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THE CAUSES OF VEGETATIONAL CYCLES*

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CONTENTS

THE DEMONSTRATION OF VEGETATIONAL CYCLES.—The work of the past decade has shown most clearly that there are cycles of vegetation which are comparable to cycles of erosion; in each there is a period of youth, which is characterized by vigor of development and by rapidity of change; in each there is a period of old age, which is characterized by slowness of transformation and by approach to stability, or at least to equilibrium. At the close of the vegetational cycle there is no such universal feature as the ultimate plain of the physiographer, since the final stage varies with the climate, and hence is called a climatic formation[1]. In the eastern United States, the final formation is a mesophytic deciduous forest[2]; farther to the north and in the Pacific states, it is a coniferous forest; in the great belt from Texas to Saskatchewan, the final formation is a prairie; and in the arid southwest, it is a desert. In every case, the ultimate plant formation is the most mesophytic which the climate is able to support in the region taken as a whole. In a prairie climate there may be trees, but they occur for the most part near lakes or streams, or in

*Presidential Address delivered before the Association of American Geographers. December 29, 1910.

[1] Plants associated under common conditions comprise collectively, a plant formation, or a plant association, the former term being the more comprehensive.

[2] Plant formations may be hydrophytic, xerophytic, or mesophytic, these terms implying, respectively, abundance of water, scantiness of water, and conditions that are intermediate as to moisture.

protected depressions, and in the planation of the region they give way to the prairie; quite the same may be said of trees in a desert climate.

It has been ascertained that the original plant formations in any habitat give way in a somewhat definite fashion to those that come after, a phenomenon that has been termed *succession*. Pioneer (*i. e.*, original) formations usually are hydrophytic or xerophytic, mostly xerophytic in arid climates, and more equally divided in moist climates. For example, the last retreat of the glacial ice left in our northern states a vast tract made up essentially of hills and hollows, the hollows, if deep enough, with lakes. The pioneer vegetation of the hills was xerophytic, and that of the hollows, hydrophytic. Finally, except on the higher hills and in the deeper hollows, these pioneer formations gave way step by step to the tundra, and, as the climate became ameliorated, this in turn gave way to coniferous forests, and then to deciduous forests as they exist to-day. So far have the higher hills and the deeper hollows lagged behind the less extreme habitats in their development that there are still to be found many places which continue to have pioneer formations, though, of course, they differ greatly from the original pioneer formations of the tundra.

While the general trend of vegetation is from diversity toward uniformity, it must not be supposed that complete similitude is ever reached even under like climatic conditions. There are species, for example, in the ultimate forest of New England which do not occur in Ohio, and species in Ohio which do not occur in Illinois; southward the difference is even more pronounced. And yet it can not be denied that from the Maritime Provinces to Minnesota and south to the Coastal Plain the ultimate forest in its larger features is of a single type; the percentages and even the kinds of dominating trees may differ, but the aspect is essentially the same. Much more diverse from one another than are the pioneer or the ultimate formations are the formations of the intermediate stages. Our northern lakes, for example, differ much less from one another in the plant species they contain than do the swamps to which they give rise. The initial formations of a rock upland in Tennessee and in northern Michigan are much alike, both in aspect and in species; the ultimate formations in these two widely separated districts are even more alike, but the intermediate stages are very different, northern Michigan having nothing at all comparable to the oak stages in the vegetational development of eastern Tennessee, and the latter region being without the complex coniferous stages of northern Michigan. In this instance it is likely that some of the northern coniferous stages correspond to some of the southern oak stages; thus we may speak of *alternative* or *substitute* stages, when different plant formations occupy equivalent places in a successional series.

In a desert climate an upland may exhibit almost no succession, since the original xerophytic formation may remain with but little change; in comparison with a successional series in a mesophytic climate, one may speak here of the *elimination* of certain stages. In marked contrast to the lack of succession or to the slow succession on a desert upland is the rapid succession on uplands in humid climates; indeed, it is possible here for mesophytes to exist side by side with xerophytes in the pioneer stages—in such a case one may speak of *telescoped* successions. Even in a climate like that of the eastern United States, telescoping may take place, as in the successions of rich fallow land and in those which follow the cutting of a mesophytic forest. With this brief survey of recent progress in the field of physiographic ecology, we may pass to a similarly brief consideration of the historical development of vegetational dynamics, and then to a consideration of the main theme of the address.

THE DEVELOPMENT OF DYNAMIC PLANT GEOGRAPHY.—The systematic exploitation of developmental or dynamic plant geography presupposes the establishment of the principles of dynamic geology and of organic evolution; hence it could not have antedated Lyell, who brought general recognition of the former, or Darwin, who brought general recognition of the latter. Results frequently lag far behind their causes, and it is only now, a full half-century after the publication of Darwin's *Origin of Species,* and three-quarters of a century after the appearance of Lyell's *Principles,* that the dynamic method is coming to be regarded as the most fundamental thing in plant geography. As in other branches of science, there have been prophets far in advance of their time, though it is only within the last decade that the prophetic insight of these pioneers has had recognition. Lyell records the struggle of the developmental idea in geology, as opposed to the ruling theories of special creation or catastrophism, noting especially the keen philosophy of certain ancient Greeks and the renascence of these views in Italy through the influence of Leonardo da Vinci and of various contemporaries and followers.

So far as we know, the beginnings of dynamic plant geography are much more recent than are the beginnings of dynamic geology, nor is this strange, since it is easier to recognize the destruction of land by waves and the deposition of material by rivers than to observe the more silent transformation of one plant association into another. Doubtless the earliest observers of such transformations failed to record the things they saw. It is hardly to be doubted, for example, that long ago many a philosophic woodsman must have noted, when he cut down the trees of a forest, that there sprang up a new vegetation differing from the old, and that gradually these first trees of the newly developing forest were displaced by other trees; and there may have been some who were keen enough to see that, after a long time, there was a return to the primeval type of forest.

The earliest account which I have discovered that clearly deals with vegetational dynamics is in a short paper in the *Philosophical Transactions* in 1685, in which William King[3] gives a good account of the origin of bog vegetation from floating mats; many times since, this has been reported as an original discovery. Perhaps the first to have a real glimmer of the doctrine of succession, as understood today, was the great French naturalist Buffon. Although better known for his splendid descriptions of animals, Buffon in his earlier life was much interested in forestry, and in 1742 he noted[4] that poplars precede oaks and beeches in the natural development of a forest. As a result of this observation, he gave the important advice to foresters that if they wished to cultivate beeches, they should plant them not in the open, but in the shade of those trees which they naturally succeed. Biberg[5], a student of the great Linnaeus, published his thesis in 1749, and in this he describes the gradual development of vegetation on bare rocks; here he observes accurately the pioneer activity of the lichens and mosses, and he notes as well the importance of *Sphagnum* in the development of bogs.

The seeds planted by Buffon and Biberg fell on sterile soil; in France it was observed that Buffon was trespassing on theological grounds, and he was obliged to recant any views which implied that the world was not made in the beginning once for all; in Sweden the influence of Linnaeus was wholly against anything dynamic; he never published anything dynamic himself, and when a student like Biberg set his face in that direction, the master frowned, and said that the student was departing from the true mission of the botanist. It is not strange, therefore, that there followed a sterile period of three-quarters of a century. Yet it was within this period that plant geography was first recognized as a definite branch of science, for this was the period of Humboldt. This also was the period of Joachim Schouw, who published the first general plant geography, and of the older DeCandolle, who gave the weight of his great name to several important treatises in the new subject. But none of these men, not even Humboldt, were permeated with the dynamic principle, so far at least as plant geography is concerned. They placed descriptive or static plant geography on a solid foundation, and gave it such momentum that for a full century it dominated the entire field of plant geography; indeed in certain places it dominates plant geography to-day.

[3] King, William, Phil. Trans. Roy. Soc. London 15:948-960. 1685.

[4] Buffon, G. L. L., Hist. Acad. Roy. Sci. Paris 233-246. 1742.

[5] Biberg, I. J., Amoen. Acad. 2:1-52. 1749.

France, so often the birthplace of great ideas, gave the pendulum an impulse in the right direction. The sane influence of Buffon had not altogether been suppressed by the theologians, and finally there arose such men as Jussieu, who introduced a flexible natural system of plant classification, which finally displaced the rigid artificial system of Linnaeus, thus making possible the development of evolutionary theories; such men as Laplace, who conceived a theory of planetary evolution, thus making possible the development of evolutionary theories in other lines of science; and such men as Lamarck and Geoffroy Ste. Hilaire, who propounded evolutionary theories in biology. The birth of dynamical conceptions in France a century ago rejuvenated science throughout Europe, making possible the development of a Lyell and a Darwin. It also made possible the development of a dynamic trend in the new science of plant geography, though, as previously noted, the momentum given to descriptive geography was too great readily to be overcome.

Very properly the first work of the new period along dynamic lines was done in France; in 1825 Dureau de la Malle[6] published the first paper which gave the results of a careful study of plant succession involving the observations of a number of years. His work was done mainly in cut-over areas of forest, and no work done since greatly surpasses it in accuracy and thoroughness. The marvelous clear-sightedness of Dureau de la Malle is well shown in the title of his chief contribution, which (in English rendering) is: "Memoir on alternation or on alternative succession in the reproduction of plant species living in association (*société*)—is it a general law of nature?" Dureau de la Malle (not Steenstrup, as frequently supposed) first used the term succession in the present sense; probably he was the first also to use the term society as an expression of plant grouping. The year 1845 is a noteworthy one because it was then that Edward Forbes gave a short paper[7] before the British Association, opening up an entirely new line of study, namely, the interpretation of past geographic features by the present. He was the first to understand the significance of endemism in relation to previous connections between islands and continents that now are isolated.

In 1841 a great advance was made by the Danish geologist Steenstrup[8], who discovered the possibility of using the fossils of the immediate (*i. e.,* postglacial) past as a means of interpreting the climatic changes and the correlated vegetational changes of recent epochs. Vaupell, a student of Steenstrup, but more botanically inclined,

[6] Dureau de la Malle, A. J. C. A., Ann. Sci. Nat. I. 5:353-381. 1825.

[7] Forbes, Edward, Brit. Assoc. Rep. 1845²:67-68.

[8] Steenstrup, J. J. S., Dansk. Vid. Selsk. Afhandl. 9:17-120. 1842.

applied his ideas in detail[9, 11], and in the years between 1851 and 1863 gave to the world his famous account of the postglacial development of Danish vegetation, showing that the birch was the chief early pioneer, and that later it was followed in turn by the pine and the oak, and finally by the beech, which dominates to-day. From 1856 to 1859 Reissek[10] worked out the dynamical development of the vegetation on the islands of the Danube. In 1876 Gremblich[12] seemed to realize the actuality of cycles of vegetation. In 1881 Hult, a Finnish botanist, made the first comprehensive study of succession[13] as it is now taking place in a given region, and he was the first to recognize that a comparatively large number of pioneer plant associations later give way to a comparatively small number of relatively permanent associations.

In 1888 Treub, whose recent premature decease we so keenly regret, began the study of the new vegetation of Krakatoa[14], thus inaugurating one of the most fruitful lines of investigation in dynamic plant geography. In 1891 Warming, to whom more than to any other we owe the present large place occupied by formational studies in plant geography, published the first of his developmental studies of Danish dune vegetation[15]. This was followed by a similar treatment of the Rhone delta by Flahault and Combres[16], and of the North German heath by Graebner[17], and also by Warming's *Plantesamfund*[18], the original Danish edition of his well known *Plant geography,* in which there is much material of dynamic import, together with the formulation of a number of "laws of succession." In 1896 Meigen[19] made a systematic study of succession, somewhat along the lines previously followed by Hult, and he showed that there is a final tendency toward equilibrium. This brings us to the period in which dynamic plant geography was taken up actively in this country, and here our historical résumé may well give place to the main topic of this paper.

The Delimitation of Successional Factors.—No systematic attempt has been made hitherto to group in an analytic manner the phenomena of succession from the standpoint of their causation.

