortening involved in the flexing of these folds meant a reduction to 65 miles of a surface that originally measured 153 miles.[2] Chamberlin's later and more accurate measurements show a compression into 66 miles of an original surface of 81 miles in a section west of Harrisburg.[3]

Single folds more than 300 miles long are known in the Appalachian region, but the lengths of individual folds are more commonly from 25 to 50 miles. The intensity of the folding increases from east to west throughout the length of the province. In the Appalachian Plateaus the folds are very gentle, with dips generally less than 10°, and there is a close approach to horizontality on the west. The rocks are unaltered, even the shales being free from cleavage planes. In the Newer Appalachians the folding was more intense, the dips are generally 30° or more, and in many areas the rocks are nearly vertical. Most of the folds are symmetrical, with shorter, steeper northwest sides, and longer, gentler southeast sides, and many of them are overturned. The result is that the northwestern is the shorter and steeper and the southeastern the longer and gentler of the mountain aspects. The structural folds are of considerable magnitude, reaching 5 miles or more in vertical dimension between the larger folds, and are not simply a unit, being composed of numerous minor folds and these in turn of still smaller folds down to minute wrinkles.[4]

A number of facts are essential to the understanding of the physiography of the zigzag ridges of the Newer Appalachians: (*a*) the Appalachian type of structure prevails throughout the region, that is to say, a series of rather regularly folded strata, the folds being in the form of more or less regular anticlines and synclines; (*b*) these folds have been base-leveled or peneplaned, so that by the end of the Cretaceous cycle of erosion the surface of the country had been worn down nearly to a plane surface; (*c*) the fact of base-leveling of these folds means, further, that hard and soft rocks were at one time exposed in belts but with only the faintest topographic expression; and (*d*) naturally all the rock strata would be exposed almost in the same plane, for the topographic cycle was long enough not only quickly to bring down the soft rocks to base level but also finally to reduce even the most stubborn members almost to the general level.

(*e*) Uplift then occurred in the region and opportunity was afforded for the rejuvenation of the streams, the belts of soft rock were worn

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[1] Topographic and Geological Survey of Pennsylvania, 1906–1908, p. 111.

[2] E. W. Claypole, Pennsylvania before and after the Elevation of the Appalachian Mountains, Amer. Nat., vol. 19, 1885, pp. 257–265.

[3] R. T. Chamberlin, The Appalachian Folds of Central Pennsylvania, Jour. Geol., vol. 18, 1910, pp. 228–251.

[4] G. W. Stose, Mercersburg-Chambersburg Folio U. S. Geol. Surv. No. 170, 1910, p. 13.

quickly down approximately to the new base level, while the harder rock belts stood out as ridges whose summits now present to our belated sight the ancient level of the Cretaceous peneplain. The ridges are even-topped because they were all worn even by the end of the earliest erosion cycle, and time enough has not elapsed since the uplift of the region and the development of extensive lowlands by differential erosion for the ridges to be very much affected by erosion. The material composing them is most resistant conglomerate (Pottsville) and a stubborn sandstone (Medina and Pocono), and when compared with the soft Coal Measures and the slates (Hudson River) and shales (Mauch Chunk) these offer incomparably greater resistance.

A sixth and last fact must be observed: (*f*) the axes of the folds are not horizontal for any distance, but pitch below the level of the peneplain, now at steep angles, now at gentle angles. Upon this feature depends the degree of divergence of the ridges. If the axes of the folds pitch at a steep angle the more strongly divergent will the ridges be formed; and conversely, the gentler the pitch the more narrow the angle between the ridges, the limit being parallelism, which would appear only when the folds became actually horizontal. According as the original folds were broad and gently pitching, or narrow and steeply pitching, the zigzags are long and wide or short and narrow.

The best example of zigzag ridges is the double series at the western end of the anthracite coal region, where the ridge crests loop back and forth as Catawissa and Line, Manhantango and Berry, and Peter's and Second mountains. Following the same course, essentially parallel to the first, and contained within them, is the second set, Big and Mahanoy, Coal and Lock, and Stony and Sharp mountains. Another example is in the Buffalo or Seven Mountains (Center and Clinton counties, Pennsylvania), where a group of narrow folds, steeply pitching, has given a series of short zigzag ridges with 7 loops to the northeast and 7 to the southwest.[1]

The student who will keep these groups of facts before him will be able to understand practically all the problems that the Appalachian ridges afford. A great variety of relief features can be assigned at once to their proper categories and order maintained in the examination of a group of data that at first sight may seem very complex. They furnish the key to the solid geometry of the region, for it is solid geometry, or a conception of three space dimensions, that is necessary in understanding the zigzag ridges of Pennsylvania.

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[1] W. S. Tower, Regional and Economic Geography of Pennsylvania (Physiography), Bull. Geog. Soc. Phil., vol. 4, 1906, p. 14.

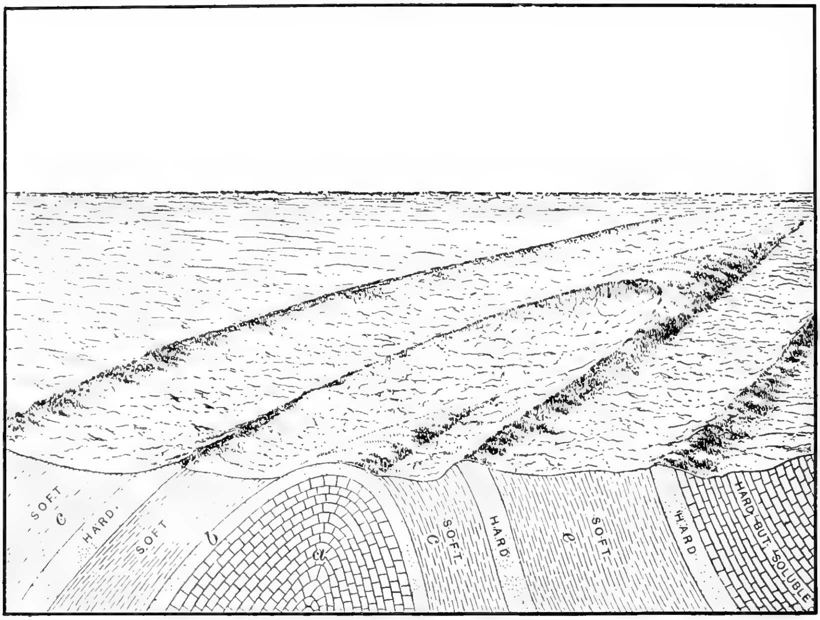

Fig. 269. — The half-cigar-shaped mountains developed on the hard rocks and the arches formed by the beds of an anticline. (Willis, U. S. Geol. Surv.)

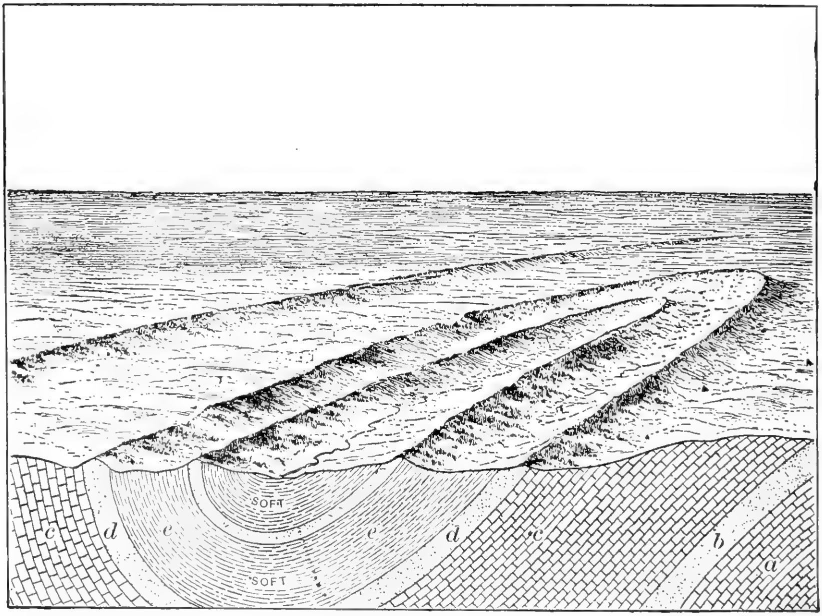

Fig. 270.— The canoe-shaped ridges of hard rocks and the arches formed by the beds of a syncline. (Willis, U. S. Geol. Surv.)

Because of the gentle inner slopes and steep outer slopes the topographic forms of the zigzag ridges have been likened to a canoe, and the resemblance is the more striking when it is recognized that the end of a synclinal mountain where it often meets in a rather sharp V is doubly resistant and usually stands out as a not quite reduced portion of the mountain region, a terminal knob suggesting the high prow of a canoe.

In the case of the anticlinal mountains as in Fig. 269 the strata dip outward as represented, and the unroofing of the anticline by peneplanation and subsequent valley excavation in the belts of softer rock has produced a group of mountain forms in sharp contrast to the forms of synclinal mountains. The steep slopes are here on the inside of the fold and the gentle ones on the outside. Fundamentally the law is the same in both synclines and anticlines, for in both cases the gentle slopes are down the dip of the strata and the steep slopes are those formed across the strata. It is the difference of direction and dip in the two cases that has produced the slope contrasts. Were the strata arched across the gap in the heart of the fold the resulting form would roughly resemble a cigar tapering down at one or both ends, so this type of mountain is described as cigar-shaped. Variations of form and degree of contrast of opposite slopes depend, as in the case of the synclinal mountains, upon the degree of dip of the strata. And like the synclinal mountain the meeting of the two ridge makers at the terminal point of the mountain doubles the resistance at that point and produces a terminal knob which in many cases exists as a residual or monadnock upon the surface of the peneplain.

It is important to see how a region may exhibit either or both synclinal and anticlinal mountains. The actual condition at a given place will depend upon the relation of the plane of base-leveling to the hard and soft strata. In A, Fig. 272, the plane of base-leveling is in such relation to the hard layer 1 that during the cycle of erosion terminating in the complete reduction of the land surface, the hard layer 1 is completely removed and hard layer 3 exposed but not removed from the underlying soft layers. When uplift opens the next cycle of erosion all the mountains will be for a time anticlinal and all the valleys will be synclinal. In B, by the same process of reasoning, half the mountains would be synclinal and half anticlinal and the valleys would be correspondingly disposed. In C all the mountains would be synclinal. In a region never base-leveled but for the first time passing through a period of subaerial denudation the changes of form and their relations to structure are brought out in Fig. 271, provided the region is still above base level.

Since a large number of the mountain systems of the earth have passed through one or more partial or complete cycles of topographic development, it is clear that a knowledge of the position of the plane of base-leveling to the resistant rock strata, or ridge makers, is a matter of fundamental importance. In the Appalachian region the plane of base-leveling appears to have cut through the strata in such a manner as to form a larger number of anticlinal than synclinal mountains, though the latter type are numerous. The diagram Fig. 272–C roughly

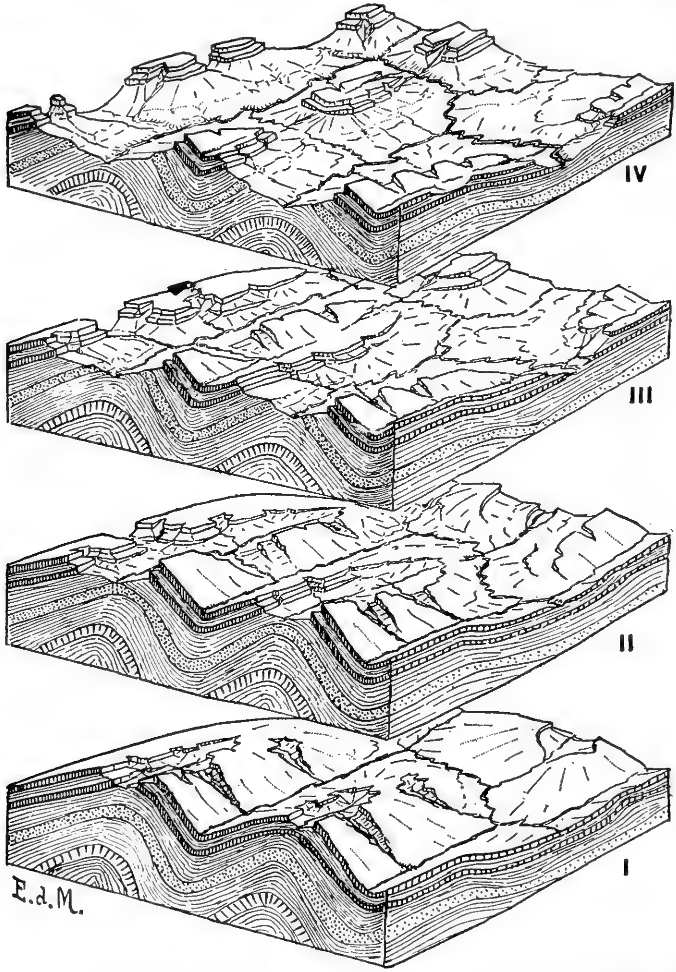

Fig. 271. — The development of anticlinal valleys and synclinal mountains from an original consequent drainage has been established in a region with Appalachian structure. (Martonne, Traité de Géographie Physique, Armand Colin.)

represents the actual conditions in the central Appalachians. Horse Valley opposite Chambersburg, and Bear Meadows north of Huntingdon, Pennsylvania, are good examples of synclinal valleys.[1]

The most striking features of the valleys of the zigzag ridges, whether of one structure or another, are their linear extent and shut-in or cove-like character. Bald Eagle and Black Log Valleys, Penn., are typical. Kishicoquillis Valley, between Stone and Jack's Mountains in Mifflin County, 53 miles long and 4 miles wide, is completely isolated except for the single outlet of Logan's Gap, near Lewiston. Tuscarora Valley is 50 miles long and 5 miles wide. Path and Nittany valleys are both over 30 miles long and from 2 to 5 miles wide, with no easy outlets except through an occasional water gap or over a higher wind gap. The sharp contrast between the linear extent and the width of the valleys is a direct result of the attitude of the strata, giving broader valleys where the strata are gently inclined and narrower valleys where steeply inclined.[2]

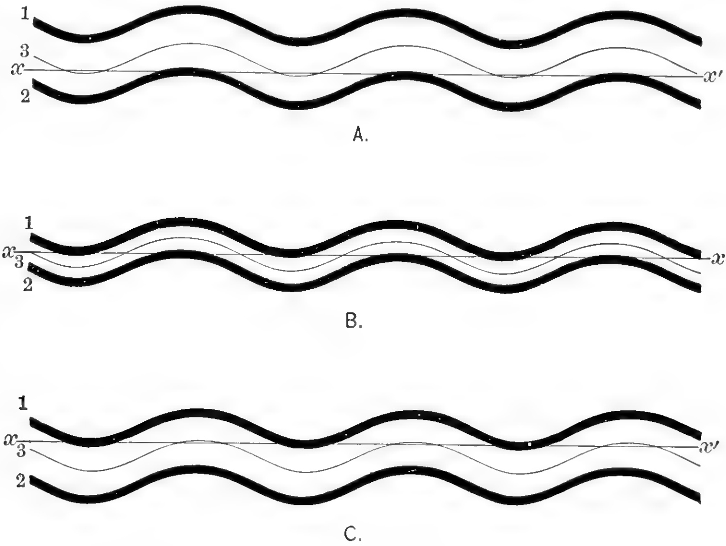

Fig. 272. — Varying positions of the plane of base-leveling to hard and soft strata and their relation to anticlinal and synclinal mountains. 1 and 2 represent hard layers; 3 represents a soft layer; $x - x'$ represents the plane of base-leveling. In A the plane of base-leveling lies below 1 and intersects 2; in B it intersects both 1 and 2; in C it lies above 2 and intersects 1. After uplift of the base-leveled surface the early stages of the erosion cycle will be marked by anticlinal mountains in A, anticlinal and synclinal mountains in B, and synclinal mountains in C.

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[1] W. S. Tower, Regional and Economic Geography of Pennsylvania (Physiography), Bull. Geog. Soc. Phil., vol. 4, 1906, p. 128.

[2] Idem, p. 128.

Variations upon the simple scheme outlined above are not difficult to understand. If for example each anticline and each syncline has several hard ridge makers, instead of one, several parallel ridges will come into existence as in Figs. 269 and 270, which represent the actual conditions in the northern Appalachians in the region north of Harrisburg. The number of ridges that will occur in a given place will depend upon the size of the folds and the number of alternations of hard and soft strata. This rule may be stated in another way as follows: As many hard layers as are truncated by the plane of base-leveling will stand forth as ridges in the following cycle, and theoretically this number is limited only by the ability of the rock to be compressed into folds. Obviously a mass of strata may be so thick that it can not be compressed in such a manner as to form folds exposing the entire section in the form of regular anticlines and synclines. The limit may be placed somewhere around 50,000 feet. A section across such a repeated series of ridge makers in a single fold appears as in Fig. 269. If the hard layers are sufficiently far apart, then each fold will repeat the ideal features shown in the figures above. If they are separated by a very thin soft layer the valleys between the ridge makers will not be deep unless the dip of the strata is unusually great. The two sides of a given ridge maker under these circumstances are also apt not to be so sharply contrasted as in the case where sufficient space occurs between the ridges for the formation of a large valley.

No less striking than the topographic features of the zigzag ridges of the central district are the drainage features of the region. The master streams flow roughly at right angles to the trends of the ridges and cut across them through water gaps of notable depth and often of pronounced beauty. The course of the Delaware through the Delaware water gap, the Susquehanna through the gaps of the central Pennsylvania ridges above Harrisburg, and the prominent gaps of the Potomac through the same or similar ridges farther south are illustrations of this feature. Where they cross the ridges in the gorge-like water gaps the main streams are swift, often descending short rapids, while across the intervening valleys they often flow lazily and in regularly meandering courses.[1]

Perhaps the chief cause for the wholesale modification of the drainage of a given region such as will bring the streams into courses directly across the grain of the country, as in the case in hand, is the warping or bowing of the surface that commonly takes place after or during the late stages of peneplanation and inaugurates a new cycle of erosion or forms one of the late substages of the first cycle. The effect of such warping or bowing is to cause a migration of the divides toward the main axis of uplift as determined by Campbell[2] and away from the area of subsidence. The antecedent drainage tends to become adjusted to the warped condition; streams come to occupy axes of depression, and divides finally become located on the axes of elevation. We have seen in Fig. 237 and accompanying text that the Appalachian

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[1] W. S. Tower, Regional and Economic Geography of Pennsylvania (Physiography), Bull. Geog. Soc. Phil., vol. 4, 1906, p. 133.