[9] Vaupell, C., Copenhagen. 1851.
[10] Reissek, S., Flora 39:622-624. 1856.
[11] Vaupell, C., Ann. Sci. Nat. Bot. IV. 7:55-86. 1857.
[12] Gremblich, J., Ber. Bot. Ver. in Landshut. 5:15-31. 1876.
[13] Hult, R., Meddel. Soc. Faun. Flor. Fenn. 8:1-156. 1881.
[14] Treub, M., Ann. Jard. Bot. Buitenzorg 7:213-223. 1888.
[15] Warming, E., Vid. Med. Naturh. For. Copenhagen 153-202. 1891.
[16] Flahault, C., et Combres, P., Bull. Soc. Bot. France 41:37-58. 1894.
[17] Graebner, P., Bot. Jahrb. 20:500-654. 1895.
[18] Warming, E., Copenhagen. 1895 (German edition, 1896).
[19] Meigen, F., Bot. Jahrb. 21:212-257. 1896.

Warming[18] made a great advance toward this end by gathering together the known records of vegetational change or succession; he noted that vegetational changes are particularly evident on new soil (as along sandy shores, and in marshes, on lava, on landslip soil and talus, and on burned and fallow land). He summarizes his studies by giving six laws appertaining to succession. Clements[20] attempted to distinguish between primary and secondary successions, the former being those on newly formed soils, and the latter those on denuded soils. This classification seems not to be of fundamental value, since it separates such closely related phenomena as those of erosion and deposition, and places together such unlike things as human agencies and the subsidence of land. Clements, like Warming, gives a summary of results in the form of laws.

While most observers very properly have paid chief attention to the actual facts of succession rather than to their underlying causes, a scrutiny of past results shows very clearly that the phenomena considered have differed greatly in kind. Obviously the phenomena of bog development, as observed by William King, had to do with a succession in which the activities of the plants themselves played the leading part; the humus accretions of the bog plants, such as the peat moss, *Sphagnum,* made possible the development of another vegetation on a higher soil level. In a comparable manner, the successions observed by Buffon, by Biberg, and by Dureau de la Malle had to do with plant activities; the forest trees of a given generation cast the shade necessary for the development of other trees which need shade rather than light for their development; Biberg's lichens accumulated a soil which made possible the development of higher vegetation on rock surfaces. Steenstrup, however, in his study of the fossils, introduced to the scientific world a new kind of succession phenomena, for in his elucidation of the postglacial history of Denmark there were recorded changes of broader significance than those hitherto observed; it was clear that the transition from the tundra vegetation through the birch and pine vegetation to the oak and beech, as developed by him and by his student Vaupell, was a record of climatic change, inasmuch as the very same vegetational changes may be observed to-day in journeying from northern Scandinavia to Denmark. A third and equally diverse kind of succession phenomena was recorded by Reissek in his study of the islands in the Danube, for here the influence of physiographic change on vegetation was clearly recognized. Thus in succession we may distinguish the influence of physical and of biotic agencies. The physical agencies have

[20] Clements, F. E., Bot. Surv. Nebr. VII. Studies in the vegetation of the State. III. 1904.

two aspects, namely, chorographic or regional (chiefly climatic) and physiographic.

Chorographic Successions.—Chorographic or regional successions are so slow in their development that they can hardly be studied without the use of fossils. Hence the experimental method, which has proven so potent in unraveling many a biological tangle, is here of no avail. It is not strange, therefore, that these successions are and probably must remain the least understood of all. There are, perhaps, four great examples of extensive regional change, which may be accepted as demonstrated, namely: (1) the change from the Carboniferous to the Permian, which is made evident particularly through the replacement of the Carboniferous ferns, fern allies, and primitive gymnosperms by the *Glossopteris* flora and later by the modern gymnosperms; (2) the subordination of the gymnosperms to the angiosperms in the Cretaceous; (3) the elimination of tropical forms in boreal regions in the late Tertiary; and (4) the postglacial invasion of southern forms into boreal regions accompanying and following the retreat of the glacial ice. Generally it is held that the dominating factor in these vegetational successions is climatic change, and that this climatic change is chiefly one of temperature. Of this there can be no doubt in the case of the changes immediately before and after the Pleistocene ice invasion. The constant relation between glaciation and the development of the *Glossopteris* flora in the Permian makes it likely that the general vegetational changes of that epoch also were due primarily to temperature.

On the whole, however, there has been a general tendency to overestimate the influence of temperature as an ecological factor. The trend of nearly all experiment has been to show that water is of vastly greater importance, and it well may be that the change from the atmospheric humidity which seems to have characterized the Carboniferous to the aridity which seems to have characterized the Permian had more to do than did the decreased Permian temperatures with the elimination of the Carboniferous flora and with its replacement by Mesozoic forms. The most puzzling of the great vegetative transformations of the past was the sudden change from the dominantly gymnospermous forests of the Jurassic to the domination of the world by angiosperms in the Cretaceous. We know that after the Permian there was a gradual climatic amelioration toward genial conditions similar to those which characterized the Carboniferous; this amelioration seems to have culminated in the Cretaceous, which, like the Carboniferous, was also in many parts of the world a period of extensive planation. Very probably the high temperatures and the great atmospheric humidity of the Cretaceous gave conditions that particularly favored the angiosperms, which as a group are much more mesophytic than are the gymnosperms.

To summarize on chorographic successions, it would seem that secular changes in climate, that is, changes which are too slow to be attested in a human lifetime, and which, perhaps, are too slow to be attested in a dozen or a hundred lifetimes, are the dominating factors. It is possible that these changes sometimes are more rapid than at other times, and there are those who would have us believe that the climate now is growing warmer, as witness the rapid recession of many of our North American glaciers; there are others who are quite as sure that the climate is growing colder, as witness the southward retreat of the "timber line" in Scandinavia. Still others feel equally confident that the recession of glaciers is due to increasing aridity; this explanation has the advantage also of accounting for retreating "timber lines." It is much more likely that all such changes are of short duration, as it were cycles within cycles, or feeble and short-lived oscillations of great climatic waves. It is to be pointed out that great earth movements, either of elevation or subsidence, that is, the far-reaching and long-enduring epeirogenic movements, as contrasted with the oscillations of coast lines, must be considered in accounting for regional successions; the elevation of the Permian and the planation of the Cretaceous must have played a stupendous part in instituting vegetational change.

Physiographic Successions.—In striking contrast to regional successions, which move so slowly that we are in doubt even as to their present trend, are those successions which are associated with the physiographic changes which result from the activities of such agents as gravity, running water, wind, ice, and vulcanism. In general these agencies occasion erosion and deposition, which necessarily must have a profound influence upon vegetation. I have considered elsewhere and in some detail[21, 22, 23] the influence of most of these agencies, and it will suffice in this place to summarize a few of the leading kinds of phenomena that are involved. As might be expected, the influence of rapid erosion generally is destructive to vegetation, or at least retrogressive (*i. e.,* tending to cause departure from the mesophytic), while the influence of deposition commonly is constructive or progressive (*i. e.,* tending to cause an approach toward the mesophytic). Progressive successions are well illustrated in the development of flood plains along rivers, and in the growth of sandy shores; retrogressive successions are associated with the eroding activities of streams and of receding shores. Slow erosion, such as characterizes advanced stages in physiographic cycles, is not destructive to vegetation and, after a time, erosion commonly becomes so slow as to permit the development of progressive successions.

[21] Cowles, H. C., Bot. Gazette 27:95-117, 167-202, 281-308, 361-391. 1899.
[22] ———, Bot. Gazette 31:73-108, 145-182. 1901.
[23] ———, Bull. Amer. Bur. Geogr. 2:163-176, 376-388. 1901.

Sometimes rapid erosion may not have a retrogressive influence and sometimes the effect of deposition is not progressive. For example, on a somewhat rapidly eroding clay cliff of Lake Michigan, there often occur certain xerophytic annuals, which develop during the comparatively stable summer period, and a few perennials, such as the sumac and *Equisetum,* which have underground organs that enable them to migrate landward as fast as the cliff recedes; here we have a remarkable instance of rapid topographic change without a corresponding plant succession, either progressive or retrogressive. A marked increase in erosive intensity would destroy all vegetation, and a marked decrease in erosive intensity might institute a progressive vegetational succession. Deposition unaccompanied by progressive changes may be illustrated by an instance from the Lake Michigan sand dunes. Frequently a growing dune is inhabited by xerophytic annuals and by a few shrubs or trees (as various willows and the cottonwood); such a place illustrates pronounced topographic change, but often the vegetation is static. A great increase in depositional intensity results in the destruction of all the plants, while a decrease in depositional intensity results in progressive succession. Retrogression or a static condition of vegetation is to be seen also along rapid streams, where there is a considerable deposition of coarse material. A striking illustration of retrogression associated with deposition is afforded by lava flows.

Biotic Successions—*a. General Features.*—Of less interest, perhaps, to the physiographer than are the vegetational changes hitherto considered, but of far greater import to the plant geographer, are the vegetational changes that are due to plant and animal agencies. These are found to have an influence that is more diversified than is the case with the physiographic agencies; furthermore, their influence can be more exactly studied, since they are somewhat readily amenable to experimental control, but particularly because they operate with sufficient rapidity to be investigated with some exactness within the range of an ordinary lifetime. If, in their operation, chorographic agencies are matters of eons, and physiographic agencies matters of centuries, biotic agencies may be expressed in terms of decades.

It has been seen that changes of climate or of topography generally institute vegetational changes; indeed this would have been predicted to be the case, even without examination. But at first thought it seems somewhat striking that far-reaching vegetational changes take place without any obvious climatic change and without any marked activity on the part of the ordinary erosive factors. Indeed, it is probably true that the character of the present vegetative covering of the earth is due far more to the influence of these relatively silent and subtle factors than to the more obvious factors previously considered. So rapid is the action of the biotic agencies that not only the climate, but even the topography may be regarded as static over large areas for a considerable length of time. It has been said that many of our Pleistocene deposits exhibit almost the identical form which characterized them at the time of their deposition; in other words, the influence of thousands of years of weathering has been insufficient to cause them to lose their original appearance. These thousands of years would have sufficed for dozens and perhaps for hundreds of biotic vegetational cycles. For example, many a sand dune on the shores of Lake Michigan is clothed with the ultimate mesophytic forest of the eastern United States, and yet the sand dunes are products of the present epoch; furthermore, sand is regarded generally as a poor type of soil in which to observe rapid succession. If a clay upland were denuded of its forest and its humus, it is believed that only a few centuries would suffice for the mesophytic forest to return.

From the standpoint of dynamic plant geography, our land areas are divided into two well marked categories: on the one hand is the erosion topography that is characteristic of the eroding and depositing phases of present streams and shores, and on the other hand is the *pre-erosion* topography (as it may be termed) which is characteristic of those areas that have not as yet been invaded by erosive forces. In our northern states the areas characterized by the presence of a pre-erosion topography often greatly exceed in extent the areas which are characterized by an erosion topography. South of the glaciated region, however, the areas characterized by the presence of an erosion topography often greatly dominate. But the influence of biotic agencies is not confined to areas that are characterized by a pre-erosion topography. For example, in our eastern forested region the development of a ravine, which furnishes a characteristic illustration of rapid erosion, exhibits only here and there actual erosion or deposition; the ravine slopes as a whole are covered with a mesophytic vegetation, because at a given spot the interval between periods of active erosion often is sufficiently long to permit the development of an entire biotic cycle. Perhaps in no other way could there be brought out more strikingly the durational contrast between physiographic and biotic cycles; a ravine is an index of extreme topographic youth, and yet in its development there is ample time for the complete development of many biotic cycles. Quite as in ravines, the cliffs of streams and shores often exhibit temporary exemption from erosion, whereupon there is at once instituted a biotic cycle, which often has sufficient time for running its full course before erosion again becomes active.

b. The Humus Complex—a. Water.—It is now time to consider the varying aspects of the biotic agencies which institute succession. Of these the first to be mentioned, because of its unquestioned supremacy, is the accumulation of humus. There are a number of different ways in which the accumulation of humus affects the trend of succession. It can scarcely be doubted that the most important of these humus influences, and perhaps the most important of all influences, inheres in the change which the humus brings about in the water relation of the soil. Speaking generally, humus accumulation occasions an increase in soil moisture on uplands and a decrease in soil moisture in depressions; hence it is probable that the changed water relation due to humus accumulation is the dominating factor in determining the mesophytic trend, both in hydrophytic and in xerophytic habitats. Although bare sand supports a xerophytic flora, the accumulation of a thin humus layer is sufficient for forest development, and the Michigan dunes show that the most mesophytic of our forests can grow on a sand dune, if there is present a humus layer a few centimeters in thickness. On rock uplands, lichens commonly are the first humus accumulators; not only do they contribute humus by their own decay, but they give shelter and anchorage to plants of higher order, whose humus-accumulating capacity is greater. As long as the vegetation is open, and the humus exposed to the sun and wind, accumulation is slow, because of oxidation. But when the vegetation cover is more fully developed, the humus is more and more protected and hence accumulates more rapidly.