[2] M. R. Campbell, Drainage Modifications and their Interpretation, Jour. Geol., vol. 4, 1896, pp. 567–581, 657–678.

region was bowed or warped up along a southwestward-trending axis located in western Pennsylvania and probably continuous with the axis in the southern Appalachians located by Hayes and Campbell in the vicinity of the Cumberland Plateau. While all the master streams do not have divides on this axis — the exceptions are the Tennessee, the New-Kanawha, and others — most of the streams conform to the general law applicable to the case.

As intrenchment progresses after uplift and other erosive agencies are set into operation differential erosion will follow, hard rock will be exposed in patterns sympathetic with respect to structure, and there will be brought about a most unsympathetic relation between the topography and the drainage, precisely the sort of drainage that now exists between the main streams and the main lines of relief within the central district. The weaker tributary streams will for a time flow across the harder ridges like the master streams, but the steady development of subsequent streams along belts of weak rock that occupy the inter-ridge spaces will in time effect an almost complete adjustment of tributary streams to structure. This wholesale readjustment means stream capture on a most extensive scale. The gradual headward growth will be accompanied by progressive capture of streams at the disadvantage of crossing the harder ridges to reach the main streams. The old water gaps will become wind gaps and a diminished river will flow in the channel of the beheaded stream. Here and there a larger tributary or one with exceptional advantages will persist like its master stream. From the map, Fig. 235, one may see all degrees of adjustment as outlined above.[1]

NORTHERN DISTRICT

The northern district of the Newer Appalachians consists of a number of well-defined valleys and ridges whose structural features are more complex than those of the central district. The topography is not capable of an analysis as simple as in the case of either the Pennsylvania zigzags or the ridges and valleys of the Chattanooga district; the ridges and valleys are here less regular both in general and in detail. In respect of border features the northern district is unlike either of the other districts of the Newer Appalachians. On the west the province is terminated not by a single plateau but by an outlier of the great Lauren-

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[1] For an excellent description of the features of northern Pennsylvania and New Jersey with respect to drainage, see Davis and Wood, The Geographic Development of Northern New Jersey, Boston Soc. Nat. Hist. Proc., vol. 24, 1890, pp. 365–423, and W. M. Davis, The Rivers and Valleys of Pennsylvania, Nat. Geog. Mag., vol. 1, 1889, pp. 183–253.

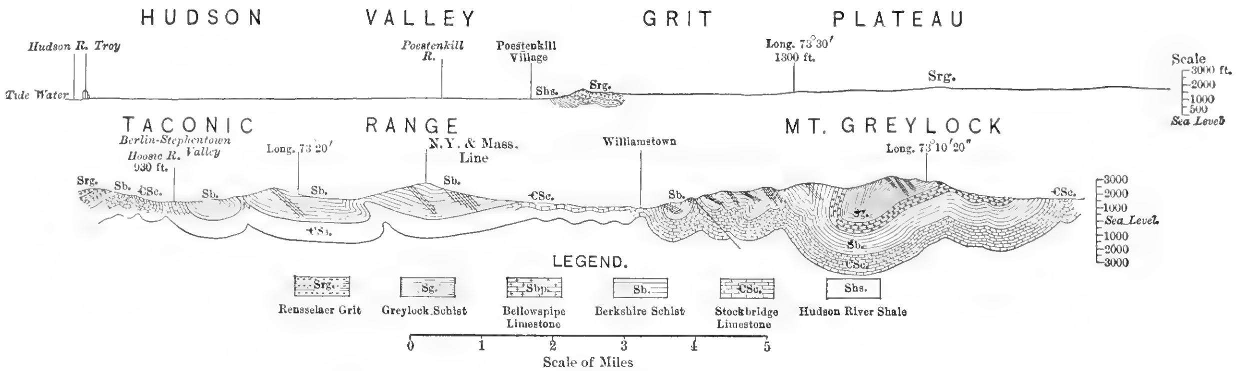

Fig. 273. — Cross section from the Hudson Valley across the Rensselaer Plateau and the Taconic Range, including Mt. Greylock, showing the relations of structure to topography. Limestone underlies the valleys; schist underlies the elevations. The valleys are anticlinal, the elevations synclinal in structure. (Dale, U. S. Geol. Surv.)

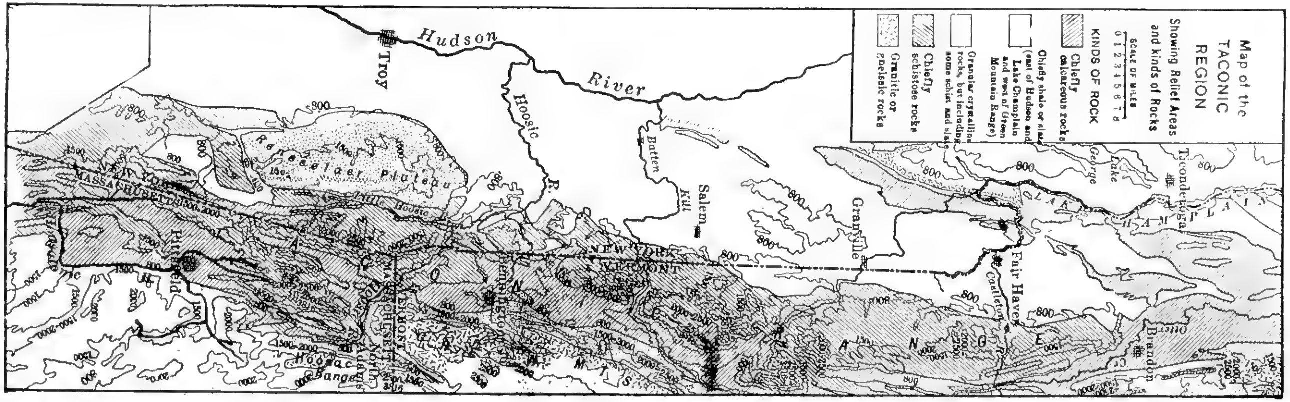

Fig. 274. — Contours express elevations and shading expresses rock types. Note the Green Mountains on the right, and in westward succession the valley of western Vermont, the Taconic Range, the Rensselaer Plateau, and the Hudson Valley. See structure section, Fig. 273. (Modified from Dale, U. S. Geol. Surv.)

tian area of Canada, the Adirondacks, and by an exceptionally high and rugged portion of the Appalachian Plateaus, the Catskill Mountains. The northern district of the Newer Appalachians is also unlike the other districts in that the mountains upon its eastern border consist partly of metamorphosed rock, the schists of the Taconic and Mount Greylock ranges.

The Newer Appalachians have a very restricted development in northwestern New Jersey, but shortly after entering New York state and specifically in the Walkill and Middle Hudson valleys the Hudson River shales thicken greatly and the whole belt has a notably broader development. Between the Highlands of the Hudson and the Catskills a broad valley lowland has been formed which continues northward along the eastern border of the state to a point between Hudson and Rensselaer, where the southern outliers of the Taconic mountains begin. From this point northward the relatively soft Hudson River shales are restricted to a narrower belt and the mountain feature of the Newer Appalachians becomes more prominent. The principal topographic feature of the district is the Taconic Range. Its geographic position and subdivisions are shown on the map, Figs. 273 and 274. The broadest development of the mountain group of which it forms a part is between the Hudson and the Hoosic valleys, roughly on the parallel of Troy. At this point the Newer Appalachians consist of the following members named in order from west to east: (1) the Hudson Valley, (2) the Rensselaer Plateau, (3) the Little Hoosic Valley, (4) the Taconic Range, including the Mount Greylock spur of the main Taconic Range, and (5) the upper portions of both the Hoosic and Housatonic valleys. From this point northward the Taconic mountains extend as a narrower range as far as northern Vermont, where they terminate. The total length of the range is about 200 miles, its width is from 5 to 10 miles. Its course is somewhat serpentine, with a north-northwest trend near Great Barrington, north-northeast to Dorset, and similar turns farther north.[1]

Many of the forms of the Taconic region are directly or indirectly

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[1] The name "Berkshire Hills" is so commonly employed to designate portions of the region here discussed that a word as to its usage is in point. Dale (The Rensselaer Grit Plateau in New York, 13th Ann. Rept. U. S. Geol. Surv., pt. 2, 1891–92, p. 297) implies a restriction of the term to the Taconic Range and the Greylock offshoot or the rugged country between the headwaters of the Hoosic and Housatonic rivers on the east and the western foot of the Taconic Range. Emerson's usage (Holyoke Folio U. S. Geol. Surv. No. 50, 1898, p. 1) corresponds to that of the inhabitants of the region and includes all the hills and mountains of Berkshire County, Massachusetts. In this usage the Hoosac Mountains, the southern continuation of the Green Mountains of Vermont, or what is called in Massachusetts the western edge of the Green Mountains Plateau, are included with the Taconics in the term "Berkshire Hills."

related to deformations acquired in three periods of folding: (1) at the close of the Cambrian, affecting the central portion of the area; (2) at the close of the Ordovician, with more far-reaching effects; and (3) in post-Silurian time (Devonian or Carboniferous).[1] The general structural features of the Taconic region are a succession of major and minor folds, as shown in the accompanying illustration, Fig. 273. These correspond approximately to the trend of the ranges. The general broad aspect of the structure of the Taconic Range is that of a synclinorium, in contrast to the geanticlinal character of the Green Mountains. The valleys are generally developed upon the softer limestone, the hills upon the harder schist.[2]

The easterly dipping cleavage of the schist determines the character of the eastern slope of the hills. There is a marked arrangement of the drainage along north-south or longitudinal lines both within the range and in the bordering valleys. There are 5 main transverse valleys — the valley of the Hoosic, the Mettawwe, the wide valley of the Walloomsac, the Battenkill, and the valley of the Castleton. Of these the Hoosic and the Walloomsac are deeply intrenched in wide valleys and the Taconic Range is greatly dissected in their vicinity.[3]

The main forms of the Taconic mountains are narrow ridges of harder rock separated by valleys developed upon softer rock. There is considerable variation in the lengths and forms of the ridges. Some are long, others short. The longer ones in many cases sag gently toward the center in response to variations in the axial pitch of the anticlines, or to the exposure of softer limestones in the heart of the anticlines. The shorter ones are in some cases roughly pyramidal in outline, irregular spurs with amphitheater-like hollows between them. There is also a small number of plateau-like masses. Few cliffs occur though some of these attain heights of 1000 feet.

The rugged hilltops and ridge tops of schist thinly veneered with soil have few agricultural resources and constitute areas of ultimate forest land. In general the valleys are deeply covered with drift and alluvium derived in large part from the underlying limestone. They are fertile and have an important agricultural population.

The Rensselaer Plateau lies between the Taconic mountains and the Hudson River in Rensselaer County, New York, and extends northward in scattered remnants toward Castleton, Vermont. Its structural fea-

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[1] T. N. Dale, Taconic Physiography, Bull. U. S. Geol. Surv. No. 272, 1905, p. 48.

[2] Idem, p. 29.

[3] Idem, pp. 20–91.

tures and geographic position ally it with the Taconic mountains on the east. It rises from 700 to 1200 feet above the adjacent valleys and from 1400 to 2000 feet above sea level. Its structure is broadly synclinal, its rocks massive, and its relatively flat surface is the product of base-leveling. The lakes that dot its surface are chiefly due to irregular glacial erosion. It bears little good soil and in this respect is in marked contrast to the fertile Hudson Valley on the west, the Berlin and Berkshire valleys on the east, and even the Berkshire Hills. It was once thickly timbered, but has since been deforested, and is to-day an unattractive region with relatively steep slopes on the east, north, and south, and with a general westerly inclination.

The extreme northern end of the Newer Appalachians is the St. Lawrence Valley, which drains out to the northeast longitudinally like the Coosa on the southwest. In this respect the extremities are in contrast to the greater part of the province, which is drained only by tributaries, the master streams crossing the mountain ridges and valleys alike at right angles. The limestones on the northern side of the St. Lawrence Valley have been weathered down into a lowland extensively covered with glacial detritus and estuarine deposits formed when the land stood lower than now and the sea washed the foot of strand lines now elevated 1500 feet above sea level. The lowland strips become narrower toward the northeast and finally disappear before reaching the mouth of the Saguenay. Beyond this point the bay of the St. Lawrence occupies the entire breadth of the lowland.

Tree Growth

The various sections of the Newer Appalachians display quite different types of tree growth. The rich limestone valleys which form so large a portion of the southern district were originally covered with an excellent growth of hardwoods interspersed with open parks or natural prairies where the limestone is most fissured and porous and therefore most dry. At present the limestone valleys are extensively cleared owing to the exceptional fertility of their soils and the abundant supply of timber available on the uncultivated ridges of the province. Likewise the lowland portions of the northern district are cleared and farmed. The zigzag ridges of the central district, on the other hand, are still for the most part tree covered. Their bordering slopes are quite too steep and their summit areas are quite too small to tempt the farmer. They constitute ultimate forest land of great value when kept in trees, and of little value, even as sheep or goat pastures, when cleared of their timber. The drier, sandier ridges formed on resistant sandstone, such as the Pocono, are marked by stunted growths of scrub pine and red and black oak; the more fertile valleys underlain by limestone have a heavy native growth of walnut, blue ash, etc. The best growth is found on the highest ridges of eastern West Virginia where the rainfall is notably greater than elsewhere in the province.

CHAPTER XXXII

APPALACHIAN PLATEAUS

THE Appalachian Plateaus consist of a number of subdivisions of the first rank: the southern or Cumberland district; the central district including the so-called "mountains" of eastern Kentucky and West Virginia; the northern district, the Allegheny Plateau of western Pennsylvania and southern New York; and the extreme northeastern portion — a special category— including the Catskill Mountains. The Catskills and the plateau of West Virginia and Kentucky are the loftiest members of the series and have truly mountainous relief and proportions. The Allegheny Plateau has been dissected into a systemless maze of spurs by the almost infinite branches of the deeply intrenched streams. The high and rugged eastern border region of the Allegheny Plateau is also known as the Allegheny Mountains, a term which includes not only the Allegheny Front but also the rough uplands immediately west of it, the northern representatives of the Cumberland Plateau.[1] Like the Cumberland Plateau the upper altitudes of the region represent an old erosion level, but dissection has progressed to the point where practically no flat land exists on the divides as an inheritance from an erosion cycle long closed. The tremendous resistance of the thick border rock of the Cumberland Plateau and the lower altitude have practically preserved it from destruction and flat uplands still persist.

NORTHERN DISTRICT

The northern district of the Appalachian Plateaus consists of the plateaus of western and northern Pennsylvania and southern New York and include such specialized tracts as the Pocono Plateau in northeastern Pennsylvania and the Catskill Mountains in east-central New York.

The western border of the district is a well-developed scarp that swings southwestward along the southern shore of Lake Erie, finally disappearing in central Ohio. At Cleveland it stands out as a ragged scarp several hundred feet high, between which and the lake shore there occurs but a narrow strip of lowland. Farther southwest the

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[1] See the Bedford quadrangle, Penn., U. S. Geol. Surv.

province has a less definite border than elsewhere except at the extreme south, where it descends gradually and dips beneath the Gulf Coastal Plain.

Its northern border is a low ragged northward-facing escarpment (Fig. 275) stretching eastward from Lake Erie to the Hudson across central New York. The eastern end of this escarpment is formed by the Helderberg Mountains, where the extremely hard Helderberg limestone outcrops in a stratum about 500 feet thick. Farther west, in the Finger Lake district, the escarpment makes a bend southward, a change in trend due to the great thickness (1000 feet) of the soft and easily eroded Salina shales. At this point too the resistant Helderberg limestone is only 90 feet thick. Farther west the shales thin out again, the sandstones and limestones become thicker, and the escarpment again swings back to a more northerly position. The present position of the escarpment is in a geologic sense merely temporary, for the sapping of the hard layers which are responsible for its prominence is going on now just as in the past. By the same reasoning it was once farther north than now, and has been steadily pushed southward, so that this part of the Appalachian Plateaus province, like so many other portions with scarped margins, is suffering a reduction in area by the extension of the lowlands about it.

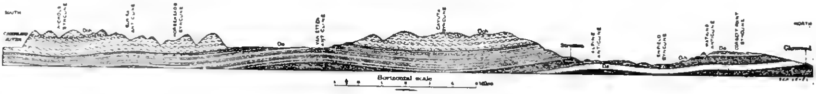

Fig. 275. — North-south section across the northern edge of the Appalachian Plateaus, Chemung River to Glenwood, N. Y. Vertical scale 5 times the horizontal. (Tarr, U. S. Geol. Surv.)

An interesting consequence of this process of escarpment retreat is progressive stream capture exhibited in many forms. The drainage of the plateau is southward almost from the very edge. The shorter, steeper, and more powerful northward-flowing streams are cutting back into the drainage systems of the Susquehanna and the Allegheny. In places they have diverted one tributary after another until almost the entire headwater systems of individual tributaries have been deflected to northerly courses. The junction of the deflected and the deflecting streams is marked by a sharp turn, so that the two stand in a curious relation designated as barbed drainage. From the extent to which this feature is developed conclusions may be drawn as to the former position of the plateau margin in recent time. An example is West River above the head of Canandaigua Lake. The southward-flowing plateau streams whose headwaters have been captured are diminished in volume and in many cases their headwaters flow as tiny brooks in broad valleys. Indeed the upper portions of some valleys on the plateau margin are without a living stream.

The eastern margin of the plateau of southern New York is also being pushed back rapidly by the short precipitous tributaries of the Hudson that descend the great scarp on the eastern aspect of the Catskills. Stream capture is here both vigorous and general. In places it means merely the westward retreat of the escarpment without sudden and great changes in the courses of the streams; at other places the valley sides are broken down by lateral attack, as in the escarpment of central New York, and barbed drainage relations developed. The best-known case is that of the eastward-flowing Kaaterskill, which has captured the headwaters of westward- and northward-flowing Scoharie Creek and turned down a 5-mile course waters which formerly flowed 50 miles to the Mohawk and down the Hudson to reach the same point.

The plateau of northern Pennsylvania and southern New York consists of a broad elevated region so extensively and deeply dissected that only small remnants exist here and there of what was once a fairly even surface.[1] The Cretaceous peneplain which by uplift became a plateau has by that erosion which is dependent upon uplift become a dissected plateau. Above its general level stand distinctly higher ridges with comparatively flat tops.

The degree of dissection of this portion of the Appalachian Plateaus is so great that the features of the central district are repeated in kind though not in degree. The lesser elevation of the northern district has resulted in shallower valleys and a less mountainous aspect than occurs in eastern Kentucky, but the relief is decidedly rugged. There is the same kind of dependence upon the valley ways in both the newer and the older systems of transportation.