The relation of swamp successions to humus accumulation is particularly close. For each level both below and above the water table, there is a characteristic plant formation. In the deeper ponds only submersed aquatics can develop, but after a time their humus débris accumulates to such an extent that plants with long stems or leafstalks (such as the pondweeds and water lilies) are able to develop. They in turn build up the humus and prepare the way for their own elimination and for the development of such plants as the bulrush, which grows in shallow water. The latter again prepare the way by further humus accumulation for the first land plants, and they again for others. In all this well-known successional series, the dominating factor clearly is a decreasing water content due to the accumulation of humus.

b. Soil Organisms.—Another important influence associated with humus accumulation is the increase of soil organisms. These may play a part scarcely second to water, but as yet we know all too little of their activities to be certain of their precise place in the scale of importance. We know, however, that nitrogen is one of the essential plant constituents, and that it is made available chiefly by certain bacteria and fungi. Since these forms live on decaying organic matter, it seems likely that humus accumulation is likely to favor their increasing development and hence an increasing supply of available nitrogen. A single instance will suffice to show the possible importance of soil organisms in succession. The beech, which is a characteristic member of the culminating forest of the eastern United States, has roots which are enveloped by fungi; it is believed that these fungi represent the absorptive system of the tree, and it is likely also that they are able to make nitrogen available, since so many similar fungi are now known to possess this power. In any event, the beech is known to depend upon the fungus, being unable to flourish without it. Obviously, then, the beech can not appear in a successional series until its associated fungus finds conditions requisite for its development in the soil. It is likely, too, that other soil organisms are detrimental to various green plants, thus becoming a factor in their elimination. There is opened up here a great field of investigation, and all that can be stated now with definiteness is that it is likely to be demonstrated that the accumulation of humus is of profound significance in the development of successive soil organisms, and probably on this account in the succession of the higher plants.

c. Toxicity.—Still another humus factor that seems likely to be of large significance, but whose exploitation is so recent that we can not yet appraise it, is soil toxicity. It has been known for a long time that the roots of plants give off various excretions, but it is only through the recent careful work of Livingston and his associates[24], and later of Schreiner and Reed[25, 26], that we have come to know much concerning their nature and influence. In the case of wheat it has been ascertained that the roots give off certain substances which are deleterious and perhaps actually toxic, especially to wheat. Such results should not occasion surprise, since it is well-known that many bacteria excrete substances which retard or even prevent the further growth of their own kind.

One of the greatest puzzles to the student of plant dynamics has been afforded by the successional series in bogs, since in spite of the wet soil there are many plants that obviously are xerophytic. There is universal agreement that there is something in bog soils which is detrimental to plant growth, but there have been various theories as to its nature. Some years ago Livingston[27] discovered that bog waters have an effect on the growth of algae which is quite comparable to the

[24] Livingston, B. E., Britton, J. C., and Reid, F. R., U. S. Dept. Agric., Bull. Bur. Soils 28. 1905.

[25] Schreiner, O., and Reed, H. S., U. S. Dept. Agric., Bull. Bur. Soils 40. 1907.

[26] ———, Bull. Torr. Bot. Club 34:279-303. 1907.

[27] Livingston, B. E., Bot. Gazette 39:348-355. 1905.

effect of various toxic agents. More recently Dachnowski, following the lead suggested by Schreiner and Reed, has been making a careful study of bog toxins[28, 29]. On account of the poor drainage of bogs, there is no other habitat where root excretions would be more likely to remain. Year by year these excreta would accumulate, thus making the bog more and more unfitted for the development of ordinary hydrophytes; hence, for a time the dominating bog plants would be those which would be able to withstand the acids and other deleterious excreta given off by the roots or produced subsequently by changes in the accumulating humus. However, when these bog xerophytes bring the humus level well above the water table, the deleterious plant products will be more and more oxidized, and ultimately there will be produced a soil of such character that ordinary mesophytes may flourish in it. While there is much in this theory which still requires confirmation, it certainly accounts for most bog phenomena and is not controverted by any known facts. It is likely also that some of the accumulating soil compounds may be of importance in neutralizing deleterious inorganic or organic soil constituents. In any event, the study of soil toxins and of their varied relations to plants is one of the great fields of investigation for the future.

d. Food.—Perhaps there are some who would have supposed that the chief significance of humus accumulation lies in the increased amount of plant food that thus is made available. Once it was believed that the well-known luxuriance of plants in humus is due to the large amount of plant food which it contains. Long ago this luxuriance was shown to be in the main due to other causes, but recent experiments have demonstrated that ordinary green plants are able to absorb certain foods (as glucose), and it may be that such plants actually utilize in this way some of the substances of the humus. It is likely that the increasing food supply in accumulating humus is an important factor in the succession of the soil organisms, but as yet this subject has never been investigated. It also offers a fascinating field for study. The depletion of mineral food stuffs in the soil has been urged as a successional factor, but it is doubtful if this is of any consequence. The great abundance of the mineral constituents of plants in nearly all soils is in strong contrast to the minute amounts which the plants contain. Furthermore, the plants in their decay return to the soil the mineral elements which they took from it.

e. Temperature and Aeration.—Finally humus accumulation alters the soil temperature and the air content of the soil. For the most part changes in air content and in temperature probably are insufficient to be of great influence in vegetative change. In bogs, however,

[28] Dachnowski, A., Bot. Gazette 46:130-143. 1908.

[29] ———, Bot. Gazette 47:389-405. 1909.

there is evidence that each of these factors is of importance. Transeau has shown[30] that in the growing season the temperature of the water and of the soil in bogs is below that of other soils, and of the superincumbent air. Such a condition certainly is detrimental to root activity. Similarly Transeau[30] has shown that the lack of aeration in bog soils is detrimental to root activity. Thus for these reasons (and probably also because of soil toxicity, as noted above) certain stages in bogs are characterized by the development of a xerophytic vegetation, since the unfavorable conditions for root absorption make existence in bogs difficult for any plants with aerial organs except such as have structures which reduce transpiration. That such bog plants are actual and not merely apparent xerophytes was demonstrated in brilliant fashion by Transeau[30], who produced plants with xerophytic structures from ordinary plants by growing them in bog conditions.

c. Shade.—Next in importance to humus among the dynamic biotic agencies is shade. The foresters have known for generations that in the reforesting of a region the first trees to appear are those which require a large amount of sunlight for their development; conspicuous among such light-requiring pioneers are the poplars and birches. Rarely is a dense growth of these trees followed by trees of similar kind, since the increasing shade makes the development of seedlings of these species more and more difficult. Other trees, however, perhaps pines and oaks, are able to thrive in a degree of shade which aspens and birches might not be able to endure. Finally the pines and oaks in turn may be succeeded by such trees as the beech, the sugar maple, and the hemlock, since these trees are able to develop in a considerable amount of shade. The latter trees may continue indefinitely, unless climatic or topographic changes intervene, since, unlike most species of trees, their seedlings are able to develop in shade as dense as that which is cast by the parent trees. While the influence of increasing shade, as here set forth, is undoubted, the extent of its influence is not known; *pari passu* with the increase of shade, and partly on account of it, there goes on the accumulation of humus. On uplands in our climate each of these factors tends to bring about the development of a mesophytic forest, but as yet it is impossible to determine which has the more potent influence. Increasing shade favors the mesophytic trend of upland successions in yet another way than through its direct influence and through its effect upon humus accumulation; the cutting off of light results in increased atmospheric humidity and hence in decreased evaporation. Some recent observations by Fuller[31] show that the pioneer plant for-

[30] Transeau, E. N., Bot. Gazette 40:351-375, 418-448. 1905; 41:17-42. 1906.
[31] Fuller, G. D., Bot. Gazette 52:193-208. 1911.

mations of the Indiana sand dunes are characterized by high evaporation, and that this evaporation progressively decreases until the minimum is reached in the mesophytic forest.

In contrast to ordinary uplands is the influence of light upon the development of vegetation in lakes. At the outset there are many lakes which are too deep to have a conspicuous vegetation of green plants on the bottom. Through the accumulation of inorganic detritus and of humus, the latter arising from the decay of green plants living in the upper waters and from the decay of other organisms at all levels, there gradually is made possible the development of a plant formation on the bottom, composed of plants which require only a minimum amount of light. In succeeding years the shallowing of the lake makes possible a greater and greater development of green herbage, unless the development of a rich floating vegetation again cuts off the light. It is obvious that the influence of light and shade on succession is not so explicitly related to life as is that of humus; humus can arise only from organisms, but shade may be cast by many other things than trees. The rapid development of a mesophytic forest in a canyon is due in large part to the increasing shade which is cast by the walls as the canyon deepens. However, the predominating influence of shade certainly is in connection with forest development, and hence it is not unfair to group it with biotic influences.

d. Plant Invasion.—A further biotic influence is that of plant invasion. In the long periods of geologic history, plant migrations from one region to another must have played a tremendous part in the changing aspect of vegetation. There is reason to believe, however, that such changes, apart from those due to human influence, have been wrought almost as slowly as those due to climatic change. So imperceptibly do these migrations take place that we know of no profound change that has been wrought by this means in natural floras within historic time.

e. Man.—The last of the biotic influences to be considered is that of man. Most of the factors hitherto considered, especially increasing shade and accumulating humus with its varied kinds of influence, cooperate to transform originally hydrophytic and xerophytic plant formations into those that are more mesophytic; that is, they institute progressive successions. The influence of man, however, almost without exception, is retrogressive. Human culture reaches its highest expression in mesophytic climates or on mesophytic soils; the xerophytic soils of rocky crags and of sand barrens are unfavorable places for human exploitation, and the desert is for man an unprofitable waste, except where he finds an oasis or makes a district mesophytic through irrigation. Similarly, the waters are of value chiefly as avenues of transportation and as a source of food, not as a habitation; and swampy tracts are considered valueless, unless made mesophytic by drainage. Man, therefore, in seeking a place of abode, in clearing land for agriculture, and in his search for timber, has destroyed chiefly mesophytic vegetation, in other words, the very vegetation which, in most areas occupied by human culture, has been seen to be the culminating plant formation.

When a forest is destroyed by cutting, the succeeding vegetation commonly is more xerophytic than that which was destroyed, because of increased light and decreased humus. The influence of fires is still more retrogressive, because the vegetation of the forest floor, as well as the trees, is destroyed, and also because the humus is more largely oxidized. Both in such areas as these which gradually return to the forest, and in other areas which are prevented from making such return, on account of their use for cultivation, or for habitation, or for grazing animals, there enter among the pioneers a large number of cosmopolitan weeds which follow in the train of man. Most of these weeds are of xerophytic tendencies, and hence are well fitted for these pioneer stages. In the revegetation of fallow land and in reforestation, these immigrants soon disappear, giving way before the returning native forms which inhabited the region before man entered with his destructive axe and torch.

f. Plant Plasticity.—Before concluding this section on biotic agencies, there should be noted some instances where change in the habitat meets with a reaction other than that of succession. Very frequently in the draining of a pond by humus accumulation, the same plants may be found in different stages, but characterized by a change of aspect. For example, the mermaid weed (*Proserpinaca*), the water hemlock (*Sium*), and the water smartweed (*Polygonum amphibium*) are fitted for existence in a shallow pond and also in a swamp where the soil level is above the water table. In the former instance the plants possess so-called water leaves, which vary greatly in form and structure from the air leaves, which are seen in the following swamp stage. Such amphibious plants thus have the power through their great plasticity of existing in two distinct plant formations; many of their companions, however, in the two situations are quite unlike, indicating that the habitat range of the latter is narrower, on account of their smaller plasticity.