> "Wherever the surface is underlain by the same set of strata, it is cut into hills and valleys of the same general style. One valley can not be called the counterpart of another, nor are the hills and uplands always alike, yet the type of topography is the same. A view from the top of any well-exposed upland gives a good idea of what the country is like. Below the upland lies a valley as variable in the nature of its slopes as it is irregular in its course. Here steep walls rise from the stream on both sides. There a sharp descent on one side is faced by a long gentle slope on the other. Numerous ravines, some short, some long, some deep, some shallow, are occupied by the smaller streams which flow in from either side. As far as the eye can see in all directions the uplands stretch away in a broad, undulating tableland, unbroken by ridges, but on every hand bearing the deep scars of a multitude of valleys and ravines."[2]
>
> "Over the entire area the streams branch again and again, until there is hardly a square mile into which one or more has not worked its way . . . the surface is that of a well-dissected plateau, varying from place to place, both in elevation and in surface detail, yet everywhere preserving the general feature of more or less rugged relief produced by the trenching valleys of innumerable streams."[3]

The topographic studies thus far made in Pennsylvania seem to show that three erosion levels can be identified. The first is the level of the ridge and hilltops in northern Pennsylvania, a feature equally well shown on the summits of the zigzag ridges of central Pennsylvania and northern New Jersey. This is the Cretaceous peneplain, and was developed widely upon rocks of diverse structure and resistance. The

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[1] M. R. Campbell, Geological Development of Northern Pennsylvania and Southern New York, Bull. Geol. Soc. Am., vol. 14, 1903, pp. 277–296.

[2] W. S. Tower, Regional and Economic Geography of Pennsylvania, pt. 1, Physiography, The Central Province, The Plateau Province, Bull. Geog. Soc. Phil., vol. 4, 1906, p. 30.

[3] Idem, p. 36.

second peneplain was early Tertiary and is known as the Harrisburg peneplain. It was developed upon the Chemung rocks of the northern part of Pennsylvania, and is also well shown in the Monongahela Valley on the Brownsville, Missiontown, Connellsville, and Union Town topographic sheets, where the surface is a very gently undulating plain which in a distant view has an almost horizontal sky line at 1250 feet. The Harrisburg peneplain is best developed east of Harrisburg, where it is at an altitude of 500 feet. It rises steadily upstream to about 800 feet in the vicinity of Sunbury, and to 1200 and 1300 feet at Pittston. Its present warped attitude is shown in Fig. 276.

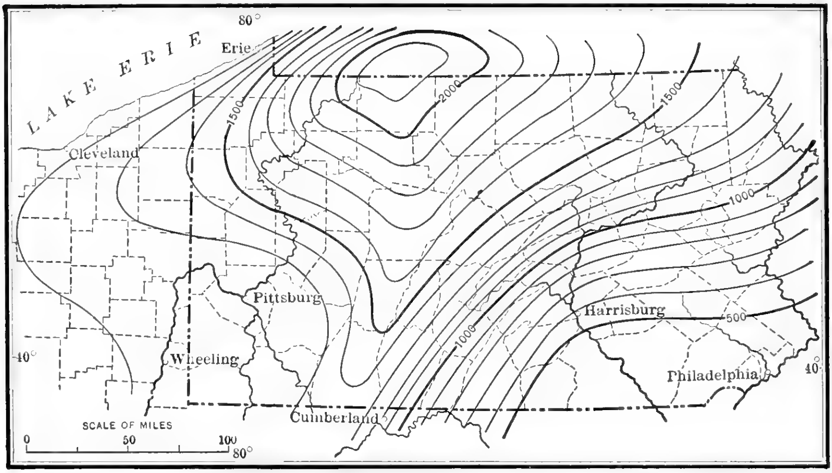

Fig. 276. — Warped surface of the early Tertiary (Harrisburg) peneplain of the central Appalachians. (Campbell.)

In the Schuylkill the rocks are considerably disturbed and consist of a heterogeneous mass of shales; yet the hilltops are very regular indeed, with occasional monadnocks rising as high as 800 feet above the general 500-foot level. On the northwestern side of the Shenandoah Valley is a region of low flat-topped hills which appears like a great plain trenched by many small valleys.

In the Potomac Valley (Hancock quadrangle) the Harrisburg peneplain is from 600 to 700 feet above the sea in the southeastern corner and about 800 feet in the northwestern corner. The geologic structure consists of broad open folds, with many minor wrinkles, and the planes of stratification are generally inclined. In spite of these structural complications the peneplain represented by the hilltops cuts across the beds whatever their angles of inclination.

The third topographic level is that formed in late Tertiary time; it is known as the Somerville or the Worthington plain. In New Jersey it was developed on the rocks of the Kittatinny Valley and on the wide outcrop of Triassic rocks which form the lowland belt across New

Jersey and Pennsylvania, Fig. 276. It is, however, of exceedingly local development, and along the Susquehanna Valley as at Harrisburg it stands at an altitude of 400 feet, at Lancaster at 350 feet, and on the Potomac River near Harpers Ferry at 500 feet. It represents a partial cycle only, and nowhere was developed extensively across rocks of different hardnesses, but was etched out upon the softer formations only.

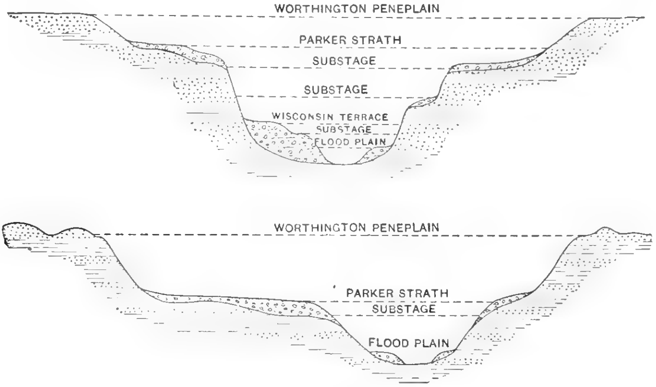

Fig. 277. — The upper section illustrates the terraces of the Ohio Valley, the lower the terraces of the Allegheny Valley. (Top. and Geol. Surv. of Penn.)

In the uplift of the third and lowest plain to the present level there was one main halt which permitted the development of broad valleys. Fragments of these valleys now occur as benches along the valley margins. All these features as well as those related to the glaciation of the region on the north are shown in Fig. 277.

Among the more prominent effects of glaciation was the development of an extensive system of abandoned channels whose origin was long in doubt. They are of widespread occurrence in western Pennsylvania, West Virginia, and eastern Kentucky. Detailed surveys and studies in recent years have at last supplied a basis for an acceptable explanation.[1] The abandoned channels appear to have been upbuilt by the streams during a period of stream aggradation associated with the waning stages of glaciation. All the southward-flowing streams heading in the glaciated country were so abundantly supplied with material that they aggraded their valley floors. The northward-flowing streams joining the southward-flowing aggrading streams were therefore compelled to aggrade their courses to the same level. In many cases they developed

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[1] E. W. Shaw, High Terraces and Abandoned Valleys in Western Pennsylvania, Jour. Geol., vol. 19, 1911, pp. 140–156.

courses to one side or the other of the older courses, crossed low points in former upland spurs, and now exhibit most striking anomalies with respect to earlier channels. Typical conditions are represented along the Monongahela and its tributaries, as shown in Fig. 278.

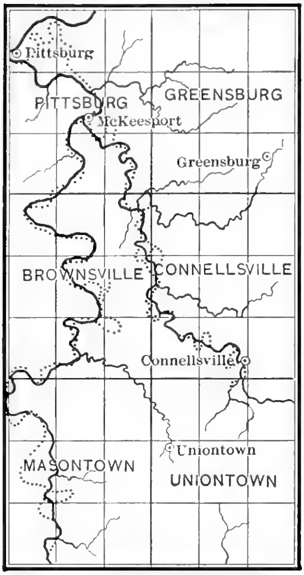

Fig. 278. — Present and pre-Pleistocene courses of Monongahela (left) and Youghiogheny rivers. (Top. and Geol. Surv. of Penn.)

POCONO PLATEAU

The Pocono Plateau, a separate division of the northern district, lies in the northeastern corner of Pennsylvania, almost completely separated from the rest of the plateau areas of that state by the deep synclinal trough of the Wyoming Valley. The Pocono Plateau covers Monroe, Pike, Wayne, and eastern Carbon counties, merges southwestward into the ridge area of the anthracite coal region, and extends east and north to become the Catskill Plateau of New York state. Almost the whole of it is underlain by the broad strata of nearly horizontal hard sandstone and conglomerate at the bottom of the Coal Measures series.

The southern edge of the plateau is often known as Pocono Mountain and presents a close analogy to the Allegheny front, both in origin and in character. It is an erosional escarpment, 1000 feet high, with a step-like ascent resulting from the horizontal position of the strata. The plateau back of the boundary escarpment (Pocono Mountain) is a nearly level upland wilderness, known to the early settlers as the "Great Beech Woods" and the "Shades of Death." Over most of its extent it stands from 1400 to 1800 feet above the sea. Below this level the streams have cut valleys from 100 to 200 feet deep, and an occasional knob rises 200 or more feet above the upland. It is often described as one of the wildest parts of the state, "a wilderness of forest and swamp," but it is made picturesque by the numerous lakes and cascading streams that are the result of the glacial action to which the region has been subjected.[1]

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[1] W. S. Tower, Regional and Economic Geography of Pennsylvania (Physiography), Bull. Geog. Soc. Phil., vol. 4, 1906, pp. 216–217.

CATSKILL MOUNTAINS

The Catskill Mountains stand upon the northeastern border of the Appalachian Plateaus as a conspicuous group of ridges and peaks of mountainous proportions. Their summits reach to heights almost double those of the adjacent plateau. Some of the principal peaks are Slide Mountain (4220 feet), Hunter Mountain (4052), Black Dome (4000), Windham High Peak (3809), etc. From the upper portions of the Hudson Valley their whole elevation may be seen in a single view, from which point they appear to have imposing form and height. The blue haze that generally hangs over them — a feature of rare beauty in autumn weather — lends to their height a majesty and to their outlines a softness which in a distant view blend to form one of the most charming sights of the Atlantic slope.

The structure of the Catskills is as simple as that of the neighboring plateau on the west. The strata lie almost flat, with slight dips to the west, northwest, and southwest in various places. Anticlinal and synclinal structures are practically absent, and even when present they trend not with the ranges of the Catskills but at right angles to them, showing no relation to the present topographic forms. Shale commonly outcrops on the lower slopes of the valleys, but sandstones occur higher in the section, and on the summits of the principal peaks the rock is generally a conglomerate, very durable and thick. The flatness of the strata is expressed in the flat summits of the mountains, a characteristic feature and one that often interferes with the view, since these mountains are all heavily wooded. The tops are often of considerable extent and are never sharp-pointed peaks as in a region of alpine forms. While the valleys among the mountains are broad and open their sides are often cliffed to a notable extent for some distance. This is due to the system of almost vertical joints, which are the principal lines of weakness along which secondary erosion and valley widening take place. Abrupt ledges are frequent and are often a source of great difficulty in ascending a peak by unusual paths. In a few places these ledges are of great height and afford splendid panoramas over the surrounding country, as at the Catskill Mountain House and Overlook Mountain. To the vertical jointing and erosion along the joints is also to be attributed the successive steps which are common features of the valley floors and give rise to numerous picturesque cascades.

There are two main ranges in the Catskills, the line of division being marked by Esopus Creek. The southern Catskills consist of a massive central chain which bears the highest mountain in the Catskills, Slide

Mountain. The roughness of the topography and the unbroken forest that covers the mountain makes the penetration of this part of the Catskills very difficult. The northern ranges of the Catskills trend northwest and the principal range is about 35 miles in length. It makes a sharp curve, bending back upon itself in a sort of secondary range. A number of lateral spurs or secondary ranges trend at right angles to the main ones. Toward the south and southwest the main range falls off in long slopes and heavy spurs. It is divided into four sections by three deep gorges or " cloves " which give access to the interior valleys.

The drainage of the Catskills is chiefly to the west by tributaries of the Scoharie system. This appears to be a consequent drainage developed upon the original surface at the time of uplift of the region. Base-leveling, which is so common a feature of the Appalachian Plateaus, appears to be absent here; the Catskills appear to have survived as residuals because of their original superior height and the protection of the heavy cap of horizontal conglomerate. Erosion produced important effects, however, and opened up the broad valleys that are characteristic of the region. A common feature of the valleys is the presence of a pronounced shoulder halfway up the valley slopes, a feature which appears to be related to later uplift and dissection in the Tertiary. Were the valleys filled almost to the level of the shoulder we should probably have a picture of the Catskills as they appeared at the close of the Cretaceous cycle of denudation. They would then present smooth flowing outlines without any important number of steep ledges; the latter are commonly found below the level of the shoulder, where vigorous erosion is now taking place. The effects of Tertiary erosion are also shown in the form of local lowlands of limited extent opened up here and there within the mountain borders.

Although the Catskills were overridden by ice, signs of which are everywhere abundant, the ice appears not to have had any important effect upon the topography; rather it conformed to the broad slopes, only slightly molding them here and there by the deposition of small quantities of glacial till or by the erosion of the sharper forms.[1]

SOILS AND VEGETATION

The most uniform type of soil in the glaciated northern portion of the Allegheny Plateau is the till sheet which veneers the hills and uplands. It is a smooth, thin, and locally stony sheet of bowlder clay.

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[1] For an excellent topographic description from which the above is largely derived see Arnold Guyot, On the Physical Structure and Hypsometry of the Catskill Mountain Region, Am. Jour. Sci., 3d Series, vol. 19, 1880, pp. 429–451.

The soil is much deeper in the valleys and of more variable form and composition, especially where morainic accumulations occur side by side with fluvio-glacial material — kames, eskers, outwash plains, and the like. In both the uplands and the valleys a large proportion of the glacially derived material is from underlying shales which weather into clay and increase the fertility of the soil by increasing its water-holding capacity. The varying proportion of this soil element causes great variation in the rapidity and thoroughness of soil drainage, so that in a dry spell one part of a field may be covered with a fresh green growth while another part near by may be parched and brown.[1] Swampy tracts are characterized by a fertile black muck of great value when drained. Besides these soil types are narrow strips of flood-plain deposits and fan-shaped alluvial accumulations where the hill streams descend abruptly to the main valley floors.

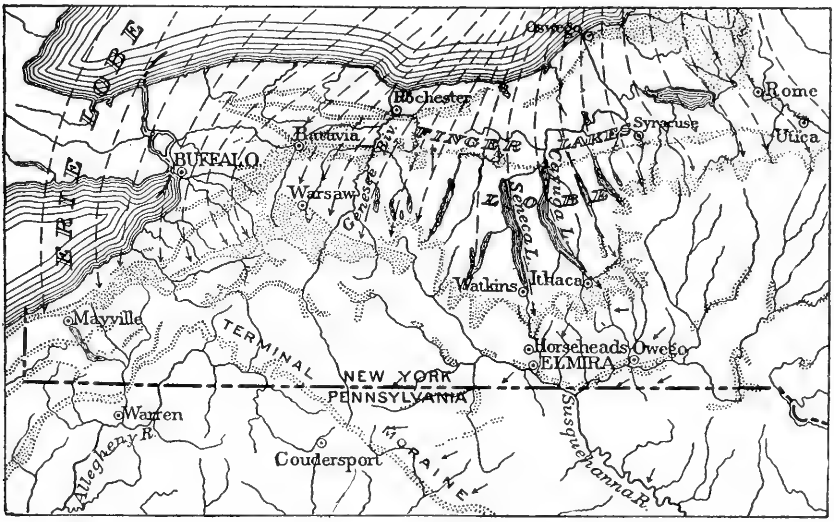

Fig. 279. — Distribution of morainal deposits and direction of ice movement in western New York. (Tarr, U. S. Geol. Surv.)

While practically none of the primitive forest can now be found in the region, yet the uplands and valley slopes, too steep for cultivation, are in the main covered with extensive forests. The forest cover is extending naturally and encroaching on the cleared lands. The thin, stony upland soils are relatively infertile, and the extension of the forest

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[1] R. S. Tarr (Williams, Tarr, and Kindle), Watkins Glen-Catatonk Folio U. S. Geol. Surv. No. 169, 1909, p. 33.

over them would benefit the region not only from the standpoint of forest products but also from that of the agricultural interests of the valleys, which suffer from increasingly destructive floods.[1]

CENTRAL DISTRICT

The central district of the Appalachian Plateaus lies in eastern Kentucky and West Virginia and is the ruggedest portion of the entire province. The highest portions are from 3000 to 4000 feet above sea level and are known locally as mountains, a name they fully deserve. The eastern rim of the district in Kentucky is Pine Mountain, whose steep eastern escarpment rises from 800 to 1500 feet above the Great Valley on the east and has but one water gap in 150 miles. The Kentucky "Mountains" are structurally a part of the Cumberland Plateau and formerly had a flattish summit; the original nearly flat surface has been so greatly dissected however that but few remnants remain to indicate the former level. These, however, show a remarkable uniformity of elevation on northeast-southwest lines, so that the eastern escarpment of the district has an almost perfectly straight sky line.

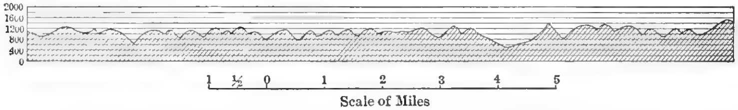

Fig. 280.— Maturely dissected Allegheny Plateau in West Virginia. The large depression on the right is the valley of the Kanawha at Charleston. Note the prevalence of slopes and the absence of flat land.

The western slopes of the district are in sharp contrast to the eastern. There is a bordering escarpment, but it is highly irregular, the streams having carved valleys far back into the elevated portions of the upland, leaving long narrow spurs running out toward the west. The valleys are steep and gorge-like; the main streams such as the Kanawha occupy canyons; flat land is seldom found to any extent either upon the hill summits or on the valley floors. It is a hill-and-valley country, Fig. 280, where so little flat land occurs that the water everywhere falls upon a slope and the run-off is heavy; floods due to spring rains and the melting of late winter snows are common and rise to great heights in the confined valleys, destroying roads and bridges, washing away the valley soils or covering the soils of the narrow flats or flood plains with heavy deposits of coarse waste. Almost all the roads and trails follow the valleys, to which the railroad lines themselves are strictly confined.

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[1] R. S. Tarr (Williams, Tarr, and Kindle), Watkins Glen-Catatonk Folio U. S. Geol. Surv No. 169, 1909, p. 33.

Travel by any means is often suspended during time of high water. The whole section is a great forested wilderness whose resources of coal and timber constitute its chief wealth, resources slow in development because of the almost insuperable topographic obstacles to transportation. Even the railways on the margin of the country have been built since 1880.

Magnificent forests once covered the central district of the plateau region. They are still untouched in the remoter localities. Oak, walnut, poplar, chestnut, maple, ash, and tulip trees grow to great size. The making of staves of white oak is a considerable industry among an isolated and backward mountaineer folk. Since the roughness of the country limits the railways to the principal streams, the lesser waterways are almost everywhere utilized for rafting both timber and lumber to the railroads and the lowlands. In many sections remoteness from transportation lines forbids any attempt at forest exploitation. As in the southern Appalachians a wasteful system of agriculture is practiced. Hillside farms are cleared of the finest timber by combined girdling and later burning, then cultivated a few years and abandoned for a new site. The abandoned clearing grows up to useless brush or is deeply gullied and the thin soil washed away.[1]

Southern District

CUMBERLAND PLATEAU, WALDEN RIDGE, LOOKOUT MOUNTAINS, ETC., AND THE HIGHLAND RIM

A first inspection of the flat-topped plateaus of the southern district leads one to the conclusion that the flatness is a function of the structure, for the strata appear to have a roughly horizontal attitude. A closer examination, however, reveals the fact that the plateau surface does not generally coincide with a particular stratum however resistant it may be; the surface is found to be composed of very soft shale as

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[1] For extremely interesting and accurate descriptions of both the physical geography of the region and the Kentucky mountaineers see the writings of John Fox, Jr., as for example Hell-fer-Sartin, Blue Grass and Rhododendron, and The Trail of the Lonesome Pine. On Horseback to Kingdom Come, Scribner's Mag., vol. 48, No. 2, 1910, p. 175, discusses later industrial development. The best scientific description of the country and the people is by E. C. Semple, The Anglo-Saxons of the Kentucky Mountains, A Study in Anthropogeography, Geog. Jour., vol. 17, 1901, pp. 588–623. In Theodore Roosevelt's The Winning of the West (The Spread of English-speaking Peoples), vol. 1, ed. of 1905, pp. 146–147, is a fascinating description of the forest of pioneer days. For a good topographic description of portions of eastern Kentucky see Ky. Geol. Surv., vol. 5, n. s., 1880. For a discussion of the natural water routes of the Kentucky mountains see N. S. Shaler, The Transportation Routes of Kentucky and their Relation to the Economic Resources of the Commonwealth, Ky. Geol Surv., vol. 3, pt. 5, 2d series, 1877.

well as of very hard sandstone. In short, the surfaces of the various plateaus truncate hard and soft beds and are much more nearly horizontal than the strata upon which they have been developed.

Following the principles we have already applied so frequently in the study of the physiography of the United States, we shall conclude that the surfaces of Walden Plateau, Cumberland Plateau, Lookout Mountain, Sand Mountain, etc., are portions of an uplifted peneplain in process of more or less rapid dissection. Along certain lines narrow anticlinal folds had developed during the period of structural deformation, with broad synclines between. The projection of the anticlines above the level of the peneplain resulted in their erosion and the exposure of softer underlying beds lying in the heart of the anticlines. When later uplift occurred, opportunity was afforded for the dissection of the softer exposed beds. The result has been that the synclinal basins of an earlier period have been converted into the mountains and plateaus of the present period.

One of the most important departures from the plateau topography is known as the Sequatchie Valley, which separates Walden Plateau from Cumberland Plateau. It lies parallel with the Great Appalachian Valley, has remarkable continuity and regularity of expression for over 100 miles, and appears to be an outlying anticlinal fold of the Appalachian system of folds.

The Sequatchie anticline, like the anticlines of the Newer Appalachians, has a typically unsymmetrical form, the beds dipping much more steeply on one side of the axis than on the other, and the gentler dips are upon the eastern side. Near the upper end of the Sequatchie Valley the strata have been broken by a thrust fault developed along the steep side of the arch. Walden Plateau on the east shows a distinct synclinal structure. Of similar structure is Lookout Mountain, but it is much narrower than Walden Plateau. Wills Valley, developed upon an anticline, separates the syncline of Lookout Mountain from the syncline of Sand Mountain, and Sand Mountain is in turn separated from Cumberland Plateau by the valley of Tennessee River, which has been developed in the southwestward extension of the Sequatchie anticline.

Along the eastern edge of Cumberland Plateau the strata dip westward at a steep angle, but these dips are maintained for very short distances, usually not more than a few rods, where they change to dips that are sensibly flat, a condition maintained across the Cumberland Plateau and the Highland Rim. Though apparently horizontal the beds dip toward the southeast from 20 to 30 feet per mile.

It must not be supposed that Cumberland Plateau and Walden Plateau were perfectly peneplaned. Along the western edge of Walden Plateau, the northern end of Lookout Mountain, the eastern edge of Cumberland Plateau, and at a large number of isolated points elsewhere, residuals in the form of isolated knobs or mesas rise from 100 to 300 feet above the general level of the plateau. In places, the residuals are composed of more resistant beds of massive conglomerate, but the residuals within the borders of the plateaus are composed of horizontal strata in some cases capped by a bed of conglomerate but more often composed entirely of rather soft sandstones and shales.

Following the uplift of the Cretaceous peneplain there ensued a period of crustal stability sufficiently prolonged to enable the forces of erosion to develop a partial peneplain at a level from a few hundred to a thousand feet lower than the Cretaceous. The peneplanation accomplished during this period was chiefly upon the softer rock of the region and was so incomplete as to leave large portions of the Cretaceous peneplain standing above the early Tertiary peneplain in the form of massive unakas, as shown in Fig. 238. The early Tertiary peneplain is called the "Highland Rim" peneplain because the Highland Rim, so-called, between the Nashville basin and the Cumberland Plateau, is the best-preserved portion.

As in the case of the well-preserved remnants of the Cretaceous peneplain, the remnants of the early Tertiary or Highland Rim peneplain have been preserved largely because of the presence of resistant beds along the outer margin, but the peneplain as a whole truncates beds of widely differing degrees of resistance to erosion. The peneplain is preserved upon rocks of intermediate resistance, chiefly siliceous limestones and sandy shales, for rocks of greater resistance than these were never base-leveled, and rocks of less resistance were dissected in the uplift which closed the early Tertiary cycle of erosion.

The elevation of the Highland Rim peneplain is about 1000 feet, west of the Cumberland Plateau in the Appalachian Valley it is about 1150 feet, toward the northern edge of the Chattanooga district 950 feet. Elevations above the topographic level developed on the Highland Rim are in the form of isolated residuals similar to those we have noted upon the Cumberland Plateau, as long irregular projecting spurs along the ragged west border of the Cumberland Plateau, or as massive unakas such as Cumberland and Walden plateaus themselves.

On the western and southern borders of Cumberland Plateau many long spurs and isolated knobs, products of circumdenudation, project irregularly westward over the surface of the Highland Rim, breaking the continuity of the eastern portion. Between the spurs are great gorges from 800 to 1000 feet deep, which, on account of their depth and narrowness, are known as "gulfs." At their heads coves are found, headwater alcoves which usually contain a pocket of limestone soil that supports a better timber growth than the flat upper surfaces of the upper and lower plateaus with their thin soils formed upon sandstones and shales. Both the distribution of the soils and the character of the topography on the border of the Cumberland Plateau are due to the structure.

Between the hard sandstone and conglomerate capping most of the Cumberland Plateau and the rock of the lower country about it are soft limestones and shales which are so easily eroded as to result in the sapping and undermining of the hard formations above them. It is this process which maintains the steepness of the border scarps (especially their upper portions, which are frequently vertical cliffs) and results in the sharp line of delineation between the Appalachian Plateaus on the one hand and the Appalachian Valley and Highland Rim on the other. These features are persistent, being found on the projecting portions of the plateau as well as at the heads of the coves.[1]

The "barrens" of Tennessee are developed chiefly upon shales (Waverly) which yield a white, siliceous, and unproductive soil. Scarcely more productive are the soils derived from sandstones which are thinly inhabited and have thin native forests of pine and oak. The surface of Cumberland Plateau, consisting of sandstones and shales, is covered with a thin poor soil; the Highland Rim is also far from having a productive soil, though on its western margin, where a limestone (Newman) outcrops, a soil of greater but not of high fertility occurs. In general the timber covering of the flat plateau summits and remnants is thin, but in the coves, hollows, and gorges, where a richer soil and more abundant water supply are found, hickory, chestnut, and oak reach a good size and grow in first-class stands. Near the watercourses, pine, hemlock, and spruce find the necessary elements of their environment, but their growth is everywhere second in importance to the members of the first-named series.[2]

LIMESTONE SOILS OF THE APPALACHIAN VALLEYS

"The limestone soils are among the most extensively developed of any in the United States and occur in both broad upland and enclosed narrow valley areas. The greatest upland development is seen upon the Cumberland Plateau in eastern Tennessee and Kentucky and upon the Carboniferous formation in central Tennessee and Kentucky, northern Alabama and Georgia, and in Missouri. The valley soils are found principally in Pennsylvania, Maryland, and Virginia, and in the mountain section of eastern Tennessee and Kentucky and northern Alabama and Georgia."[3]

The limestone soils are residual in origin, being derived from the weathering in place of limestone of several ages and variable composition. This is accomplished by the removal through solution of the calcium carbonate of the limestone. Limestone soils are remarkable for the fact

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[1] C. W. Hayes, Seuanee Folio U. S. Geol. Surv. No. 8, 1894, p. 1.

[2] A. Keith, Wartburg Folio U. S. Geol. Surv. No. 40, 1897, p. 4, col. 3, and M. R. Campbell, Standingstone Folio U. S. Geol. Surv. No. 53, 1899, pp. 4-5.

[3] Soil Survey Field Book, U. S. Bur. of Soils, 1906.

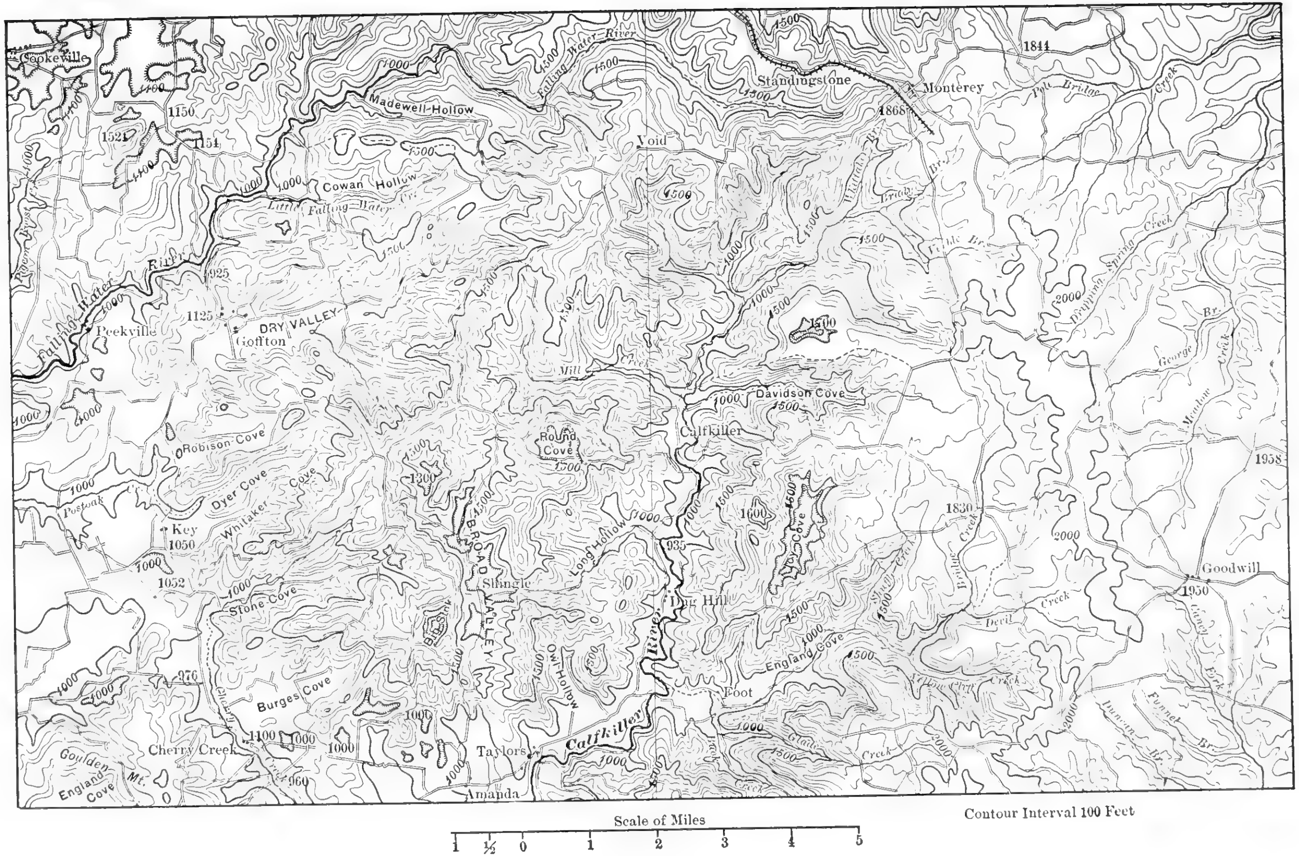

Fig. 281.—On the right is the summit of the Cumberland Plateau; on the left is the surface of the Highland Rim; between is a belt of rugged country which marks the descent from the higher to the lower level. (U. S. Geol. Surv.)

that they constitute but a small percentage of the original limestone rock, the larger part having gone into solution, leaving behind the more resistant siliceous minerals. It has thus required the solution of many feet of rock to form a foot of soil. They have a naturally heavy character. Solution and subsequent filtration of pure massive limestone of Cambro-Silurian age have given rise to a soil which as a rule occurs in valleys bordered by areas of the more resistant sandstones and shales. The series is typically developed in the limestone valleys of the Great Appalachian Valley and in the central basins of Kentucky and Tennessee, but smaller areas are found as marginal deposits in the Piedmont section and in the deep valleys of the Appalachian Plateaus, where the underlying limestones have been exposed to weathering by deep erosion. The most productive valley phase occurs in the Great Appalachian Valley.

The cherty and fossiliferous limestones (St. Louis) of the region have given rise to a second soil type which occurs on both the level and the undulating uplands and in rough, hilly country with steep valleys. Where the latter features predominate the soils are generally unproductive and very stony, but in some sections are adapted to fruit, especially apples. The soils formed from beds of purer limestone occupying level and gently rolling areas are as a rule very productive.

Local Lowlands

BLUE GRASS AND NASHVILLE BASINS

The upland quality of the general regional slope of the Appalachian Plateaus is interrupted in Kentucky and Tennessee by lowlands of unusual size and importance. The Kentucky lowland is the Blue Grass country, famous for its rich limestone soils and its nutritious blue grass; the Nashville lowland or Central Basin is of equal importance, though it has for some reason never gained such general renown. In respect of soil fertility and easy cultivation both are in happy contrast to the uplands about them, which are as a whole either too broken to permit easy tillage or too thinly covered with soil of inferior quality to tempt men in large numbers. These two lowlands are essentially alike in structure and origin in spite of many detailed differences. Both are great structural domes which extended above the general level of the surface of erosion once developed here. The Blue Grass lowland was developed in the early Tertiary cycle of erosion and was so denuded by the base-leveling of that period as to have its cap rock either partially or wholly removed. With later uplift, erosion quickly cut below the hard and into the underlying soft strata, Plate V and Fig. 282. The result was a lowland, while the surrounding areas, underlain by the hard strata once arching over the dome, remained as uplands. The central basin of Tennessee or Nashville Basin was developed in the late Tertiary cycle of erosion under similar conditions.

BLUE GRASS COUNTRY

The general altitude of the Blue Grass country of north-central Kentucky is from 800 to 1000 feet above sea level. The region may be described as a broad plain on whose southern margin the hills rise abruptly; in the hill country the large streams have cut deep narrow gorges which only become slightly less deep and narrow throughout the Blue Grass region itself. Although in short distances the surface of this plain appears to be structural and to correspond with the bedding of the limestone rocks (Ordovician) which compose the greater part of the surface, a large view discloses the fact that the surface cuts across rocks of different ages and varying degrees of hardness, and is an uplifted peneplain, called the Lexington peneplain.[1]

The hills which rise above the Lexington peneplain have a fairly constant altitude of about 1500 feet. They generally have round or sharp tops and a regular altitude despite the variation of the underlying rock, hence it is inferred that they too represent a former peneplain, the Cretaceous peneplain of the Appalachian region.

It is noteworthy that the valleys of the Lexington peneplain of the Blue Grass region exhibit a topographic unconformity showing two episodes of erosion. Long gentle slopes lead down from the surface of the Lexington peneplain to an inner valley with steep walls. The gentle slopes evidently constitute the borders of an older broad valley in the bottom of which the modern narrow gorge has been cut. The floors of the older valleys bear deposits of sand, while the sides of the modern valleys are in many cases rock cliffs.[2]

The Blue Grass country of Kentucky is developed upon a broad structural arch known as the Cincinnati anticline, which extends from Nashville through Lexington, nearly to Cincinnati. Its occurrence north of the latter point will not be described here, for it is of lesser topographic importance than glaciation which has largely concealed it. The Cincinnati arch south of Cincinnati may be divided into two broad domes, one of which culminates near Nashville, Tennessee, and the other in Jessamine County, central Kentucky.[3]

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[1] M. R. Campbell, Richmond Folio U. S. Geol. Surv. No. 46, 1899.

[2] Idem.

[3] G. C. Matson, Water Resources of the Blue Grass Region of Kentucky, Water-Supply Paper U. S. Geol. Surv. No. 233, 1909, pp. 26–27.

A large part of the Blue Grass region, and particularly that part of it in Woodford, Franklin, and Fayette counties, Kentucky, has flat-topped divides with practically no surface drainage. This condition furnished exceptionally favorable opportunities for the formation of caverns and the development of underground drainage systems for which Kentucky is noted. The topography is marked by a series of sink holes which receive a large part of the rainfall. It is inferred that before the uplift of the Lexington peneplain so large a part of the surface was drained by underground streams that surface drainage was probably limited to the larger streams and their principal tributaries.[1] The sink-hole topography of the Blue Grass region favors the quick removal of surface water and its rapid absorption by the rock.[2]

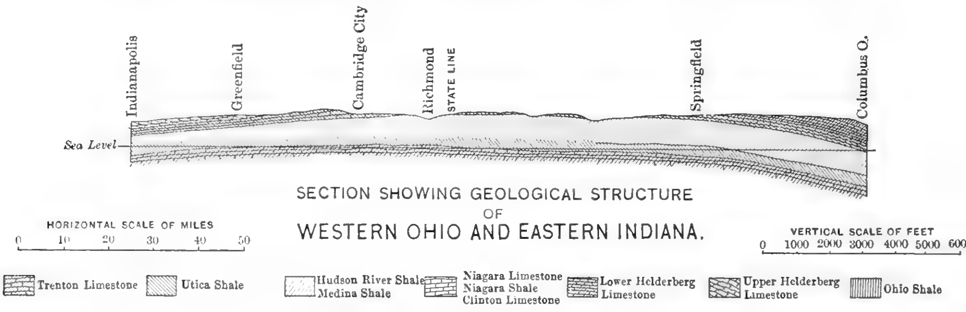

Fig. 282.—Northern portion of the Cincinnati arch, showing exposure of the lower and softer beds of shale and limestone.