In the western forests, the Douglas spruce may be a xerophytic pioneer, and yet may remain through all the stages of forest development, including the culminating mesophytic forest; this remarkable tree may even dominate in each of the stages. The Douglas spruce differs from the amphibious plants in that it exhibits no such striking changes in leaf habit in the different conditions in which it lives; however, the change in the accompanying vegetation is much more profound than in the swamp, for at the outset the Douglas spruce may be accompanied by xerophytic pines and junipers, and at the close by the mesophytic hemlock and by a luxuriant carpet of mesophytic ferns and mosses. Thus it is clear that the life range of some plants is very broad and of others very narrow; obviously the latter are the best markers of habitat dynamics, for with a change of conditions they soon give way to other forms. Of especial interest to the physiologist is the situation in such plants as the Douglas spruce, whose leaves without change of form or structure seem equally fitted for light or shade, for dryness or humidity.

Conclusion.—It is not to be supposed that all the influences which are involved in plant succession have been outlined in the preceding pages. Indeed, some minor contributory factors have been purposely omitted, because of the brief time allotted upon such an occasion. However, it is to be hoped that the dominating factors, so far as known at present, are here mentioned. From a survey of the various agencies involved, it seems clear that the influences which bring about succession differ profoundly in their nature, and also in the rapidity of their action. Although they grade into one another as do all phenomena of nature, we may recognize chorographic agencies which institute vegetational cycles whose duration is so long that the stages in the succession are revealed only by a study of the record of the rocks. Within one such cycle there may be many cycles of erosion, each with its vegetative cycle. The trend of a physiographic cycle can be seen by a study of erosive processes as they are taking place to-day, but the duration of the cycle is so long that its stages can be understood only by a comparison of one district with another; by visiting the parts of a river from its source to its mouth, we can imagine what its history at a given point has been or is to be. Within a cycle of erosion there may be many vegetational cycles, and among these are some whose duration is so short that exact study year by year at a given point makes it possible to determine not only the trend of succession, but the exact way in which it comes about. We can see one formation replacing another before our eyes, and hence we may hope some day, if we exercise sufficient ingenuity and patience, to understand the underlying causes of the change. It is clear therefore that vegetational cycles are not of equal value. Each chorographic cycle has its vegetational cycle; each erosive cycle within the chorographic cycle in turn has its vegetational cycle; and biotic factors institute other cycles, quite independently of climatic or physiographic change. It is small wonder that within this complex of cycle within cycle, each moving independently of the others and at times in different directions, dynamic plant geography has accomplished so little in unraveling the mysteries of succession. It may be some small contribution to this end, if the preceding considerations assist in delimiting the problems.

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THE COLORADO FRONT RANGE

A STUDY IN PHYSIOGRAPHIC PRESENTATION

W. M. DAVIS

DEDICATED TO THE MEMORY OF ARCHIBALD R. MARVINE

Born in Auburn, N. Y., Sept. 26, 1848
Graduated at Harvard, M. E., *summa cum laude,* 1870
Died in Washington, D. C., March 2, 1876

"The mountain zone lying between the main divide and the Plains . . . a park region of rolling pine-sprinkled surfaces . . . impresses one as being, with a few exceptions, a region of very uniform or gently undulating general elevation, carved by the powers of erosion, perhaps partly glacial but mostly by streams, into a mountain area of which portions are exceedingly rugged."

A. R. MARVINE, in Hayden's Report for 1873.
Washington, 1874, p. 89.

CONTENTS

Two Visits to the Rocky Mountains.—In the summer of 1869, Professor J. D. Whitney visited the Rocky Mountains of Colorado with a small party, including four of his students in the Mining School at Harvard. His object was chiefly to determine the altitude of the loftiest ranges that he could reach, regarding which a brief report was published in *Petermann's Mitteilungen* (1871). The highest summit that he found was in the Sawatch Range west of the upper Arkansas Valley, and was named Mt. Harvard (14,375 feet) after the university in which he was then teaching; while the next highest summit immediately to the south in the same range was named Mt. Yale (14,187 feet) after the university from which he had graduated thirty years before. The name Mt. Princeton (14,196 feet) was given, a few years later, to the fine mass next south of Mt. Yale. Mts. Elbert (14,421 feet) and Massive (14,424 feet), farther north in the same range, have been found by later surveys to have greater height.

The four students in Whitney's party were:—Archibald R. Marvine who, after finishing his studies in 1870, joined the Wheeler Survey and later the Hayden Survey, his excellent work being cut short by his death in 1876; Henry Gannett, whose membership in the Hayden Survey has been followed by long and expert service in the United States Geological Survey; Joseph H. Bridge, who made successful application of his mining studies in the West; and myself who, after a détour into astronomy which took me to South America from 1870 to 1873, returned to geology and geography at Harvard in 1876.

After having various sights of the Rocky Mountains in 1877, 1883, 1891, 1897, 1900, 1901, 1902, 1904, and 1909, some only from passing trains, others more deliberate, I had opportunity of visiting the ranges of Colorado again in the summer of 1910, in company with Professor Mark Jefferson of Ypsilanti, Mich., Professor W. M. Gregory of Cleveland, O., and Professor E. W. Shuler of Fort Worth, Tex., when we carried on the work of a field course in advanced physiography as part of the Harvard Summer School of that year. We spent something more than two weeks together, and my companions remained about three weeks longer, to continue a closer examination of selected problems. Our studies made repeated application of the results announced for the Boulder district by Fenneman (1905) and for the Georgetown district by Ball (1908, 31-35).

The contrasts between the visits of 1869 and 1910 were strongly marked in many ways. In 1869, Cheyenne was the nearest railroad station; we went thence by stage over-night to Denver, a small frontier town, where we outfitted for a camping trip of six weeks in the unsurveyed mountains. In 1910, Denver was a good sized city and an important railroad center, from which we could quickly enter or cross the mountains by train, to the Northwest, West or Southwest, in the most convenient fashion for rapid work. But there was another contrast:—in 1869 the highest geographical ambitions of our party were to determine the latitude, longitude and altitude of the more important mountains, to make hachured sketch maps of the district and to write brief empirical descriptions of the scenery. In 1910 there was no need of surveying, as fairly good governmental maps were available for much of the field; our efforts were therefore directed almost exclusively to the preparation of systematic explanatory descriptions of the mountain landscape, following methods that were unimagined in 1869.

Investigation and Presentation.—When a geographer returns from a field of observation, such as the Rocky Mountains in Colorado, and after a period of study proposes to present the results of his work at a meeting of his colleagues, his attention passes from the science of geographical investigation to the art of geographical presentation. Through observation and reflection, he has learned the facts of his field and their meaning. It is then his task to arrange a suitable selection of his material in such form and order that the essential features of his problem, upon which he has spent weeks or months, can be acquired by his hearers in half an hour or an hour. The things that he has seen must be presented in *Wort und Bild,* as the Germans say, so that those who have not visited his field may gain a repaying appreciation of its main features.

The Six Chief Methods of Geographical Presentation.—An inspection of geographical articles in scientific journals discloses six chief methods of presentation, which may be called the narrative, the inductive, the analytic, the historic, the systematic, and the regional. In narrative presentation, the observer recounts the facts that he observed and the thoughts that they suggested, in the order in which they were encountered. In inductive presentation, the observed facts are arranged in some reasonable order, independent of theory as well as of the order of observation and record, so that their leading characteristics may be generalized. In analytical presentation, the best theoretical explanation of the observed facts, as dependent on certain unobservable facts and processes of past occurrence, is selected from various proposed explanations, and set forth in such form that the hearers may judge of its sufficiency. In historic presentation, the gradual development of a problem is reviewed by summarizing the successive contributions made to its solution by various investigators. In systematic presentation, typical examples, as acquired by observations, induction, analysis, and history, are arranged in a well considered order, so that they may be easily found when wanted. In regional presentation, the climax of geographical work is reached:—here the attempt is made to describe, in their actual spacial relations, all the geographical features which occur together in a given district; these features having previously become well known by observation and induction, well understood by analysis, well appreciated by historic review, and well arranged in relation to similar features elsewhere by systematic classification.

Evidently enough, the six methods of presentation may be variously combined: evidently also, when an investigation is finished, and the opportunity for presentation approaches, the investigator must choose among the several methods of presentation, and select that one which will best accomplish his object. In this particular instance, the problem is to determine how the results of three weeks' physiographic observation in the Rocky Mountains in the summer of 1910 can be best set before the members of our Association.

The Various Treatments, Grades, and Forms of Presentation.—All the methods of presentation above noted, except the analytic, may be treated either with the older fashioned empirical motive, or with the newer fashioned explanatory motive; thus eleven varieties of presentation become possible. Each of these eleven varieties may be adapted to different grades of geographical proficiency; for example, to the youthful grade of pupils in secondary schools, or to the higher grade of mature but not proficient hearers, or to the highest grade of proficient experts: thus we have thirty-three varieties of presentation. Furthermore, each of these varieties may be condensed into a brief form, given a medium length, or expanded to a full and detailed statement. Thus there are at least ninety-nine varieties of presentation; and if it be desired to subdivide grades and forms more minutely, the number of varieties might be still farther increased. When so many kinds of presentation are possible, it behooves a geographer to be all the more careful to choose the particular kind that shall best suit his needs. The problem here encountered is a practical one, and one that needs careful consideration. Let us examine briefly the advantages and disadvantages of the various styles of presentation, considering treatment first, then form and grade.

Explanatory Treatment Better Than Empirical.—In these modern days of an evolutionary philosophy, it is desirable to discard the empirical treatment of geographical problems, and to adopt as far as possible a thorough-going explanatory treatment: not that everything geographical can today be safely explained to the satisfaction of all geographers; but that all geographers are now satisfied that everything geographical has been evolved from past conditions into present conditions by ordinary, orderly processes, and is therefore in its nature susceptible of reasonable explanation, even if the explanation is not yet found; and further that many, though perhaps not yet most, geographers are persuaded that there is no way of describing geographical facts so effectively as by explaining them. A conscious and intentional effort will therefore be made to adopt an explanatory treatment in this essay, that is, to introduce so much of the past history of the facts under consideration as is helpful in describing their present condition. If in some problem where no satisfactory explanation is found, it may be necessary to fall back on empirical statements, this will be done consciously and intentionally, but with expressed discontent, and with a lively hope that the missing explanation may soon be found.

Brief and Medium Forms of Advanced Grade.—If it be appropriate anywhere to apply a terse and technical form of explanatory treatment in the discussion of a physiographical problem, it must be at a meeting of the only geographical society in the world which, as far as I know, requires some expert knowledge of and some creditable performance in geography as a qualification for membership. Hence experiment in that kind of presentation will here be made. It will be followed by a statement in more expanded form, in which the fuller meaning of the terse statement will be explicitly set forth, just as a terse geometrical theorem is often followed by corollaries in which explicit statement is made of various consequences that are implicitly contained in the theorem.

Choice Among the Six Methods of Presentation.—The simple experiences of a summer vacation in Colorado hardly deserve narrative presentation at a meeting of the Association of American Geographers. True, it may sometimes be worth while to state concisely the itinerary of a trip, but that is a very dry form of record, quite unlike the lively, story-telling quality of good narrative, and it is not needed here. Furthermore, the disorderly sequence of observations, now on one railroad line, now on another, here strolling over the highlands, there descending the steep sides of a young valley, would produce a very confused impression when set forth in narrative style, and such an impression must be avoided. Even if we had had novel adventures, which was by no means the case, it would not suit the objective purpose of our Association to introduce so much subjective matter as narration usually contains; for however well subjective narration may serve to entertain a popular audience, it is poorly fitted for the presentation of the scientific results of a journey, or for the edification of the members of this Association.