The residual soils of the Blue Grass region range in thickness from 3 to 5 feet on the average, but with extreme ranges from a few inches up to about 30 feet. The residual material absorbs and stores the rainfall and delivers it gradually to the underground channels. Were the rock surface exposed, springs would flow only a short time after each rain, and the stream flow would be exceedingly irregular.[3]

The Blue Grass region has been famous for its excellent soils ever since the first settlers under Daniel Boone penetrated the region. The finest types of soils occur where the Lexington limestone is from 140 to 160 feet or more thick. It is composed of bluish finely crystalline limestone in thin irregular beds frequently separated by intervals of calcareous shale.[4] The soils of the Lexington limestone are loamy.

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[1] G. C. Matson, Water Resources of the Blue Grass Region of Kentucky, Water-Supply Paper U. S. Geol. Surv. No. 233, 1909, p. 30.

[2] Idem, p. 60.

[3] Idem, p. 62.

[4] M. R. Campbell, Richmond Folio U. S. Geol. Surv. No. 46, 1899, p. 2.

The upland soil of the Blue Grass region is adapted to a large variety of crops such as blue grass, corn, wheat, tobacco, and hemp. In the Ohio Valley occur small areas of loam which are well adapted to general farming, but they do not equal the upland areas either in extent or in value. The purest soils of the region are those derived from the Eden shale, which usually occupies the hilly areas. It is subject to rapid erosion because of its softness, and in many places attempts to farm this soil have been abandoned and it has been converted into pasture and timber.

It is not always the case in the Blue Grass region that each rock formation yields a distinctive type of soil. It has been found that a soil derived from a calcareous shale may be little different from one derived from a clayey limestone. The large amount of limestone dissolved to form the soils of the Blue Grass region naturally means that a certain amount of carbonate of lime is found in the soils to-day, which gives it a slight tendency toward aggregation into soil crumbs. The analyses show that the sizes of the openings between the crumbs of the Blue Grass soils are very small and that the soils have great capacity for retaining moisture. The small size of the pores also brings the ground water into contact with a large amount of soluble material and favors the solution of the various elements of plant food. Chemical analyses of the Blue Grass soils show that the plant elements are so abundant in them that it is generally unnecessary to add fertilizers. The average of 32 analyses of soils from the Lexington limestone is represented in the following table.

AVERAGE COMPOSITION OF SOILS FROM LEXINGTON LIMESTONE

	Per cent
Organic and volatile matters	6.211
Alumina, iron, and maganese oxides	11.200
Lime carbonate	.749
Magnesia	.644
Phosphoric acid (P_2O_5)	.328
Potash extracted by acids	.404
Sand and insoluble silicates	73.380

Another feature of these soils that gives them a high degree of fertility is the large quantity of phosphorus contained in them in the form of phosphate of lime derived from Ordovician limestones. They are richer than the average in those mineral elements which support plants.[1]

The low productivity of the soils developed upon the Ohio shales is

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[1] G. C. Matson, Water Resources of the Blue Grass Region, Kentucky, Water-Supply Paper U. S. Geol. Surv. No. 233, pp. 33-35.

to be attributed not to a deficiency in the elements of plant food, but to an excess of moisture. They are so clayey that they retain too large quantities of rainfall and tend to remain wet and sour.[1]

NASHVILLE BASIN (CENTRAL BASIN OF TENNESSEE)

From the steep and ragged western escarpment of the Cumberland Plateau the country extends westward as a more or less deeply dissected plateau about 1000 feet above sea level, known as the Highland Rim. This in turn terminates on the west in an escarpment which practically surrounds a lowland known as the Central Basin of Tennessee. It is about 70 miles across, extends north and south about 60 miles, and stands about 600 feet above sea level. It is drained by the Tennessee and its tributaries through a narrow gorge-like valley that cuts through the surrounding uplands. It has a gently undulating surface save on the border, where spurs from the surrounding plateau and isolated hills, which represent detached and greatly eroded spurs, occur in numbers. The deeper and richer soils of the basin, its lowland character, and its relation to the surrounding uplands that stand about 400 feet above it, give it a distinctive character. These features all rest back upon the structure and late physiographic development of the region.

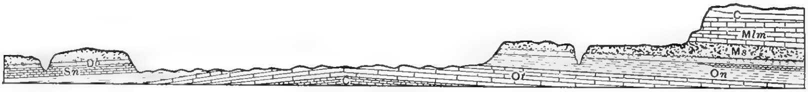

Fig. 283. — Section across the Nashville Basin of Tennessee and the country adjacent, from the Cumberland Plateau (right) to the Harpeth River. C, Cambrian; Ot, Trenton limestone; On, Nashville shale; Sn, Niagara limestone; Db, Berea shale; Ms, sandstone; Mlm, Mountain limestone; C, Coal Measures. Length of section about 120 miles. (Safford, Geol. of Tenn.)

The present lowland was originally an upland with respect to surrounding tracts. This relation was owing to its domed structure, the rocks dipping outward in all directions though at varying rates. During the erosion cycle in which the Highland Rim was formed (early Tertiary) the topographic effects of the doming were obliterated and the cap rock, a cherty limestone, reduced in thickness because of its domed attitude. The base of the formation was, however, below the plane of base-leveling, hence the formation, though thinned, was not broken through at any point.

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[1] For the soils of this region see R. Peter, Comparative Views of the Composition of the Soils, Limestones, Clays, Marls, etc., of the Several Geological Formations of Kentucky, etc., Geol. Surv. of Ky., 1883.

The early Tertiary erosion cycle was interrupted by uplift which enforced dissection. Soon the intrenched streams cut through the thin cherty limestone capping the dome, but were not able elsewhere to breach the formation because of its greater thickness. The underlying limestones are free from chert, are soft, shaly, and easily eroded, and were worn down to a lowland while the surrounding country capped by the hard cherty formation maintained its level. Though the whole Highland Rim is more or less dissected, considerable areas of dissected remnants occur which preserve the ancient level; in the lowland no trace of the ancient level remains except on the margins. After the development of the lowland there occurred two later uplifts of the land. After the first uplift the valleys were broadly opened several hundred feet below the general level. The second uplift caused the streams to cut narrow valleys within the broad ones, leaving the remnants of the broad valleys as terraces along the upper levels of the lower valleys. The descent from the lowland to any valley floor is over a terrace which marks a topographic unconformity or break between a younger and lower and an older and higher set of slopes.

In the Nashville Basin the soil characters are very intimately related to the underlying geologic formations. The conditions in the Columbia district in the southwestern part of the basin are typical. The former great red-cedar glades of middle Tennessee were here formed upon the Lebanon limestone, which has a shallow and rocky but fertile soil. The purest soil of the region is derived from a cherty shale and limestone known as the Tullahoma formation, which is flinty and nearly always occurs on steep slopes. When thoroughly leached and light in color it constitutes the "barrens" of the Highland Rim. If the formation is underlain by clay so that the calcareous matter can not be readily leached out, the soil is very good and capable of producing abundant crops. A number of good soil makers have a limited outcrop or outcrop on steep slopes where the soil is readily washed away, and are of little importance to vegetation. Among the best of natural blue-grass soils in the Nashville Basin is the Bigby limestone, which is a crystalline phosphatic limestone from 30 to 100 feet thick in the Columbia region.[1]

The surrounding uplands, or the Highland Rim, have a thinner and less fertile soil. Toward the north the upland is underlain by sandstone, and here occur the famous " barrens " of Kentucky and Tennessee, long without more than a mere sprinkling of agricultural population. The first settlers in Kentucky also regarded the untimbered limestone lands of the western part of that state as infertile, and gave them the

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[1] Hayes and Ulrich, The Columbia Folio U. S. Geol. Surv. No. 95, 1903, p. 6.

name of "barrens" from their previous experience of the relative infertility of untimbered lands. Several years passed before the true character of these "barren lands" was ascertained and their fertility recognized.[1] So, too, the sandstone barrens to the east of the lowlands have had their day of neglect, but are now cultivated to an increasing degree, and when properly fertilized yield profitable though not as a rule abundant harvests. On steep slopes they are too thin and cultivation is mechanically too difficult, and such belts along stream valleys are commonly left timbered; the interfluves are formed on gentler slopes and have a deeper though rarely a fertile soil.

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[1] N. S. Shaler, The Origin and Nature of Soils, 12th Ann. Rept. U. S. Geol. Surv., pt. 1, 1890–91, p. 325.

CHAPTER XXXIII

LOWLAND OF CENTRAL NEW YORK

THE most noteworthy topographic depression across the Appalachian tract is the lowland of central New York. It is remarkable for its continuity from Lake Erie to the Hudson, its low gradients and elevation, its thoroughgoing transection of the upland in which it occurs, besides its swarms of drumlins and its narrow, deep, picturesque lakes and bordering glens. Among its exceptional features are to be noted also its dense population, numerous and busy railways, its canals, and its long and romantic historical development. In many of these respects it is a happy contrast to the adjacent provinces. The Adirondacks on the north are more grand, but they are thinly peopled, have few railways, and limited resources. On the south the uplands of the Appalachian Plateaus are also thinly populated. In recent years they have suffered a relapse into the ways of a back country and exhibit an increasing number of abandoned farms.[1] Between these two rugged uplands extends the relatively narrow central valley with its deep, fertile soil, pleasing countrysides, and prosperous homes.

The geologic map of New York, Fig. 285, largely explains the central valley. The strata outcrop in westward-trending belts and the thickness and interrelations of the hard and soft members from place to place determine both the local topographic expression and the width of the central valley (Plate IV). The southern border of the lowland is the frayed northern border of the Appalachian Plateaus. Spurs from 10 to 20 miles long, from 2 to 5 or more miles wide, and from 100 to 500 feet high extend north on the interfluves between the deep narrow valleys whose floors are occupied by lakes. The border is maintained definitely because of a capping layer of hard sandstone. The central lowland is developed upon the Salina and Hudson River shales and other soft formations. Formerly the strata extended farther north, overlapping and wrapping about the Adirondack old-land. When first uplifted above the sea the sediments formed a simple coastal plain. In time this plain was dissected, and since the soft formations weathered more rapidly,

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[1] R. S. Tarr, Decline of Farming in Southern-Central New York, Bull. Am. Geog. Soc., vol. 41, 1909, pp. 270–278.

they were worn to a lowland, while the hard formations stood in relief. Similar features extend westward across Ontario and through northern

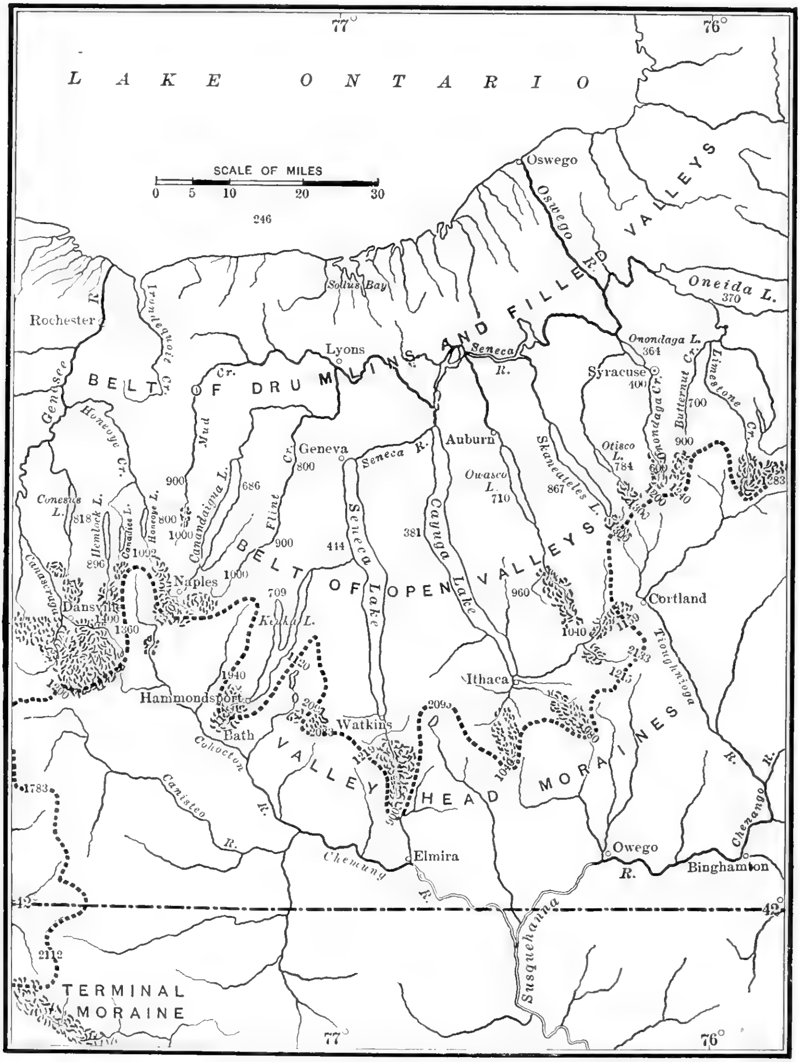

Fig. 284. — Physiographic belts in central New York. Heavy dotted line is on the divide. Figures represent elevations above sea level. (Modified from Fairchild.)

Michigan and eastern Wisconsin, as shown in Plate V. They represent an old coastal plain so eroded as to present both its structure and its relief in rudely parallel belts, hence an ancient belted coastal plain.

The upper Susquehanna still pursues a consequent course; the Mohawk is a subsequent stream, while the normal courses of most of the streams farther west have been modified by glaciation. In such a description Lake Ontario and Georgian Bay lie upon the inner lowland, Lakes Erie and Michigan upon the outer lowland of the plain. In western New York the plain is a double depression separated by the Niagara escarpment which dies out east of Rochester.

Many of the detailed topographic features of the depression of central New York, such as drumlins, lakes, glens, old abandoned channels, etc., depend chiefly upon glaciation. The ice advanced southward as far as northern Pennsylvania, overriding and somewhat modifying the divide between the Ontario and the Susquehanna-Allegheny drainage.

Not everywhere in southern New York and northern Pennsylvania were moraines accumulated at the margin of the ice. In few localities does one find moraines developed on the uplands between valleys, though they are well developed in the valleys themselves.[1] As shown in Fig. 284 the valley heads draining north everywhere have well-defined morainic accumulations which were formed in front of local ice tongues that extended along each valley after the margin of the great continental ice sheet had been melted from the inter-valley tracts. In addition there are three major features, more or less directly due to glaciation, whose character and mode of formation deserve attention. These are (1) the Finger Lakes, (2) the glacial-marginal drainage channels, and (3) the drumlins of the central lowland.

FINGER LAKES

The basins of the Finger Lakes were first generally explained as the result of ice erosion, a kind of glacial overdeepening, but with the action confined to a single glacial period. Later and more detailed studies have shown that the forces which produced these basins are complex in their nature and relations. Glacial erosion is indeed the most important element of the explanation, as the steepened sides of the basins, the hanging tributary valleys, and the presence of lateral and terminal moraines at the valley heads testify. The last-named feature is clearly shown in Fig. 284, and proves that the valleys were highways of more active glacial motion.

The most important facts pointing to complexity of origin relate to the hanging valleys tributary to the Finger Lakes. On the steepened slopes of the main valley sides a series of buried gorges has been found.

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[1] Williams, Tarr, and Kindle, Watkins Glen-Catatonk Folio U. S. Geol. Surv. No. 169, field ed., 1909, p. 124.

The gorges are occupied by drift deposits of the last (Wisconsin) ice invasion, which indicates that they were formed before that invasion.[1]

From the known facts it is concluded that before the glacial period there was a system of mature drainage with main valleys along the axes of Cayuga and Seneca lakes and with tributaries entering them at grade. With the overspreading of the region by glacial ice there was begun a process of exceptional deepening in the main valleys because they served as lines of most rapid glacial flow. At the end of the first ice invasion the valleys had been broadened and deepened, the amount of the deepening being about 500 feet. Lakes may have formed in these overdeepened valleys after the ice had been melted away. At any rate the discordance of level between tributary and master valleys was pronounced and the tributaries began to cut down their valleys to the level of the main valleys, making gorges of notable breadth and depth before the second glacial invasion filled them with drift, reëxcavated and deepened the main valleys, increased the discordance between tributaries and master streams, and so altered the topography in detail that the postglacial streams do not flow everywhere in the interglacial courses. Wherever a postglacial stream enters one of these buried gorges with its easily eroded drift in contrast to the hard rocks of the rest of the valley

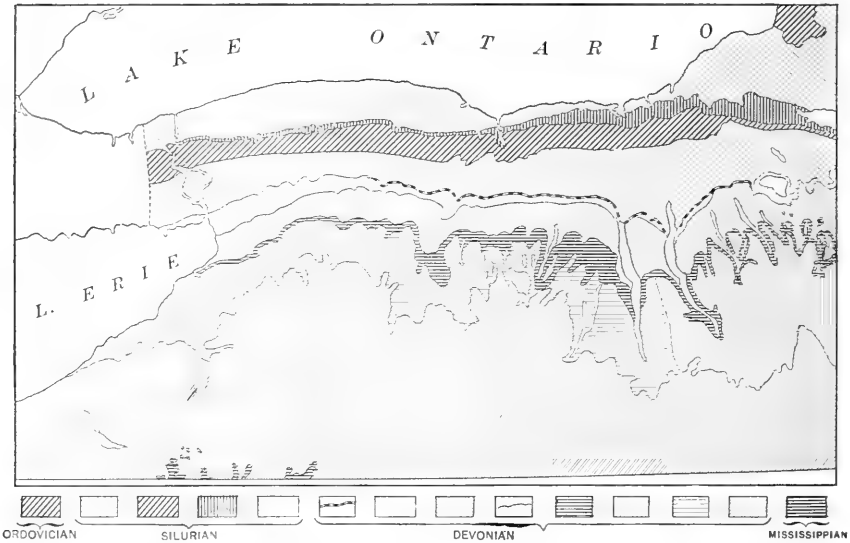

Fig. 285. — Map of portion of New York. 1, Ordovician; 2–5, Silurian; 6–13, Devonian; 14, Mississipian.

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[1] R. S. Tarr, Watkins Glen and Other Gorges of the Finger Lake Region of Central New York, Pop. Sci. Mo., vol. 48, 1906, pp. 387–397.

there the valley broadens suddenly; where the stream leaves the buried valley the valley contracts. It is these features, together with the irregular as well as regular jointing of the bedded rock — shales and sandstones — that give to the gorges so much of their surprising variation from place to place and to the beautiful waterfalls and cascades of the many glens their wild, picturesque quality.

The lower portions of the valleys of the tributaries to each of the Finger Lake basins are for the most part more or less completely drift-filled gorges, so that the rock floor is in many cases far below the drift floor of the valley, a condition brought about not by overdeepening of the main trough but by the clogging of the tributary valley with drift. There are, however, perfect examples of hanging valleys with rock floors in the Cayuga and Seneca troughs and in the Tioughnioga and Cayuta valleys.[1]

The abrupt descents of the valley slopes in the Finger Lake region is illustrated by the change at the 900-foot contour just west of Watkins in the Cayuga trough. The slope from the 900-foot contour to the valley bottom, which has an elevation of 477 feet, takes place in a distance of a little over a half mile, while west of the 900-foot contour the valley side rises only 700 feet in a distance of 5 miles.[2]

Abandoned Channels

Among forms indirectly due to glacial action an important part is taken by the features relating to marginal drainage of the ice, such as have been described for the Great Lake region and will now be noted for the central New York region. In central New York the northward slope of the margin of the Appalachian Plateaus furnished unusual conditions for the impounding of glacial waters in front of the retreating ice cap, when that front had receded northward so as to lie beyond the divide between the Lake Ontario and the Susquehanna drainage.

The earliest accumulations of ice dammed the waters at the heads of the great valleys on the south. Upon the gradual retreat of the ice lower outlets were offered past the ice margin and across the ridges or plateau spurs between the lakes, so that high valley lakes drained into lower valley lakes; as the ice front receded still farther the lakes were successively lowered and shifted northward and rivers formed in the inter-valley or spur tracts. In central New York all the glacial waters escaped westward to the glacial lake in the Erie basin and ultimately to the Mississippi River, from a point west of Batavia; and the same is

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[1] R. S. Tarr, Watkins Glen and Other Gorges of the Finger Lake Region of Central New York, Pop. Sci. Mo., vol. 48, 1906, p. 233.

[2] R. S. Tarr, Drainage Features of Central New York, Bull. Geol. Soc. Am., vol. 16, 1905, pp. 220–242.

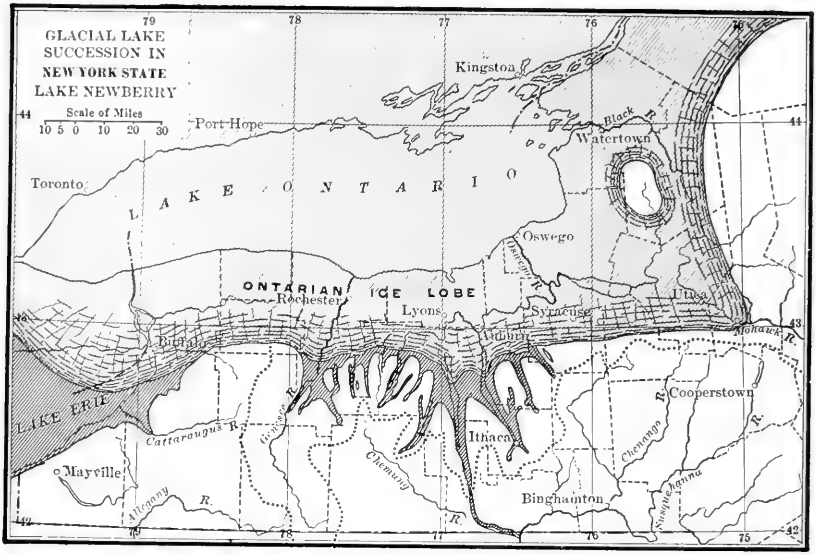

Fig. 286. — Note overflow southward into the Susquehanna. Elevation over 1000 feet.

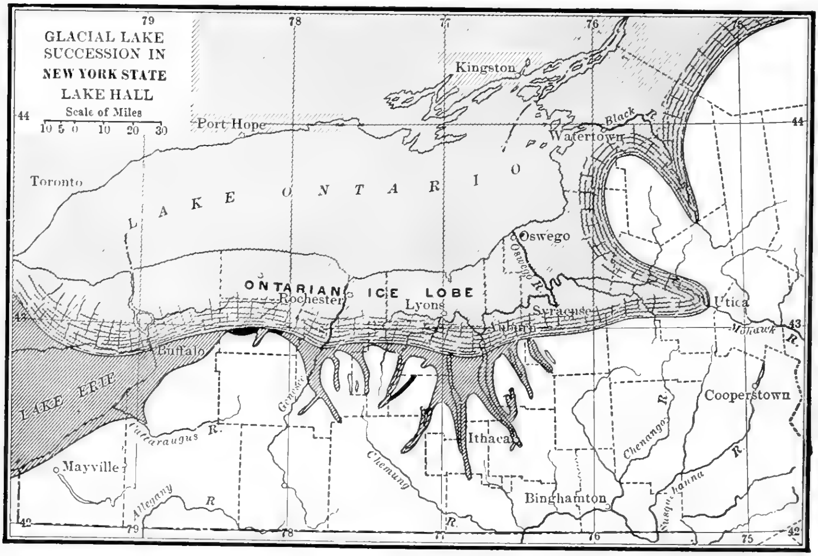

Fig. 287. — Overflow at this stage was westward to the Mississippi instead of southward to the Susquehanna. Elevations from 1000 feet on east to 900 feet on west.

true of all the waters held in the Genesee region under about 1200 feet, as well as in several other lake regions. But all the drainage under 900 feet at a later period was eastward past Syracuse to the Mohawk Valley. In the general region of the Finger Lakes between Batavia and Syracuse at least 13 separate valleys sloped to the north and these lie from Oatka Valley on the west to the Onondaga at the east, and include such important valleys as the Genesee, Canandaigua, and Cayuga. The higher and more local glacial waters in these valleys escaped southward, but at later stages the water of the broad area collected here mainly into two large lakes, one of which occupied the large low central valleys of Seneca, Cayuga, and Keuka, with an outlet to the Susquehanna, and another in the Genesee Valley region which escaped by a different route to the Susquehanna, Allegheny, and Mississippi. In a later stage of development and before the beginning of the extensive spur channeling so prominent in central New York, these two bodies of water were united into one extensive lake overflowing westward into the Mississippi drainage above 900 feet and eastward to the Hudson below that level.

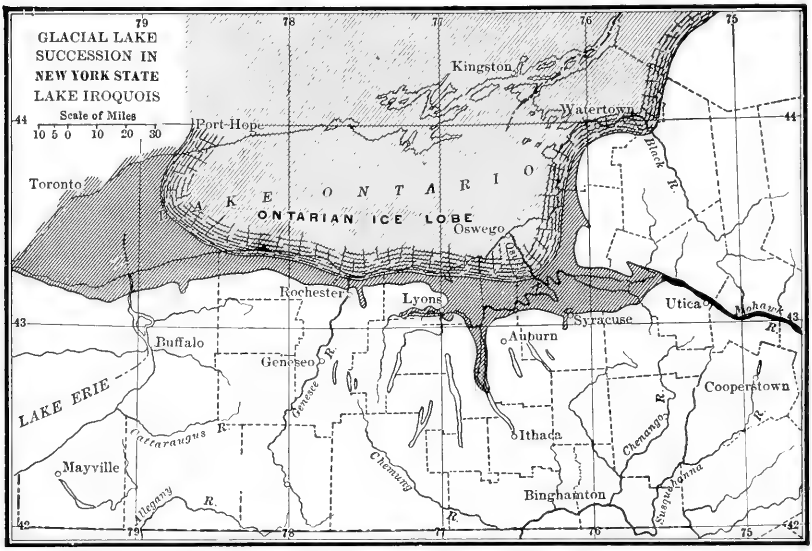

Fig. 288. — Overflow eastward to the Mohawk. Elevation under 360 feet. A number of intermediate stages are omitted from this series. The three stages shown here are of chief importance. (After Fairchild, Bull. N. Y. State Mus.)

A study of the channels which drained the valleys of the separate lake waters through a single outlet shows that they lie in series falling

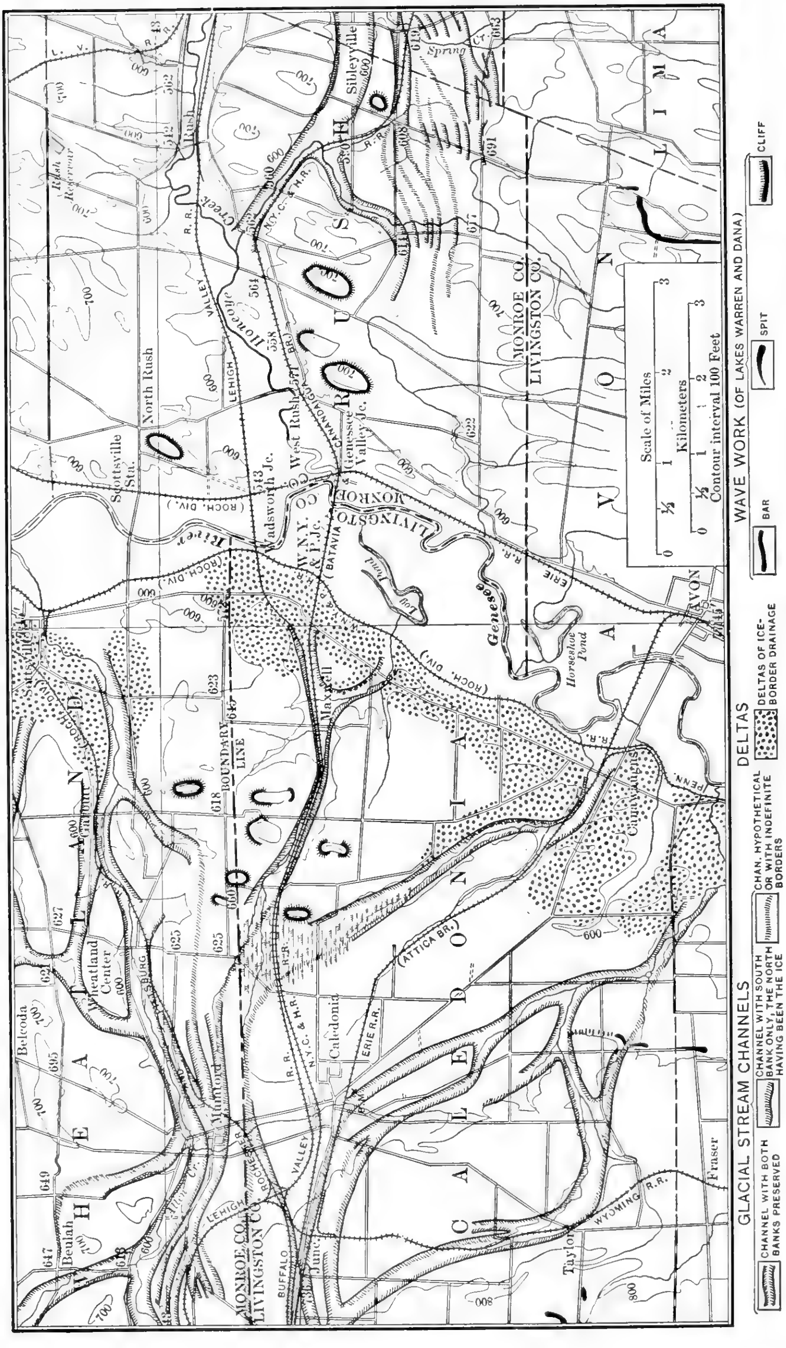

Fig. 289. — Channels and deltas of a part of the ice-border drainage between Leroy and Fishers, New York. (After Fairchild, N. Y. State Mus.)

northward on the theory of a receding barrier, though not as controlled by a steady continuous single recession of the ice front but by an oscillation of the ice front and a certain amount of seesawing between Batavia and Syracuse.[1]

Typical features of the channel series may be seen at Spread Rock and Jamesville and on the meridians of Mumford and Rush, etc. They were carved directly in front of the ice, and in such a position that the streams that occupied them must in many cases have laved the ice front, in which case only the southern banks are now in existence, since the northern banks were formed by the glacier ice. In some instances, as in the case of the Fairport-Lyons channel, the channel that was initiated on the ice front remained effective long after the ice had retreated from the region.

Fig. 290. — Gulf channel, looking southeast (downstream) near mouth of channel. Four miles north of Skaneateles, New York. The depth of the gorge is 100 to 150 feet, the width from an eighth to a quarter of a mile. The walls are of shale. The gorge ends in a huge fan delta. (Gilbert.)

The most compact and remarkable set of cross-ridge channels is north of the parallel of Jamesville; the lowest is the finest glacial lake outlet

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[1] H. L. Fairchild, Glacial Waters in Central New York, Bull. New York State Mus. No. 127, pp. 7–10.

channel in the state. It is 2½ miles long, 800 to 1000 feet wide at the bottom, and 125 to 155 feet deep in rock. The channel sides are composed of nearly vertical limestone. The highest channel of the Jamesville group is associated with a cataract, a semicircular amphitheater about 100 feet in diameter, with steep limestone walls 160 feet high; Jamesville Lake, 60 feet deep and 400 to 500 feet across, occupies the plunge basin at the foot of the cataract. Below the cataract is a gorge cut in limestone, and above it the limestone is worn and terraced in a manner characteristic of rapids.

NIAGARA FALLS

Niagara Falls came into existence during the retreatal stages of the continental ice cap of the Wisconsin epoch. For a time the glacial marginal waters were confluent over both the Erie and Ontario basins and extended northward as far as the ice barrier, but with the lowering of the water level the escarpment of Lockport limestone gradually emerged. This escarpment held up the Erie waters to its upper level, while the level of the Ontario water was controlled by the relations of the ice and the topography at the northern escarpment in lower country. Thus the waters of Lake Erie came to cascade over the cliff of Niagara limestone and drop into the water of the Ontario basin. As the Ontario waters receded the river cascaded over the scarp and formed a gorge which by upstream retreat had gradually been brought into its present position and character. The first spilling of the Erie waters over the escarpment took place at at least two points of overflow, one at Lockport and one at Lewiston; but by the more rapid development of the Lewiston channel the Lockport channel was abandoned.[1]

Drumlin Types and Belts

Among topographic forms due to glaciation drumlins are scarcely less important in areal extent and importance to soils than terminal moraines. They deserve a word of detailed description not only for this reason but also because of the remarkable development of drumlins in certain areas in New York, Wisconsin, etc., where their slopes constitute the most important elements of the relief. That the forms of drumlins are of glacial origin is evident from the location of drumlins only within glaciated areas; that their material is of glacial origin is shown also by their composition, which is for the most part compact till or ground moraine, and their position in the zone in which the transporting power of the ice was incompetent to carry along all the material

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[1] H. L. Fairchild, Glacial Waters in Central New York, Bull. New York State Mus. No. 127 p. 30.

within it. In form they vary from mounds to long slender ridges, their most general form being a smooth oval; in size they vary from massive conspicuous hills from 100 to 200 feet high to indefinite swells of drift surface. A less common type of drumlin than the one described above has been known as the drumloid or, as has been lately proposed, roc drumlin.[1] The term is employed to designate ice-made rock masses whose form is so closely allied to that of the drumlin as to deserve correlation with it.

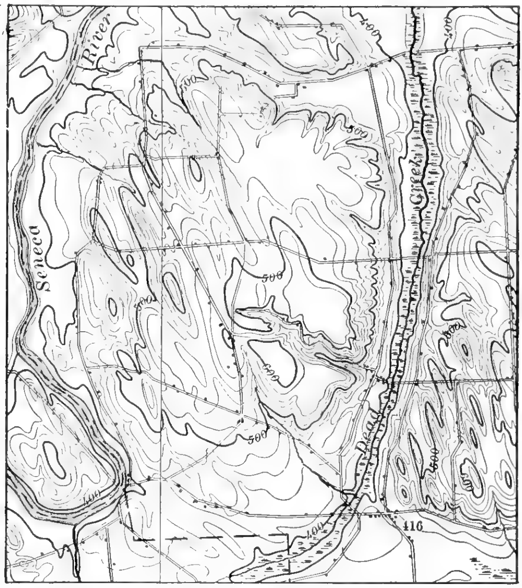

Fig. 291. — Roc drumlins or drumloids. The drumlin-shaped forms in the upper part of map are developed on shale (Salina). (Baldwinsville quadrangle, U. S. Geol. Surv.)

They are distinct from the more common type of drumlin in that they are due to erosion, while the ordinary drumlin is a product of upbuilding and of shaping. Roc drumlins occur in much smaller numbers than ordinary drumlins, but are sometimes found in the same general field, as in central New York and northern Wisconsin and Michigan. The last-named occurrence has been described by Russell.[2]

Three general regions of great drumlin development have been identified in the United States: (*a*) the New England area, including southern New Hampshire, where about 700 drumlins have been mapped, Massachusetts with about 1800, and Connecticut with an unnumbered amount; (*b*) the Michigan area, which includes eastern Wisconsin and adjacent

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[1] H. L. Fairchild, Drumlins of Central-Western New York, Bull. New York State Mus. No. 111, 1907, p. 393.

[2] I. C. Russell, Rept. Mich. State Geologist, 1906.