Inductive presentation is likewise not appropriate for the present purpose. It is a good method for the presentation of well defined facts to an audience of small experience and of undeveloped critical powers, but it is a poor method of treating novel problems before an audience of experts, because only simple geographical generalizations can be reached by induction alone, and most of these have been reached years ago. Hence, instead of here attempting to re-establish simple generalizations by going over their induction again, they will be treated, in so far as they are here pertinent, as accepted truths. For example, the relation of trunk and branch valleys at their junctions may be established by observations in the Rocky Mountains; but as this important relation has been known with respect to normally eroded valleys for more than a century, and with respect to glacially deepened valleys for more than a decade, it need not be treated today as a novelty that still demands the support of new instances. On the other hand, most of the physiographic problems of the Rocky Mountains are far beyond the reach of inductive solution, because they involve the theoretical discussion of unobservable past facts, as well as of observable present facts. If, in spite of being slow, inductive presentation is prized as being safe, let it be remembered that safety is really a quality of investigation, while the correspondingly admirable quality of presentation is clearness; and inductive presentation is not necessarily clear, indeed, it is not strictly applicable unless the problems dealt with are very simple. It sometimes happens that a would-be cautious investigator presents his conclusions inductively, as if thereby to fortify them; but in such cases deduction often enters as an essential although unintentional and unrecognized supplement to induction; and the unrecognized use of deduction renders would-be inductive presentation turbid. If deduction is to be used at all, let it be used consciously, as it is in the analytical method. Inductive presentation is therefore discarded in this essay, excepting in so far as it enters into other methods of presentation.

The analytical method of attacking various problems was repeatedly employed while our work was going on in the field and afterwards, for this is the only method that is capable of supplying safe explanations for many of the facts we encountered; and inasmuch as our intention of using explanatory treatment has already been avowed, analysis is an essential part of our work. Analysis is, indeed, after observation, the mainstay of the explanatory treatment of geographical problems; and it must always be so, as long as the problems involve the understanding of unseen facts in past time as the explanation of the seen facts of the present time. Analysis is, moreover, the most effective method of presenting intricate problems to an audience of mature experts, from whom the author desires a critical consideration rather than a passive acceptance of his conclusions. Analytical presentation would therefore here be preferable to inductive presentation of the features of the Front Range of the Rocky Mountains, if the choice lay only between these two methods; but practically all the problems that we encountered had already been solved, inductively or analytically, elsewhere; and what we wished to do was not to discover new explanations for the already explained things that we saw, but to use the known explanations in our descriptions; and for this purpose analysis is only a prerequisite. Furthermore, analytic presentation at the best tends to carry the reader's attention away from present features, and direct it to past conditions and processes from which present features have been evolved; and in this respect analysis is associated more with geology than with geography. Only by conscious effort and continued study are the explanations that are reached through analysis made familiar enough for use in geographical descriptions; and this effort leads us to the systematic method of presentation. It will therefore serve our present object to use the results gained by analysis, instead of here demonstrating them by analytical study.

Historical presentation serves a useful purpose in bringing forward the work of earlier geographers, even though their knowledge was necessarily more limited than ours. An essay of this kind, in which the object is simply to show the successive stages in the approach to our present knowledge, rather than to emphasize present knowledge, is more nearly associated with history than with geography; but when its intent is to bring out clearly the present status of a problem by following the line of its development and making appropriate citations from the work of earlier investigators, it has great geographic value. In the present instance, however, an historical presentation of exploration in the Rocky Mountains of Colorado would be of little service in describing the mountains themselves; and an historical review of the gradual development of the various problems there encountered would lead us too far from our local subject. Hence the historical method will not be followed.

Systematic study of various kinds of things is essentially the successor of observation, induction, analysis, and historical review, and as essentially the precursor of regional study; for it is by means of the systematic classification of results already gained that the geographer who wishes to undertake regional work equips himself with a varied assortment of standardized ideal types, each of which he strives to conceive as the mental counterpart of possible real things, and all of which he strives to arrange in a well-considered order; and it is by means of systematic presentation that he reveals his equipment to his colleagues, so that they and he can understand each other. Indeed, inasmuch as everything that a geographical observer sees when he visits a new field must be described in terms of previously known mental counterparts, it is evidently desirable that, before a geographer undertakes regional description, his previous experience in observation, induction, analysis, and review should be widely extended, and that the results of his extended experience should be carefully systematized and standardized. Only in this way can he insure a conscious return from his geological analysis of past processes, and from his historical review of earlier theories, to a sufficiently direct consideration of the results reached by his analysis and review: only in this way can he thoroughly familiarize himself with a comprehensive and well classified series of standardized explanatory concepts, which shall, as occasion offers, serve as the counterparts of the geographical facts that he encounters in a newly visited field.

Still further, it is essential that the standardized type-concepts with which one geographer is equipped, as well as the terms by which he names them, should be known to his fellow geographers; for otherwise his descriptions will not be understood. If his colleagues think of a hollow when he says "hill," they will gain no correct mental picture of the landscape that he tries to describe. Hence systematic nomenclature is of very great value. Geographical descriptions are indeed successful in direct proportion to the sufficiency of the observer's equipment and to the possession of the same equipment in common by the observer and his hearers. It is in order to serve as sources of common equipment that text-books, from which geographers acquire much of their training, are usually arranged systematically; accounts of related types being placed on neighboring pages, and actual examples being adduced from various parts of the world, in order to attest the correctness of the types. However, our object here is not to provide a standardized equipment in which related types are placed together, but to use an equipment, already provided, in the description of different kinds of real things which occur together in the part of the Rocky Mountains that our party saw during our summer excursion; hence systematic presentation will not serve our needs any better than narrative, inductive, analytic or historic presentation. We shall assume that systematic study and presentation are behind us, and use their results.

Regional presentation then remains as the only method that is at all adequate as a means of describing the varied features of the Front Range in their spacial relations. In adopting this method of presentation, we propose, as has already been stated, to give it an explanatory treatment, an advanced grade, and in the first instance at least a condensed form. In such a presentation there is no place for narrative, inductive, analytic, historic, or systematic presentation; nevertheless, training in the processes of observational narration, inductive generalization, analytical explanation, historical review, and systematic classification are all helpful preparatory steps towards the regional goal. This is particularly true in the present case as regards analysis and systematization; for if the features of the region are to be described in terms of their explanation, they or their equivalents elsewhere must have been previously studied analytically in order that a correct explanation of them shall have been found; and if readers not familiar with the region are to understand the results of such analysis, the results must be stated in terms of standardized explanatory types which are best established, named and made known through systematic presentation.

Relation of Explanatory Regional Presentation to Analysis and System.—The principle just announced deserves more emphasis. Explanatory regional description necessitates the statement of every element of a landscape in terms of a rational counterpart or type that is already a familiar element of the observer's mental equipment. In order that a correct mental counterpart shall be already provided for a newly observed external fact, the mental counterpart must have some basis in previous and pertinent observational experience; in order that the mental counterpart shall have a broad value rather than only an individual value, it must be generalized by safe induction; in order that it shall have a correct explanatory value, the explanation that it suggests must be grounded on logical analysis; in order that it shall embody the best results of earlier workers, it must include all the successful suggestions that come from historical review; in order that various mental counterparts shall be easily remembered and appropriately named, they must be carefully arranged; in order that they shall be familiar enough for ready use, they must be repeatedly studied; and in order that they shall become generally known to geographers, they must be systematically presented in appropriate publications. If these essentials are neglected, the types that form a geographer's equipment may be merely isolated empirical items, memorized in hap-hazard order and known only to himself; and such a geographer's regional descriptions will not be particularly accurate or lucid.

It is particularly in the expansion of a systematic series of standardized types of land forms, with which this essay is chiefly concerned, that the mental process of deduction is of great service. After several related facts have been carefully observed and successfully explained by the analytical discussion of their mental counterparts, and thus shown to be particular instances of a general case, it is possible by deduction to form mental counterparts of new intermediate examples which shall complete an ideal series of standardized types. The types may then be named by nouns of generic value, and qualified by adjectives of specific value; yet, although thus standardized and named, the types are not made rigid. They are elastic and adaptable concepts, easily modified into endless sub-specific varieties, and thus fitted to serve as helpful counterparts of the endlessly various facts of nature. Yet, elaborate as the mental equipment of a well prepared regional geographer thus becomes, it is easily understood by others, because all its parts are reasonably related. Herein lies the real value of the explanatory as contrasted with the empirical treatment of geographical problems. Explanatory descriptions are not to be commended simply because they are more interesting than empirical descriptions; not merely because they are more easily remembered; not only because they tell a larger truth; but still more because they can be phrased in terms of a thoroughly elaborated equipment of standardized types, and because the series of types employed by the observer can, by reason of well tested relationships, be so readily and accurately understood by those to whom the observer presents his results. This has been proved by experience to be true of land forms, and I believe it to be equally true of all other parts of geography.

Structure, Process and Stage.—There is still a matter of importance to be agreed upon, namely, the scheme by which regional presentation shall be guided, in so far as land forms are concerned. The scheme here adopted is the one which was presented in the Round Table discussion at our Chicago meeting in December, 1907, and for which the proposed name is, the scheme of structure, process and stage. Under this scheme each element of the landscape is treated as the surface of a structural mass which has been carried forward from an initial form to some specified stage of development in the cycle of erosion by the action of some specified process or processes; the form thus genetically described being further qualified as to the strength of its relief and as to the texture of its dissection. Let it however be understood that, while the essential features of this scheme may be thus briefly set forth, no sufficient comprehension of them for practical use in regional description can be gained simply by reading over the foregoing lines. Hence it is not merely on the basis of this brief statement of the scheme, but on the basis of a gradually acquired acquaintance with all its details, which it may be assumed that all our members possess, that the scheme is here introduced without further explanation.

The Front Range of the Rocky Mountains in Central Colorado: Condensed, Technical, Explanatory, Regional Description.—The Front Range in Central Colorado is one of those highlands of disordered crystalline rocks which, after reaching an advanced stage in an earlier cycle of erosion, has been introduced by broad uplift into a new cycle that has now reached a submature stage. Or, to phrase it somewhat less briefly, the Front Range is a highland of disordered crystalline rocks, for the most part resistant schists and granites, whose greater original mass long ago suffered more or less complete planation, depression and burial under a heavy series of strata; the compound mass thus formed being divided by a pronounced monoclinal displacement along a north-south belt into a lower eastern area—the Plains area—and a higher western area—the Mountains area. In the cycle of erosion thus introduced, both areas advanced to old age; the weaker stratified rocks of the Plains area presumably being worn down to very faint relief, the more resistant crystalline rocks uncovered in the Mountains area being less completely worn down to a rolling peneplain, here and there surmounted by craggy or subdued monadnocks, five hundred to twenty-five hundred feet in relief, irregularly placed, singly or in groups. The region northwest of Denver was then broadly up-arched into a highland attitude, the broad crest of the arched peneplain forming the present crest of the Front Range at altitudes of from ten to twelve thousand feet, while the higher monadnocks that chance to stand on or near the crest reach altitudes of fourteen thousand feet or more; the eastern slope of the arch descending gently (about one hundred and sixty feet in a mile) for some twenty miles, to altitudes of seven or eight thousand feet at the mountain border. During the cycle of erosion thus introduced and still current in the mountainous highlands, the revived east-flowing streams and their wide-spaced, usually insequent branches have eroded young or early mature valleys from five hundred to one thousand feet in depth, which submaturely dissect the highlands, giving them a relief of medium measure and a coarse-textured form; while the upper valleys and the valley heads among the loftier monadnocks along the range crest have recently been severely and submaturely or maturely glaciated. In the same cycle, the weaker strata of the Plains have already reached advanced old age, being thus worn down some five hundred or one thousand feet lower than the mountain border; and since then have entered upon two later episodes of erosion in which broad, shallow valleys have been excavated beneath the still broader undissected interfluves, although the work of erosion in the mountains, contemporaneous with these later episodes, seems to have caused only a narrow deepening of the chief valleys near the mountain border.

Remarks Upon Condensed Technical Presentation.—When a statement so condensed as the foregoing is spoken at an ordinary rate of delivery, it can be only imperfectly understood even by an audience of experts, because its full understanding requires the extension of various lines of thought to their corollaries; and for such extension oral presentation allows no sufficient time. Hence a terse and technical statement is less adapted for oral than for printed presentation. Even if printed, it can not be fully understood at the first reading. Its limitations in this respect are fully recognized; its introduction here in so condensed a form has been intentional, in order to show by trial that over-condensation is easily possible.

Apart from the terse style of the statement, attention should be directed to the intentional avoidance of geological matters, as such, in the explanatory phrases. Nothing geologic is mentioned that does not bear strongly on the explanatory description of the mountains. The crystalline rocks of the Front Range are commonly regarded as Archean, but for the geographer this date is unimportant; sufficient is it for him to know that the Front Range consists of "disordered crystalline rocks, for the most part resistant schists and granites." Knowing this he can easily infer the kind of stony soils that must cover the broad surface of the highland peneplain; he is ready to understand that the denser granites, where little jointed, will form craggy monadnocks, while the more fissile schists will be rounded into subdued forms and cloaked with creeping angular rocks and scraps; he is prepared to imagine that ragged ledges must crop out on the sides of the younger valleys of the later cycle, eroded beneath the uplifted and soil-covered peneplain of the earlier cycle, even though no mention of such soils and ledges is made. The rocks being of disordered structure and generally resistant, the geographer can infer that no pronounced trends are to be seen in the arrangement of the residual reliefs, and this inference is afterwards confirmed by the explicit statement that the subdued monadnocks are "irregularly placed, singly or in groups," and that the branch valleys are "usually insequent."

A geologist would undoubtedly specify the Paleozoic and Mesozoic dates of the heavy strata which were spread over the worn down and subsiding crystallines, and which, before the monoclinal displacement took place, presumably extended over much of the present Mountains area, although their truncated and worn-down surface is now restricted for the most part to the Plains area; but the addition of the terms, Paleozoic and Mesozoic, does not aid in picturing the present landscape. True, these geographically irrelevant terms enable a reader who has geological inclinations to correlate the Plains strata with strata of similar age elsewhere, and the terms thus have geological importance; but they do not aid a geographer in conceiving the present landscape of the Plains.

Graphic Aid in Geographical Presentation.—It has already been explicitly recognized that a statement so terse as that given above regarding the Front Range will ordinarily be imperfectly understood by hearers or readers. But even a condensed statement may be made much more intelligible by the use of a simple device; namely, a correspondingly condensed diagram, in which the essential features of the region concerned are as much simplified and compressed graphically, as they are simplified and compressed verbally in the terse explanatory description; all the better if the diagram is designed to illustrate as many cycles of evolution as are helpful in understanding the explanatory description. This is again no novelty. It is well known that there are many geographical matters which are better presented pictorially, cartographically, or diagrammatically than verbally. Hence it is just as important to study the proper and effective use of various forms of graphic presentation, as it is to study the values of different methods, treatments, grades and forms of verbal presentation.

Large scale maps are unequalled as a means of empirically presenting actual features in their areal relations. In this respect the maps of the Blackhawk, Boulder, Central City, Georgetown (these on scale, 1:62.500), Canyon City, Castle Rock, Denver, Pikes Peak and Platte Canyon quadrangles (these on scale, 1:125,000) are of great service in presenting the features of certain parts of the Colorado Front Range. Good photographs and carefully drawn sketches from well chosen points of view have vastly greater power than words in the presentation of such parts of a district as can be seen from a single point. Diagrams have another and quite a different value. They do not attempt to present the actual features; they are often drawn as if from unattainable view-points; they are, at their best, the graphic equivalents of the standardized mental types, in terms of which the verbal presentation is couched. In this respect their value is altogether different from that of photographs or sketches of actual things. Diagrams are translations of simplified mental concepts into graphic language.

Diagrams have a great value, in that they can be easily apprehended and remembered. Their parts can be seen in systematic relationship, so that they and the whole which they constitute can be easily named. Thereafter the names bring the parts to mind, and also the relations in which the parts stand to each other. It may therefore be fairly maintained that the explanatory description of a type form ought first to be illustrated by a diagram of the ideal form, simplified to about the same degree as the verbal description, and only afterwards by a picture of a corresponding actual form. When it is remembered that all verbal descriptions give only the merest abstracts of

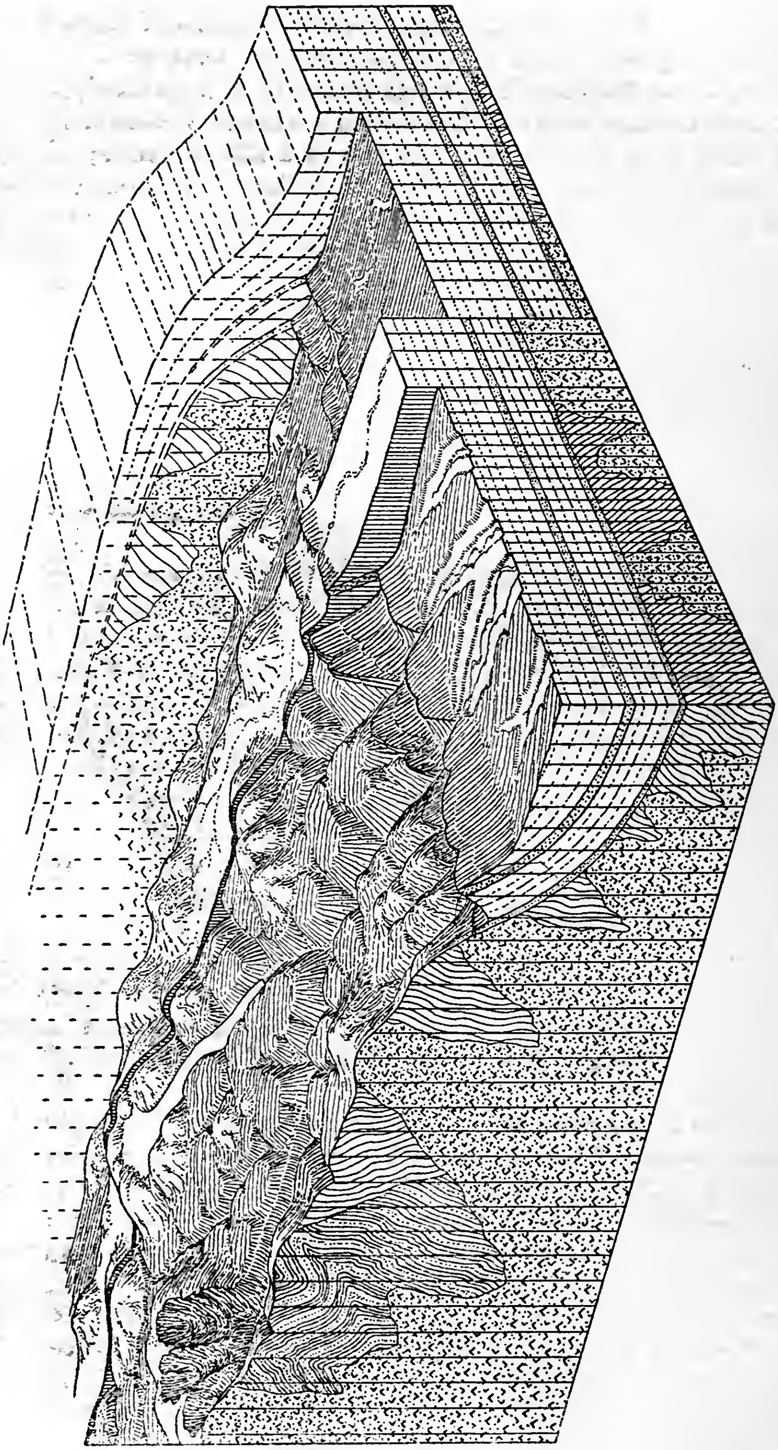

Fig. 1.—Condensed Diagram of the Front Range in Central Colorado.

the facts of nature, it may be better understood why their graphic equivalents are simplified and compressed diagrams, from which all manner of unessential complications and details have been intentionally omitted. Let us now make the experiment of adding a condensed graphic illustration to the condensed verbal description previously given.

Condensed Technical Presentation and Condensed Diagram of the Front Range.—The Front Range of the Rocky Mountains in Central Colorado is a highland of disordered crystalline rocks, for the most part resistant schists and granites, as shown in the foreground block and section of Fig. 1. The originally greater rock mass long ago suffered more or less complete planation, depression and burial under a heavy series of strata; the compound mass thus formed being divided by a pronounced monoclinal displacement along a north-south belt, as in the faint-lined background block of Fig. 1, into a lower eastern area—the Plains area—and a higher western area—the Mountains area. In the cycle of erosion thus introduced, both areas advanced to old age, as in the second, darker-lined block; the weaker strata of the Plains area at the east (right) end of the block being presumably worn down to very faint relief, the more resistant crystalline rocks uncovered in the Mountains area being less perfectly worn down and appearing as a peneplain, here and there surmounted by craggy or subdued monadnocks, five hundred to twenty-five hundred feet in relief, irregularly placed, singly or in groups. The whole region was then broadly up-arched into a highland attitude, as in the slightly shaded third block of the diagram; the broad crest of the arched peneplain forming the present crest of the Front Range at altitudes of from eleven to twelve thousand feet, while the higher monadnocks that chance to rise on or near the crest reach altitudes of fourteen thousand feet or more; the eastern slope of the arch descending gradually (about one hundred and sixty feet in a mile) for some twenty miles, to altitudes of seven or eight thousand feet at the mountain border. During the cycle of erosion thus introduced and still current in the mountainous highlands, the revived east-flowing streams and their wide-spaced, usually insequent branches have, as in the largest or foreground block of Fig. 1, eroded young or early mature valleys from five hundred to one thousand feet in depth which submaturely dissect the highlands, giving them a coarse-textured form and a relief of medium measure; while the upper valleys and valley heads among the loftier monadnocks along the range crest have recently been submaturely or maturely glaciated, one glacier being represented on the further side of the foreground block, and some evacuated cirques and overdeepened troughs being shown on the nearer side. In the same cycle the weaker strata of the Plains have already reached advanced old age, being thus worn down some five hundred or one thousand feet lower than the mountain border; and since then have entered upon two later episodes of erosion in which broad, shallow valleys have been excavated beneath the still broader undissected interfluves, as shown in the right foreground. The work of erosion in the mountains, contemporaneous with these later episodes, seems to have caused only a narrow deepening of the chief valleys near the mountain border.

Remarks Upon Illustrated Technical Presentation.—A verbal statement is so much illuminated by the addition of a condensed diagram that all the labor of designing and drawing is fully repaid. Yet, with its advantages, a diagram has certain disadvantages. It is too specific; for example, the figure here given shows in the foreground section a particular kind of disorder in the structure of the crystalline rocks, instead of leaving the disorder undefined; it indicates too positively in the background block the undetermined overlap of the Plains strata upon the ancient planation surface of the crystallines in the uplifted Mountains area. The verbal statement properly enough leaves these features vaguely defined; the diagram necessarily exhibits them with undesirable definiteness. But on the whole the advantages of a diagram far outweigh the disadvantages; so greatly, indeed, as to warrant the recommendation that some moderate practice in the construction of diagrams should be made part of the training of all geographers who propose to reach proficiency in the analytic, systematic and regional methods of presentation. As far as outline diagrams of the sort here considered are concerned, the common excuse, "I can not draw," reveals an essentially inefficient training. It was once remarked to me, in effect, by a professor in a European university: "That method of giving diagrammatic illustration to systematic and regional treatment is all well enough for those who can draw, but I can't." I protested that he must learn to draw diagrams by repeated practice. A year or so later he wrote me: "I am now constantly using diagrams in my lectures, and with real success."