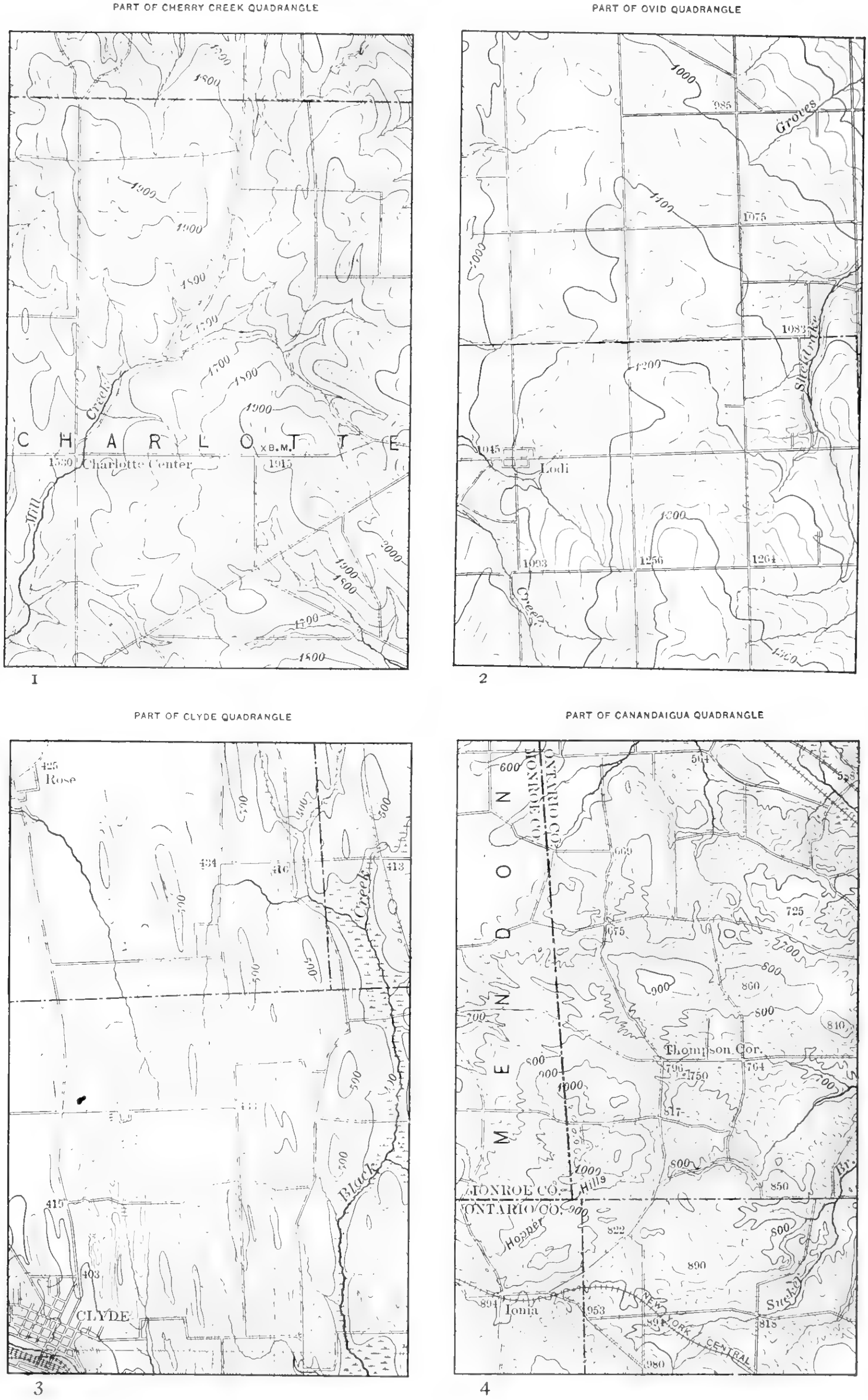

Fig. 292. — Topographic types, central New York. 1, rock forms, non-glacial; 2, till-covered slopes, expressionless; 3, drumlins; 4, moraine. (Fairchild.)

portions of Michigan, where the estimated number is 5000; and (*c*) the drumlin area of central New York. The last-named is a belt about 35 miles wide bordering the southern side of Lake Ontario and about 140 miles long, from the Niagara River to Syracuse; this area probably includes not less than 10,000 drumlin crests; 15 drumlins to the square mile is common, though the average is about 3 to the square mile.

On the south the drumlin area of central New York reaches up the north-facing slope of the Allegheny plateau, where it fades off into smooth drift or is lost in the bolder relief of the rock hills. The most abrupt ending of the drumlin topography is along the crests of ancient drainage levels, as between Victory and Geneva, New York. The most massive development is on the low ground north of Finger Lakes and south of Lake Ontario, chiefly under 500 feet altitude. The greatest development lies over the greatest thickness of the soft Salina shales, where the drift is most clayey and adhesive. Those on the southern border of the drumlin belt are attenuated, while those toward the north and under the deeper ice are broad. The greatest steepness and greatest regularity of form seem to occur in the middle of the drumlin belt.

The drumlins have been but little modified in postglacial time by ordinary stream erosion, but in the zone of wave erosion on the southern shore of Lake Ontario, as at Sodus Bay, the drumlins have been extensively cut or entirely removed, and similar shore cutting was accomplished, though on a smaller scale, during the existence of temporary glacial-marginal lakes that occurred at a higher level than Lake Ontario during the later stages of the glacial period. The general relations of the drumlin area of central New York to the surrounding topographic features are shown in Fig. 292. The various categories of form are indicated in the following table:

"1. Domes or mammillary hills and low broad mounds.
2. Broad oval drumlins.
3. Oval drumlins of high relief.
4. Long oval drumlins, commonly bolder on the north or struck end; the dolphinback or whaleback hills.
5. Short ridge drumlins.
6. Long ridge drumlins. This includes two extreme varieties of form: (*a*) the long broad ridges or rolls or gentle swells which are not generally recognized as belonging in the drumlin class, and commonly fail of representation on the contoured maps; (*b*) the small, close-set, parallel ridges which lie as minor moldings between the larger and conspicuous ridge drumlins, or those which form the attenuated edge of a drumlin belt.
7. Abrupt struck slopes.
8. Low or gentle struck slopes.
9. Sharp-crested hills with steep, or even concave, side slopes. Many occasional or peculiar forms and characters might be noted, but they are not regarded as genetically important."[1]

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[1] H. L. Fairchild, Drumlins of Central-Western New York, Bull. New York State Mus. No. 111, 1907, pp. 422–423.

In regard to the relation of drumlins to moraines it may be said that the moraines are weak where the drift was left in drumlin form and strong where the drift was not drumlinized.[1] The drumlins are believed to be shaped by the sliding movement of the lowest ice, a movement that was produced by thrust on the marginal ice, caused by the pressure rearward applied in such a manner that the margin of the ice was pushed bodily forward. It is believed that this condition of ice movement is fundamental to drumlin formation.[2] In this manner the drumlins were constructed by a plastering-on process on the obstructions, a process favored by the plastic and adhesive drift. As masses of drift the drumlins were produced by the accretion of drift, but their peculiar form is due to erosion. The whole process has been aptly compared to clay modeling, a process of plastering on and rubbing away.[3]

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[1] H. L. Fairchild, Drumlins of Central-Western New York, Bull. New York State Mus. No. 111, 1907, p. 425 et al.

[2] Idem, p. 430.

[3] Idem, p. 432.

APPENDIX A

SOIL CLASS; SOIL TYPE; SOIL SERIES[1]

SOIL CLASS

Because soils are made up of particles of different sizes, they may be grouped according to texture, that is, according to the relative proportions of the particles of different sizes which they contain. This grouping is known as the "soil class." By means of mechanical analyses the particles less than 2 millimeters in diameter are separated into 7 grades and the various percentage relationships of the different grades determine the class of soil — sand, sandy loam, loam, clay, etc., as in the table below. In addition to the fine earth, of which a mechanical analysis is made, many soils contain larger particles, which if of small size are called "gravel," and if of larger size are called "stones," so that in the soil classification it is possible to have a gravelly sand, loam, or clay, and likewise stony members of the various classes.

In outlining soil boundaries, it is necessary to (1) make preliminary borings in sufficient number to show the location of a considerable body of soil material of uniform character, (2) record the general description of one or more borings, (3) select a color to represent this description and color in so much of the map as undoubtedly corresponds with the description, (4) work away from this identified area until soil materials are found which manifestly do not fit the former description, (5) select a second color for this new set of soil characteristics and color in on the map only where the new material undoubtedly occurs, (6) work in between the areas of the two classes thus established until a zone or line is found where all material on one side becomes increasingly characteristic of the one class and on the other side of the other class, (7) draw a line on the map to represent this line or to represent the center of the zone of gradation of soil characteristics. This line will constitute a soil boundary. Usually the distinctions between adjacent soil classes are sharp and clear in a moderately broken country and grade into each other in a flat country, although there are many exceptions to this rule. In a glaciated region the mixing action of the ice may thoroughly confuse the rock waste, so that the most minute examination is required for the separation of many soil classes distributed almost at haphazard. Sometimes this is true to such an extent that a new designation is required, such as the geologic term "till," although this should be avoided if possible. Drainage differences and attendant differences in the content of organic matter, depth of soil, etc., may constitute a basis of distinction. Postglacial wash is sometimes responsible for considerable differentiation of material, which may be made the basis of distinctions between soil classes. When minor differences of texture, structure, organic-matter content, or succession of materials occur in the soil sections representing single areas of 10 acres or more, such variations may be described in the report as phases.

The soils of different classes grade into each other and therefore the line of separation between the different classes is necessarily an arbitrary one. The particles also may be very irregularly distributed between the different grades, so that it is not possible to make a rigid classification according to the mechanical analyses. The following table is the result of an examination of thousands of soil samples from all over the United States by the U. S. Bureau of Soils and may be accepted as a standard for the classification and description of the soils of a given area, large or small. Uniformity and close adherence to the standard are the chief considerations which it is desired to secure. The table therefore constitutes a codification and

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[1] Based on the Soil Survey Field Book, 1906.

arrangement of facts reported up to this time to the Soil Survey. It has been found convenient to number the different grades into which the soil is separated by mechanical analysis. The name of the grade to which these numbers refer is given in the table. Care should be taken in interpreting the table not to confuse these grades for either the soil class or the soil type.

SCHEME OF SOIL CLASSIFICATION BASED UPON THE MECHANICAL COMPOSITION OF SOILS.

Class.	**1.** Fine gravel. 2–1 *mm.*	**2.** Coarse sand. 1–.5 *mm.*	**3.** Medium sand. .5–.25 *mm.*	**4.** Fine sand. .25–.1 *mm.*	**5.** Very fine sand. .1–.05 *mm.*	**6.** Silt. .05–.005 *mm.*	**7.** Clay. .005–0 *mm.*
Coarse sand.	More than 25 per cent of 1 + 2.					0–15	0–10
	More than 50 per cent of 1 + 2 + 3.					Less than 20 per cent of 6 + 7.	
Medium sand.	Less than 25 per cent of 1 + 2.					0–15	0–10
	More than 20 per cent of 1 + 2 + 3.					Less than 20 per cent of 6 + 7.	
Fine sand.	Less than 20 per cent of 1 + 2 + 3.					0–15	0–10
						Less than 20 per cent of 6 + 7.	
Sandy loam.	More than 20 per cent of 1 + 2 + 3.					10–35	5–15
						More than 20 per cent and less than 50 per cent of 6 + 7.	
Fine sandy loam.	Less than 20 per cent of 1 + 2 + 3.					10–35	5–15
						More than 20 per cent and less than 50 per cent of 6 + 7.	
Loam.							15–25
						Less than 55 per cent of 6.	
						More than 50 per cent of 6 + 7.	
Silt loam.						More than 55 per cent of 6.	Less than 25 per cent of 7.
Clay loam.						25–55	25–35
						More than 60 per cent of 6 + 7.	
Sandy clay.						Less than 25 per cent of 6.	More than 20 per cent of 7.
						Less than 60 per cent of 6 + 7.	
Silt clay.						More than 55 per cent of 6.	25–35 per cent of 7.
Clay.							More than 35 per cent of 7.
						More than 60 per cent of 6 + 7.	

SOIL TYPE

In mapping a small area the soil class is the matter of chief and possibly even of ultimate interest. The determination of the class tells about all the facts of texture that a forester requires. When, on the other hand, large areas are under consideration it may be necessary to distinguish soil types. A soil type is conceived to embrace all soil material in any region which is marked to corresponding depths by identity or close similarity in texture, structure, organic-matter content, and color, and by similarity of origin and of topography. A type comprises all soil material which may properly be included in one general description covering these points. In the humid regions description covers the material to an average depth of 3 feet; in the arid regions to a depth of 6 feet. In the determination of a type of soil there are many factors to be considered in addition to texture, such as the structure, which deals with the arrangement of the particles and their chemical composition, the organic-matter content, origin, color, depth, drainage, topography, native vegetation, and natural productiveness. The value of the type idea lies in the possibility of distinguishing between two soils of, let us say, practically identical texture, whose chemical composition, depth, humus content and drainage conditions, etc., are markedly unlike. Both may be, for example, sandy loams, but the one may possess other characteristics than textural which make it infertile, while the other may possess a high degree of fertility.

SOIL SERIES

In working in a very large territory such as the whole United States it has even been necessary to recognize still larger groups or soil series. It has been found that in many regions the members of a given set of soil types are so evidently related through source of material, method of formation, topographic position, and coloration, that the different types constitute merely a gradation in the texture of an otherwise uniform material. Different types that are thus related constitute a series. A complete soil series consists of material similar in many other characteristics but grading in texture from stones and gravel on the one hand through sands and loams to a heavy clay on the other.

In arranging the soils in series the same factors should be considered that are used in separating soils of the same class into different types. For example, the Marshall silt loam and the Miami silt loam have been separated because of the difference in the amount and condition of the organic matter in the surface soil and the essential differences in coloration. The former is dark brown to black, while the latter is light brown to almost white. This relation has been found to exist between soils of other classes in the glacial regions, and has been used as a basis for separating the glacial soils into the Marshall and Miami series.

On account of the very different processes of their formation, residual and recent alluvial soils should not be included in the same series. Soils may, however, be very similar in origin and texture but occupy such entirely different topographic positions that their relation to crops is entirely changed, and this fact should be recognized by the use of another serial name. An example of this is found in the separation of the soils of the Piedmont Plateau and the Appalachian Mountains into the Cecil and Porters series.

The color of the soil is one of its most noticeable physical features, and is often a factor in separating the soils into different series. The soils of the Orangeburg series, for example, have been formed in a manner very similar to the Norfolk series, but are distinguished from the latter by the red color of the subsoil and by associated differences in agricultural value. Soil series may grade into each other in a manner similar to the intergradation of the types within the series. Thus the Marshall series may grade into the Miami series and the Norfolk series into the Orangeburg or Portsmouth series.

UNCLASSIFIED MATERIALS; SPECIAL DESIGNATIONS

There are certain conditions of soil, or in many areas even local absences of true soil, which do not readily fall into any general classification. They may be due to excessive erosion, to overflow, to insufficient drainage, or to wind action, or the soils may be infertile on account of their texture or their present topographic position. Areas of this kind are as follows:

ROCK OUTCROP

Areas consisting of exposed rock or fresh accumulations of stone, entirely unfit for cultivation. The most extensive areas of this type of surface are found in the strongly glaciated portions of northeastern Canada. The type is also common in mountain regions undergoing vigorous dissection and in wind-swept arid regions, etc.

ROUGH STONY LAND

Areas so stony and broken as to be nonarable, although permitting timber growth and pasturage. They frequently consist of steep mountain ridges, bluffs, or narrow strips extendng through definite soil types. These areas differ from rock outcrop by supporting vegetation of economic value, and from the stony loams in being nonarable.

GYPSUM

The surface consists of a light-brown or reddish-brown sandy loam or loam underlain by soft saccharoidal gypsum at a depth of from a few inches to 6 feet. Gypsum is often present at the surface. The type occupies level bench land. It is derived from disintegration of gypsum deposits and possesses remarkable power of transmitting seepage waters by capillarity and gravitational flow. Where the irrigation water possesses a high salt content this is not a desirable land for agricultural purposes. It often contains large quantities of alkali.

PEAT

Vegetable matter consisting of roots and fibers, moss, etc., in various stages of decomposition, occurring as turf or bog, usually in low situations, always more or less saturated with water, and representing an advanced stage of swamp with drainage partially established.

MUCK

This type consists of black, more or less thoroughly decomposed, vegetable mold from 1 to 3 feet or more in depth and occupying low, damp situations, with little or no natural drainage. Muck may be considered an advanced stage of peat brought about by the more complete decomposition of the vegetable fiber and the addition of mineral matter through deposition from water or from æolian sources, resulting in a finer texture and a closer structure. When drained, muck is very productive and is adapted to a large variety of agricultural crops. Extensive areas of it occur in the glaciated Middle West, where it grades into peat or swamp on the one hand and into conventional soil classes on the other.

MADELAND

Areas are occasionally encountered where filling has taken place over considerable tracts. The arrangement of the materials and even the materials themselves may be artificial and not in harmony with any soil classification. In many instances such areas are extensive and should be represented by a color on the map.

DUNESAND

Dunesand consists of loose, incoherent sand forming hillocks, rounded hills, or ridges of various heights. Dunes are found along the shores of lakes, rivers, or oceans, and in desert areas. They are usually of little value in their natural condition on account of their irregular surface, the loose, open nature of the material, and its low water-holding capacity. Dunes are frequently unstable and drift from place to place. The control of these sands by the use of windbreaks and binding grasses is frequently necessary, as at Cape Cod and on the coast of California, for the protection of adjoining agricultural lands. In certain regions they have been improved for agricultural purposes or employed as catchment areas in city water supplies or planted to pine forest for the protection of agricultural land and for revenue.

SANDHILL

This term is used to describe ridges and uneven areas of sand not in motion, either on account of partial consolidation or because the sands are fixed by a natural growth of grasses such as the Sand Hills tract of western Nebraska. Such areas sometimes occur in the vicinity of old shore lines of lakes and seas; again they may be related to river action, as where flood plains are alternately flooded and drained and river sands exposed to the winds.

RIVERWASH

Sand, gravel, and bowlders, generally in long narrow bodies, but occasionally spread out in fan-shaped areas. These areas occupy river bottoms or flood channels, and occur where the streams are intermittent or liable to torrential overflow. They are of such recent origin as not to be covered by vegetation and are subject to modification during the next season of high water. The flood plains of the Missouri and the Platte supply examples.

MEADOW

Low-lying, flat, usually poorly drained land, such as may occur in any soil type. Frequently used for grass, pasturage, or forestry, and can be changed to arable land if cleared and drained. The present character of meadowland is due to lack of drainage, and the term represents a condition rather than a classification according to texture. The soils vary frequently in texture, even within small areas and on account of occasional overflow the character of the soil at any one point is subject to change. Wherever it is possible to separate such areas into distinct soil types the term *meadow* should not be used.

MARSH

This term is used to designate low, wet, treeless areas, usually covered by standing water and supporting a growth of coarse grasses and rushes. Marsh areas occur around the borders of fresh-water lakes and the lower courses of streams. They can seldom be drained without diking and pumping. When this is done the soil is usually productive.

SWAMP

Areas too wet for any crop and covered with standing water for much or all of the time. Variations in texture and in organic-matter content may occur. Swamp frequently occupies areas which are inaccessible, so that detailed mapping is impossible. The native vegetal growth consists of water-loving grasses, shrubs, and trees. Many areas of swamp are capable of drainage, and when this is properly accomplished they not infrequently constitute lands of high agricultural value. Drainage may be employed also to improve the soil by aerating the organic matter and permitting humification, or it may make possible the introduction of new forest types. The salt-water swamps of the Coastal Plain, the swamps of the glaciated region of northern United States and Canada, and the river swamps are the three chief occurrences. Wherever small areas of swamp occur within a definite soil type and the texture of the soil is known to be the same as that of the surrounding type, they should be mapped with the type and the swampy condition shown by symbol.

APPENDIX B

The various factors of importance in a study of soils are summarized in the accompanying outline. It is intended to present only a suggestive outline. A categorical adherence to this outline is very undesirable, since a condition or a brief list of conditions may be of such predominating influence in determining the value of a soil as quite to obscure other conditions. Not all the suggestions are applicable to a given small area; as many as possible should be identified and others not in the table should be found. The relative value of the soil qualities should be strongly brought out in every soil survey and greatest attention given to those of most prominence. Under special conditions this principle may properly be carried so far as to ignore even the standard mechanical classification of soils.

OUTLINE FOR A SOIL SURVEY IN FOREST PHYSIOGRAPHY

Location and Boundaries of Area —

Present condition as to settlement.

Chief towns.

Transportation facilities.

Markets, etc.

Topography and Drainage —

Geologic structure and rock types.

Topographic forms and stage of physiographic development.

Brief description of the regional surface drainage in relation to form and structure; stream gradients and sizes, characteristics of valley sides and floors in relation to run-off, seepage, floods, etc.

Climate —

Direction and strength of winds.

Relation to plant distribution.

Rainfall: amount, frequency, and distribution in the year.

Disposal as controlled by geologic and physiographic conditions; the regional run-off, absorption, evaporation.

Daily and yearly temperature variations, extremes and means; relief controls of temperature and rainfall; proximity to the sea, latitude, etc. The growing season, temperatures necessary for germination and growth, degree to which climatic conditions meet the needs of forest types.

Soils —

(1) A general study of the soils of the area, showing their broad relation to the geologic formations and to each other, to drainage, erosion, and other agencies, their classification and distribution. (2) A detailed and full description of the classes of soil and subsoil, noting texture, structure, color, depth, and ease of cultivation; follow this with a statement as to the location of various soils in the area, topographic and drainage features, origin and process of formation, peculiar mineral or chemical features—as alkali, its chemical composition and vertical distribution, and approximate area; native vegetation, its value in determining soil classes and its responses to them, etc. Unclassified materials that require special designation: rock outcrop, talus, marsh, dunesand, etc.

- Underground water conditions.
    - Depth of water table.
    - Fluctuations of level.
    - Occurrence of springs and seepage lines.
    - Forms and effects of subirrigation.
    - Character of ground water and reclamation possibilities.
- Soil temperature as related to:
    - Air temperature.
    - Slope exposure.
    - Underground water conditions.

Soil fertility; cultural methods and conditions that have effected or will effect improvements.

The soil humus, forest litter, drainage effects upon, maintenance by shading, by protection from the wind.

APPENDIX C

ANALYSES OF FIVE COMMON ROCK TYPES IN THEIR FRESH AND IN THEIR DECOMPOSED CONDITION

(From Merrill's *Rocks, Rock-weathering, and Soils.*)

Constituents	I[1]	II	III
Ignition	1.22%	3.27%	4.70%
Silica (SiO_2)	69.33	66.82	65.69
Titanium (TiO_2)	not det.	not det.	0.31
Alumina (Al_2O_3)	14.33	15.62	15.23
Iron protoxide (FeO)	3.60	1.69	......
Iron sesquioxide (Fe_2O_3)	......	1.88	4.39
Lime (CaO)	3.21	3.13	2.63
Magnesia (MgO)	2.44	2.76	2.64
Soda (Na_2O)	2.70	2.58	2.12
Potash (K_2O)	2.67	2.04	2.00
Phosphoric acid (P_2O_5)	0.10	not det.	0.06
	99.60%	99.79%	99.77%

[1] (I) fresh gray granite, (II) brown but still moderately firm and intact rock, and (III) the residual sand.

ANALYSES OF FRESH AND OF DECOMPOSED GNEISS, ALBEMARLE COUNTY, VIRGINIA

Constituents	Fresh Gneiss	Decomposed Gneiss	Calculated Amounts Saved and Lost		
	I	II	III	IV	V
	Bulk Analysis	Bulk Analysis	Loss	Percentage of Each Constituent Saved	Percentage of Each Constituent Lost
Silica (SiO_2) $\left\{\begin{array}{l}\text{in HCl}\\ \text{in Na}_2\text{CO}_3\end{array}\right\}$	60.69%	45.31%	31.90%	47.55%	52.45%
Alumina (Al_2O_3)	16.89	26.55	0.00	100.00	0.00
Iron sesquioxide (Fe_2O_3)	9.06	12.18	1.30	85.65	14.35
Lime (CaO)	4.44	Trace	4.44	0.00	100.00
Magnesia (MgO)	1.06	0.40	0.80	25.30	74.70
Potash (K_2O)	4.25	1.10	3.55	16.48	83.52
Soda (Na_2O)	2.82	0.22	2.68	4.97	95.03
Phosphoric acid (P_2O_5)	0.25	0.47	0.00[1]	100.00	0.00[1]
Ignition	0.62	13.75	0.00[1]	100.00	0.00[1]
	100.08%	99.98%	44.67%	......	......

[1] Gain.

ANALYSES OF FRESH AND OF DECOMPOSED DIORITE FROM ALBEMARLE COUNTY, VIRGINIA

Constituents	Fresh	Decomposed	Calculated Loss for Entire Rock	Percentage of Each Constituent Saved	Percentage of Each Constituent Lost
Silica (SiO_2)	46.75%	42.44%	17.43% loss	62.69%	37.31%
Alumina (Al_2O_3)	17.61	25.51	0.00 "	100.00	0.00
Iron sesquioxide (Fe_2O_3)[1]	16.79	19.20	3.53 "	78.97	21.03
Lime (CaO)	9.46	0.37	9.20 "	2.70	97.30
Magnesia (MgO)	5.12	0.21	4.97 "	2.83	97.17
Potash (K_2O)	0.55	0.49	0.21 "	61.25	38.75
Soda (Na_2O)	2.56	0.56	2.17 "	15.13	84.87
Phosphoric acid (P_2O_5)	0.25	0.29	0.00	80.11	19.87
Ignition	0.92	10.92	0.00	100.00	0.00
	100.01%	99.99%	37.51% loss	......	......

ANALYSES OF FRESH AND OF DECOMPOSED ARGILLITE, HARFORD COUNTY, MARYLAND

Constituents	Fresh Argillite	Residual Clay	Percentage of Loss for Entire Rock	Percentage of Each Constituent Saved	Percentage of Each Constituent Lost
Silica (SiO_2)	44.15%	24.17%	25.34%	42.43%	57.57%
Alumina (Al_2O_3)	30.84	39.90	0.00	100.00	0.00
Iron oxide (FeO and Fe_2O_3)	14.87	17.61	1.23	91.22	8.78
Lime (CaO)	0.48	None	0.48	0.00	100.00
Magnesia (MgO)	0.27	0.25	0.08	71.84	28.16
Potash (K_2O)	4.36	1.24	3.39	22.04	77.95
Soda (Na_2O)	0.51	0.23	0.33	0.36	99.64
Ignition (C and H_2O)	4.49	16.62	0.00	287.37	None
	99.97%	100.02%	40.83%	.....	......

ANALYSES OF FRESH LIMESTONE AND ITS RESIDUAL CLAY

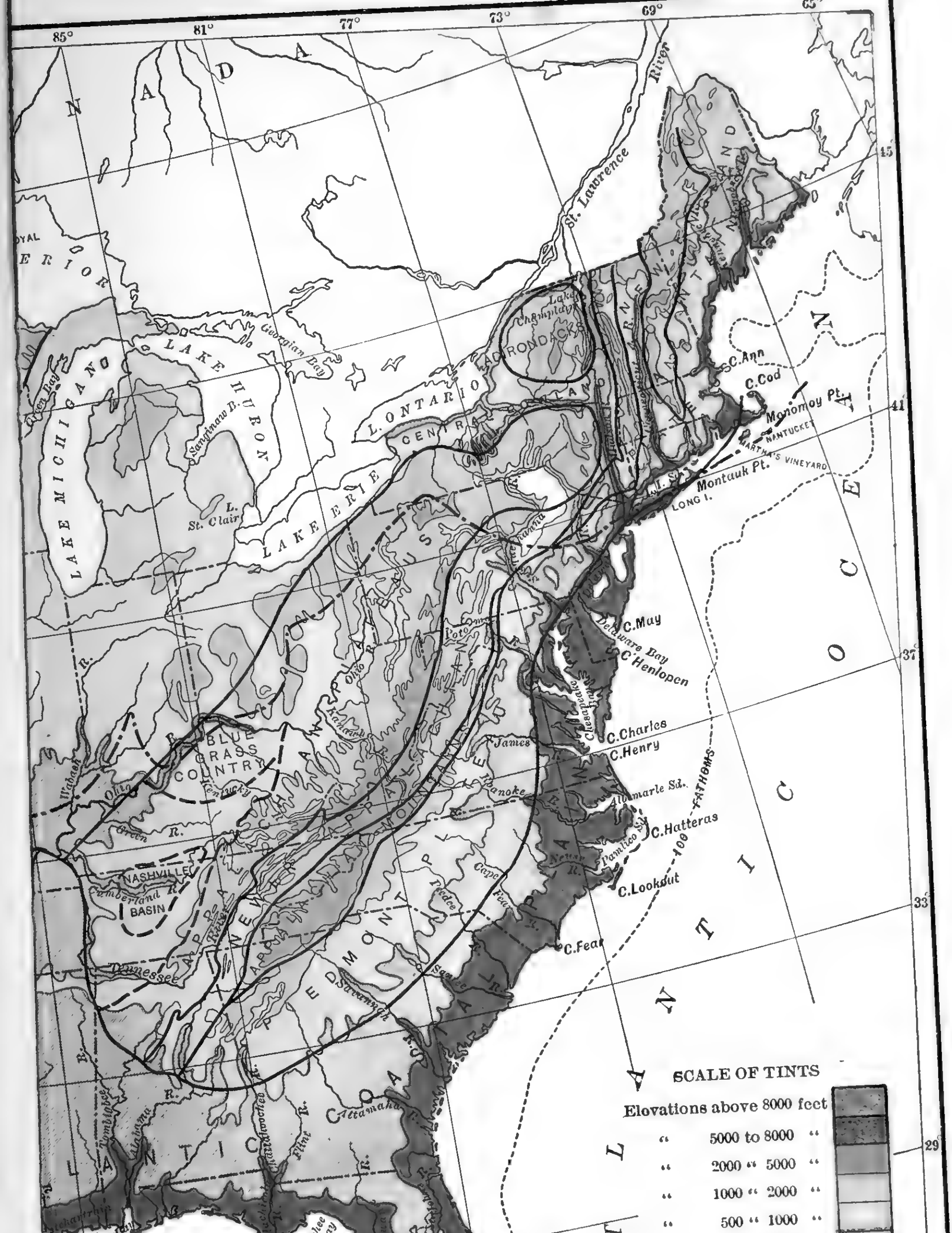
Constituents	Fresh Limestone	Residual Clay	Percentage of Loss for Entire Rock	Percentage of Each Constituent Saved	Percentage of Each Constituent Lost
Silica (SiO_2)	4.13%	33.69%	0.00%	100.00%	0.00%
Alumina (Al_2O_3)	4.19	30.30	0.35	88.65	11.35
Ferric iron (Fe_2O_3)	2.35	1.99	2.13	10.44	89.56
Manganic oxide (MnO)	4.33	14.98	2.49	42.41	57.59
Lime (CaO)	44.79	3.91	44.32	1.07	98.93
Magnesia (MgO)	0.30	0.26	6.25	10.62	89.38
Potash (K_2O)	0.35	0.96	0.23	33.63	66.37
Soda (Na_2O)	0.16	0.61	0.085	46.74	53.26
Water (H_2O)	2.26	10.76	0.95	58.37	41.63
Carbonic acid (CO_2)	34.10	0.00	34.10	0.00	100.00
Phosphoric acid (P_2O_5)	3.04	2.54	2.73	10.24	89.76
	100.00%	100.00%	97.635%	......	......

APPENDIX D

THE GEOLOGIC TIME TABLE[1]

Old classification		New classification	
Paleozoic	Cambrian	Georgic Acadic Ozarkic or Cambric	Paleozoic
	Ordovician or Lower Silurian	Canadic Ordovicic Cincinnatic	
	Siluric Devonic	Siluric Devonic	Neopaleozoic
	Mississippian or Sub-Carboniferous	Mississippic Tennesseic	
	Pennsylvanic-Permic	Pennsylvanic-Permic	
Mesozoic	Triassic Jurassic	Triassic-Jurassic	Mesozoic
	Cretaceous	Comanchic Cretacic	
Tertiary or Cenozoic	Eocene Oligocene	Eogenic	Neozoic
	Miocene Pliocene Pleistocene	Neogenic	

[1] The new classification is suggested by Charles Schuchert, Paleogeography of North America, Bull. Geol. Soc. Am., vol. 20, 1910.


85°
81°
77°
73°
69°
65°
45°
41°
37°
33°
29°
25°
89°
85°
81°
77°
73°
C A N A D A
St. Lawrence River
LAKE SUPERIOR
LAKE MICHIGAN
LAKE HURON
Georgian Bay
Saginaw B.
L. St. Clair
LAKE ERIE
L. ONTARIO
Green Bay
Lake Champlain
ADIRONDACKS
NEW ENGLAND
CENTRAL LOWLAND
APPALACHIAN PLATEAUS
BLUE GRASS COUNTRY
NASHVILLE BASIN
NEWER APPALACHIANS
OLDER APPALACHIANS
APPALACHIAN MOUNTAINS
PIEDMONT PLATEAU
ATLANTIC COASTAL PLAIN
C.Ann
C.Cod
Monomoy Pt.
NANTUCKET
MARTHA'S VINEYARD
Montauk Pt.
LONG I.
C.May
Delaware Bay
C.Henlopen
Chesapeake Bay
C.Charles
C.Henry
Albemarle Sd.
Pamlico Sd.
C.Hatteras
C.Lookout
C.Fear
Neuse R.
Cape Fear R.
Pedee R.
Santee R.
Savannah R.
Altamaha R.
Roanoke R.
James R.
Potomac R.
Susquehanna R.
Delaware R.
Hudson R.
Connecticut R.
Kennebec R.
Penobscot R.
Ohio R.
Kanawha R.
Wabash R.
Kentucky R.
Green R.
Cumberland R.
Tennessee R.
Alabama R.
Tombigbee R.
Chattahoochee R.
Flint R.
Apalachicola R.
Suwanee R.
St. Johns R.
Lake Pontchartrain
Mobile Bay
CHANDELEUR IS.
Mississippi Delta
Appalachee Bay
CEDAR KEYS
Tampa Bay
C.Canaveral
Lake Okeechobee
The Everglades
C.Florida
C.Romano
Chatham Bay
Bay of Florida
KEY WEST
GULF OF MEXICO
BAHAMA ISLANDS
ATLANTIC OCEAN
100 FATHOMS
100 FATHOMS
SCALE OF TINTS
Elevations above 8000 feet
" 5000 to 8000 "
" 2000 " 5000 "
" 1000 " 2000 "
" 500 " 1000 "
" 100 " 500 "
" 0 " 100 "

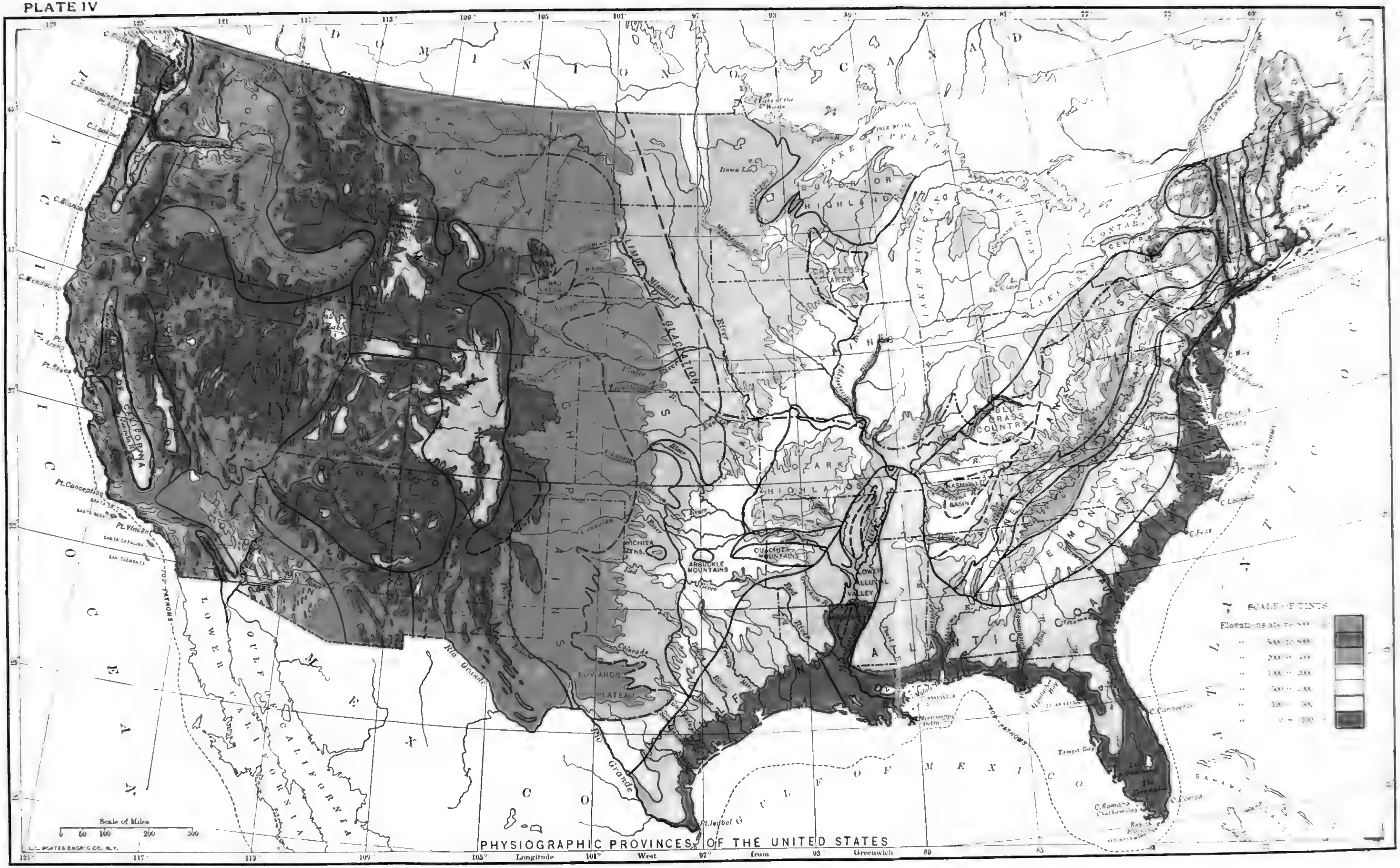


Plate IV. — Physiographic Map of the United States.

Generalized from the
Geologic Map of North America
BY THE
U.S. Geological Survey, 1911
Formation classifications by C Schuchert

H. S. Selden, Del.

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Geologic Map of North America

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