Explicit Statement of the Corollaries implied in a Condensed Technical Statement.—A condensed technical description may be expanded by an expert reader, if he gives the time to it, so that its lines shall grow into pages; but when thus expanded it is still only of a general nature; it lacks quantitative data and specific details, and is wanting in the local color that comes from the mention of particular instances. Moreover, the mental effort required for the correct expansion of a condensed statement is more than many readers care to give; they are warranted in the feeling that it is for the writer rather than for them to develop more explicitly the ideas that are implicitly contained in a terse statement, just as the corollaries in a text-book of geometry are usually explicitly stated after their implicit presentation in a theorem. The terse statement will then serve as a concise introduction to what follows, and, as far as its compacted phrases are made intelligible by the aid of appropriate diagrams, will take the place of an outline of contents, in view of which each topic, as it is more fully treated, will be all the better apprehended in its proper relation to every other topic.

Subdivisions of the Front Range.—It is usually necessary, in passing from a very general to a more specific description, to make some use of place names. The names thus far used—Rocky Mountains, Front Range, Colorado, Denver—are assumed to be well enough known not to need definition; the names introduced in this section are, on the other hand, assumed to be unknown to most readers or, if known at all, not to be known in relation to the features here discussed; hence they can not, without further definition, be properly used as guides to the location of other unknown features. The ordinary habit of using the names of mountains, streams, villages, and so on, without previously locating these smaller features with reference to known larger features, seems ill-advised: it is often a hindrance rather than a help to the reader; it should be avoided instead of adopted. If a condensed description, given at the outset as an introduction to what follows, is a correct generalization of a district, then a systematic expansion of it ought to lead easily to the recognition of natural subdivisions, within each of which certain smaller features can be located with respect to the larger features; and after this has been done, the names of the subdivisions and of the smaller localities within them can be helpfully employed when need arises, all the better if accompanied by an outline map.

The underlying principle here to be observed is to avoid the empirical use of unknown place names, even if shown on an empirical map, as guides to the location of unknown natural features, and to insist as far as possible on placing every smaller locality in its proper relation to the larger localities that are indicated in the introductory explanatory description of the whole region concerned.

The highland of the Front Range is easily recognizable over a north and south length of some two hundred miles; but we are here concerned only with about one hundred and twenty-five miles of its southern part, included in Fig. 2. Beyond the southern end of the Front Range highland, the Rocky Mountains are continued in the Wet Mountain and other ranges, in which the highland quality is not apparent. The end of the highland is near an embayment due to an irregularity in the usually north-south monoclinal displacement by which the Mountains area is separated from that of the Plains; and here the range is cut across by the deep canyon of the east-flowing Arkansas

River, which rises in an intermont basin some forty miles to the west. Canyon City lies at the mouth of the Canyon—the so-called Royal Gorge of the Arkansas—and the industrial city of Pueblo lies on this river forty miles to the east on the Plains.

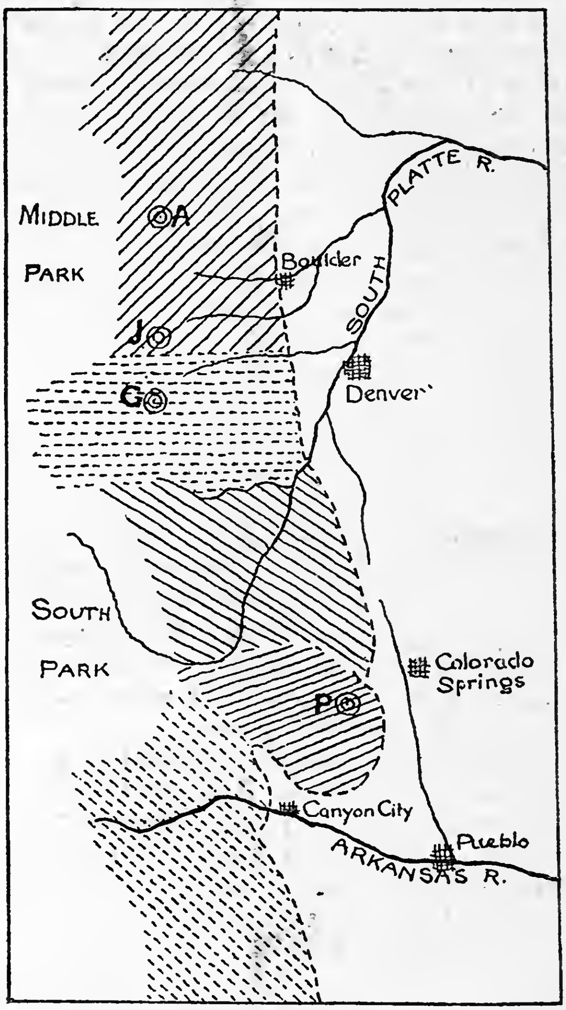

FIG. 2.—Outline map of the Front Range in Central Colorado.

About thirty miles north of the Canyon City embayment is a smaller embayment of similar origin: Manitou lies at its inner angle, and Colorado Springs, five miles to the east. The highland mass between the two embayments may be named after the commanding monadnock of Pikes Peak (14,108 feet), which gains an unusual prominence because it stands near the front of the highland, and because the highland was here given an unusually full measure of uplift at its front. The Pikes Peak highland is about fifteen miles wide; it descends but little on the west to the lofty basin-plain of South Park, drained northeastward by the South Platte; next westward rises the Park Range, then follows the intermont valley of the upper Arkansas River, already mentioned, and beyond this is the Sawatch Range, with the College Peaks. The South Platte River may give its name to the Front Range highland that it traverses, thus defining an extension of about sixty-five miles northward from the Manitou embayment. On the Plains near the mid-front of this division is a village, chiefly occupied as a summer resort and named after an artificial pond, known as Palmer Lake: this point is significant as being the divide between two streams, Monument Creek, which with Fountain Creek flows southward about sixty miles to the Arkansas at Pueblo, and Plum Creek which, with the South Platte that it joins, flows eighty miles northward, before the river turns eastward at the agricultural city of Greeley. Thus the mountain front is adjoined by what seems to be a pair of broad and shallow subsequent valleys, presumably excavated on weaker strata, and apparently inclosed on the east by a low escarpment of harder strata. The valleys may reach a width of five or ten miles or more; but where their heads come together they are narrowed so that the escarpment and the higher part of the plains (7,500 feet) that it borders extend close to the mountain base, except for the small depression in which Palmer Lake lies. Here the mountain highland, at an altitude of nine thousand feet, is only fifteen hundred feet higher than the Plains, a few miles to the east.

North of the South Platte division is a particularly mountainous part of the Front Range highland, including Grays, Torreys, Evans, James and other lofty monadnocks; this division is twenty miles or more in north-south extent, and will be called the Georgetown district, after an important mining town in its center: it is drained by Clear Creek, on which at the mountain base lies Golden, the seat of the State School of Mines; while Denver, the capital of the State, lies fifteen miles east of the mountains, near the junction of Clear Creek with the South Platte. Next, for about twenty-five miles, comes what may be called the Boulder division of the highland, drained by South, Middle, and North Boulder Creeks; at the gorge-mouth of one of these creeks lies the town of Boulder, the seat of the State University. A similar division next north is drained by St. Vrains Creek. To the west of both of these divisions the highland descends into the intermont basin of Middle Park, drained westward by the Grand River to the Colorado; hence the crest of the Front Range here is the Continental Divide. Its culminating summits are Mt. Arapahoe (13,520 feet) near the head of St. Vrains Creek, and Longs Peak (14,271 feet), which rises over the highland some miles farther north, beyond the district here studied.

THE HIGHLAND PENEPLAIN OF THE FRONT RANGE.—The condensed explanatory description of the Front Range clearly indicates that its dominant feature is the elevated peneplain or highland, which gently ascends from the mountain border to the broad mountain crest; a highland surmounted here and there by craggy or subdued monadnocks, irregularly placed, singly or in groups; a highland submaturely dissected by submature or mature valleys. The highland must therefore be imagined as an elevated rolling surface between the monadnocks that rise above it and the valleys that sink below it; for even where typically developed a peneplain must not be conceived as a plain. In the neighborhood of the monadnocks its inequalities often constitute low hills, which if they occurred everywhere would make the peneplain unrecognizable; but in other districts the gently rolling upland is so well developed and so well preserved that its interpretation is beyond doubt, and its imperfections elsewhere thus come to be understood in their true value. A characteristic view of a well developed part of the highland peneplain in the Boulder district is given in Plate Ia.

Let it be explicitly noted that the reason for describing the highland as an uplifted peneplain is not merely that it is now the fashion thus to describe such forms, for it was once similarly the fashion to describe them as uplifted plains of marine abrasion. Fashion is a poor guide to scientific decisions. The reasons for excluding marine action and for regarding the highland as an uplifted peneplain of normal erosion are, first, that its undissected form, as far as that can be reconstructed from its present dissected surface, must frequently have had a gently rolling surface, such as an old surface of normal, subaerial degradation should have, and not a smooth surface such as a plain of marine abrasion ought to have; second, that no line of ancient sea cliffs is found, separating a smoothly abraded surface from a neighboring area of hilly land, such as the theory of marine abrasion either tacitly or explicitly presupposes; and third, that none of the numerous monadnocks exhibit sea cliffs on their exposed side, as they should do if the surrounding surface had been planed off by sea waves. If the highland were stated to be an uplifted plain of marine abrasion, the occurrence of all these features would be implied. The mere statement that the highland is an uplifted peneplain ought therefore immediately to indicate that it possesses none of the above-specified features of a plain of marine abrasion, but that it exhibits many or all of the characteristic features of a plain of subaerial degradation. It is in problems like this that the common and familiar possession of a well established series of ideal types by well trained geographers goes so far towards making geographical descriptions effective.

The dissection of the peneplain being described as submature, even though some of its valleys are mature, it must be inferred that significant areas between the larger valleys still remain undissected; yet in the neighborhood of these valleys, many small ravine heads must be imagined as already encroaching upon the highland surface. In the mountains of the Boulder division, northwest of Denver, where the undulating skyline of the highlands is repeatedly seen as one walks over the highlands, the westward ascent of the peneplain, about one hundred and sixty feet in a mile, is easily recognized, especially where the highland is free enough from monadnocks to expose long stretches of its surface in a single view. One part of the slanting highland in this district, standing at about ten thousand five hundred feet altitude, is known as Caribou Flats, C, Fig. B2; if neighboring and similar slanting highlands are called Bryan Mountain, R, and Chittenden Mountain, H, this probably means only that they were named as seen from the valley bottoms.

So distinct an inclination as one hundred and sixty feet in a mile is much stronger than that of a peneplain at the time of its degradation, and must be due to tilting at the time of elevation. This is easily proved by reverting for a moment to analysis. Note first that the valleys of several streams in the district northwest of Denver become somewhat deeper as they are followed westward into the highlands; hence the eastward slope of their streams is not so strong as that of the highland surface; yet these submature streams, heavily loaded with coarse waste, must have a decidedly stronger slope now than their ancestors had on the lower lying peneplain; all the stronger, therefore, is the eastward slope of the uplifted peneplain than was that of the peneplain before its uplift: hence the uplift was here accompanied by gentle eastward tilting. From favorable points of view, as for example, from the cirque walls at the head of Middle Boulder Creek, M, Fig. B2, one may look eastward down the slope of the highlands, as in Fig. E3, and see that the eastward projection of the highland surface would intersect the Plains some twenty or thirty miles east of the mountain base. Hence the slanting or arching uplift, whereby the mountain belt was introduced into the current cycle of erosion, was decidedly greater in the mountains than farther eastward; indeed, the uplift may have soon died out in that direction, just as the much earlier monoclinal displacement did.

It is interesting to note that the highland as a mass, from the base of the mountain front to the crest of its arched uplift, occupies the zone of altitude within which tree-growth is here possible. The Plains, sloping gently eastward from the mountains, are treeless, owing to aridity. The monadnocks which rise above eleven thousand two hundred or eleven thousand four hundred feet are for the rest of their height above the timber line, owing to low temperature. The mountainous surface between these limits usually has an open tree-growth, close-set forests being exceptional.

Southwest of Denver in the South Platte division, the slant of the highland is less marked, and in some views—for example on the highland, Fig. A2, west of Palmer Lake, between Denver and Colorado Springs, the skyline seems to be essentially level; much more so in the actual view than would be inferred from the crowded contours of the Platte Canyon map-sheet. It was in this part of the range that we saw the smoothest horizon at altitudes of ten or eleven thousand feet; it was rarely interrupted by monadnocks, although the foreground of some views was rather broadly interrupted by wide-open valleys, of which that of the South Platte at Buffalo, Fig. A1, may be taken as an example. The destruction of the open forest by fire has disfigured many views. In this district the uplift of the peneplain must have been very even. It may be noted that here, as well as in the Boulder district, the present altitude of the peneplain must not be taken as a direct measure of its uplift; for the peneplain before uplift may have had an altitude of several thousand feet, by reason of the great length of the rivers by which it was drained. The peneplain may have even then deserved to be called a highland, rather than a lowland; it was surely at a significant altitude above baselevel, and hence ought not to be described as having been "baselevelled." Cvijič has called attention to this corollary of the theory of peneplanation and has coupled therewith Philippson's principle, in accordance with which a peneplain may be dissected without suffering elevation, provided the district between it and the sea is depressed or drowned. In the absence of evidence regarding such depression, and in view of the tilting of part of the Front Range highland, as proved above, uplift of the highland itself appears probable; but the uplift may not have measured more than some five thousand feet.

West of Denver in the Georgetown district the monadnocks are often so numerous, so closely set and so high that the elevated peneplain can hardly be recognized; yet it was from a study of this district that an excellent statement of the physiography of the Front Range was prepared by Ball[1], who for the first time fully set forth its character as a two-cycle mountain mass. Far north in Wyoming the peneplain is remarkably well developed, as one may judge not only from the disappointment of the casual traveller who sees no mountains

[1] S. H. Ball (with J. H. Spurr and S. H. Garrey) Economic Geology of the Georgetown quadrangle, Colorado. Prof. Paper. 63, U. S. Geol. Surv., Washington, 1908, 31-35.

as he crosses the crest of the range on the Union Pacific Railroad, but still better from the explicit description by Darton in Folio 173 of the U. S. Geological Survey. Far south, beyond the canyon of the Arkansas River, the even skyline was not apparent from our points of view in that district; it seemed as if the mountains there had been uplifted in a more disorderly manner at the beginning of the present cycle of erosion, and that their crests had been more deeply sculptured during the present cycle than is the case farther north.

The extension of the peneplain west of the range crest is intentionally left unmentioned. Our route did not enable us to determine the manner in which the highland descends into the broad and elevated basins known as South and Middle Parks; but our inference was that, while irregular warping of the mountain mass at the time of its last uplift may have contributed to the smaller initial altitude of the park areas, their altitude today is in large part the result of the erosion of bodies of weaker rocks—similar to those of the Plains—which occupied basin-like structures probably formed in association with the monoclinal displacement by which the present mountain area was first differentiated.

It follows from the foregoing that the Front Range belongs in that lately recognized and rapidly growing class of mountains, in which the deformation that produced their disordered structure has little or nothing to do with their present form. The greater deformation of the crystalline rocks in the Front Range was produced long before their ancient planation; and hence long before their burial under the covering strata now seen in the Plains. The strong monoclinal displacement was followed by peneplanation, except where the monadnocks survive. The present form and altitude of the range is therefore not due to the monoclinal displacement of the compound mass, still less to the remotely ancient deformation of the crystalline basement, but to the broad and simple up-arching of a much later date. In so far as the range is really mountainous, this character is to be associated with the monadnocks that survived the cycle of peneplanation, and with the valleys that have been eroded since the peneplain was elevated. As a matter of fact, many a view even at altitudes of ten or eleven thousand feet is by no means mountainous, but monotonous instead, as on the highland (Figs. C3, C4) west of Colorado Springs and northwest of Pikes Peak (Fig. C5), where it is crossed by the Colorado Midland Railroad. Here, however, part of the present simplicity of the landscape is due to a heavy cover of gravel, now late-maturely dissected to small relief, which hides the rocks of the highlands for many miles. Cross[2] has suggested that these gravels are associated with glacial

[2] W. Cross, Folio 7, Geol. Atlas of the United States. U. S. Geol. Surv., Washington, 1897.

action, but as they are some miles distant from the nearest signs of glaciation in the cirques and moraines of Pikes Peak, the gravels seemed to us more probably associated with obstruction of drainage by warping at the time of uplift.

A brief systematic digression may here be made with profit.

Highlands and Mountains Treated as Uplifted and Dissected Peneplains.—The attempt to treat mountains as the result of erosional processes, working on uplifted masses which reflected their disordered internal structure in an extremely irregular initial surface, has been attended with difficulty; a difficulty indeed so serious that this chapter of the physiography of the lands has generally been treated unsystematically, except for a few special cases of simple deformation, such as block mountains and domed mountains. The difficulty has, however, been very much reduced by the studies of the past twenty years. It has been found that most mountain ranges of the world are not to-day in a first cycle of erosion, initiated by the great deformations to which the extreme disorder of their structure is due; but that, in a large number of investigated ranges, the first cycle of erosion, presumably introduced by the production of their disordered internal structure, had ages ago advanced far towards its close; and only after its initial inequalities had been thus almost completely removed, even to their peneplanation in many cases, has a new cycle been introduced by much simpler movements than those of the primary deformation.

All such mountains are open to relatively easy systematic treatment; for their initial forms in the current cycle are the subdued and simplified forms developed in the late mature or old stage of the preceding cycle, now more or less uplifted, warped, dislocated and tilted, but not again thrown into strong disorder. On those simple forms, the rivers, perhaps partly persistent in courses consequent on initial deformation, but as a rule adjusted to the deformed structures on which they had worked so long, are revived into new activity, and develop a new mountainous form by the incision of deep valleys. "Mountains of circumdenudation" is therefore no longer a term to be applied only to dissected plateaus of horizontal structure: it applies equally well to many ranges of deformed structure, and this important principle was recognized for the Front Range by Marvine in 1873. The scheme for the systematic treatment of mountain forms has thus been most effectively as well as unexpectedly aided by the facts of nature.

Two-Cycle Mountains.—Many analytical discussions of mountains, which bear evidence of two cycles of erosion, might be instanced. The earliest example to be recognized is in Wales; Ramsay sixty years ago explained the comparatively even Welsh uplands, in which the valleys of to-day are carved, as an uplifted plain of marine erosion. Singularly enough no detailed account of this interesting district has been prepared by later British students of land forms. The Highlands of Scotland are perhaps more familiar examples of two-cycle mountains than the uplands of Wales, because of the attractive description that they have received at the hand of Sir Archibald Geikie. As in Wales, marine erosion was formerly held accountable for the broad truncation of the disordered Highland structures and the reduction of an ancient disordered mass to a comparatively even surface, in which, after elevation to its present altitude, the existing valleys have been carved; but British opinion seems now to be generally in favor of attributing the undulating truncation of the Scottish Highlands, as well as of the Welsh uplands, to normal erosion during a former lower stand of the region, rather than to marine erosion.

The rolling highlands of the Slate Mountains which border the gorge of the Middle Rhine were explained as surfaces of marine abrasion by the older German geologists and geographers; in this respect they followed the lead of von Richthofen, whose attention had been directed to the broad truncation of disordered structures during his studies in China: but in Germany, as in Great Britain, a number of the more recent observers ascribe such uplands as those of the Slate Mountains to normal peneplanation.

In the central highlands of France various observers have recognized a well developed peneplain, more or less dissected: one of the best accounts of this region concerns its northwestern part, the Limousin, in which the dominant peneplain has lately been described by Demangeon as surmounted by remnants of a still older peneplain in certain highland areas, and which may therefore be regarded as involving a three-cycle development since the last disorderly movement of its rocks. Still more recently, Briquet has studied the forms of the present landscape in the southeastern part of the same region, which he believes represent four successive cycles of erosion, separated only by simple changes of level; the earliest cycle being represented by an elevated peneplain on which the valleys had reached extreme old age; the latest cycle by narrow, steep-sided young valleys.

Brückner and Machatschek regard the Jura as in a second cycle, following a first in which the folded mass was reduced to moderate relief. Even in the Alps there are many traces of vast erosion on enormously deformed structures, before the torso thus prepared was warped into its present attitude and thus introduced into the cycle of erosion now current: the simplest line of evidence to this conclusion is found in the tame manner in which enormously deformed and deeply eroded structures disappear with small relief under the modern deposits of the plain of the Po.

High standing, deeply dissected peneplains are described by de Martonne in the Transylvanian Alps; Danes, Cvijič and others have found lower standing peneplains in the Dinaric Alps. Various authors, among whom Reusch, Richter, Vogt, Nussbaum and Machatschek may be named, have interpreted the highlands of Norway as an uplifted peneplain in various stages of dissection. The southern extension of the Ural Mountains is still a low-lying peneplain, undissected over large areas; but farther north uplift and dissection of what seems to be part of the same peneplain produces a topography of sub-mountainous relief. The Tian Shan and the Pamir exhibit numerous and extensive highland peneplains, more or less perfectly developed before uplift to their present altitude, and more or less completely dissected since then; the observers here to be referred to are Friederichsen, Keidel, Huntington, R. W. Pumpelly and the present writer. Lofty highlands of erosion in the northwestern Himalayas are described by Oestreich; Loczy and Filchner describe similar forms in Tibet, though without calling very explicit attention to their meaning. Willis has given abundant description and discussion of high standing, dissected peneplains in the mountains of China. Lately de Martonne[3] has summarized these and other records in an important article on the evolution of the relief of central Asia.

Andrews describes dissected peneplains in the highlands of northeastern Australia. Bornhardt, Uhlig and Jaeger describe highland peneplains, more or less dissected, in equatorial east Africa; Passarge and Hassert in southwest and west Africa. Keidel reports uplifted peneplains in the eastern members of the Argentine Andean *massif,* where they are of greater extent and perfection than those he had previously seen in the Tian Shan. Bowman describes a lofty peneplain in the Bolivian Andes, little dissected in its more arid areas, deeply dissected on its rainy eastern slope.

In our own country the evolution of the Appalachians in two or more cycles of erosion has been repeatedly discussed. The Laurentian Highland, hardly a mountainous region though often so represented on maps, is regarded by Willson as a vast peneplain; and the highlands of northern Wisconsin are similarly treated by Smyth and Weidmann. The Sierra Nevada of California is generally believed to be a more or less faulted and tilted block, an uplifted part of a vast peneplain, now sloping westward from the strong and somewhat elaborately dissected escarpment that it presents to the basin of Nevada. In that basin, Louderbach has given a convincing demonstration of two-cycle origin for at least one of the Basin Ranges, thus substantiating, as far as one example among many can, the view long

[3] E. de Martonne, L'évolution du relief de l'Asie centrale. La Géogr., XXIII, 1911, 39-58.

ago presented by Gilbert. Diller has found peneplains at various altitudes in the mountains of Oregon; Willis describes the Cascade Range as an elaborately dissected peneplain; Dawson some years ago recognized an uplifted and deeply dissected peneplain of wide extent in the highlands of western Canada, concerning part of which Camsell has recently given some details. Gilbert regards the approximate equality of mountain altitude in parts of Alaska as suggestive of a two-cycle origin for some of the ranges that there border on the sea. Finally, Marvine clearly recognized the two-cycle origin of the Front Range, as is shown in the citations from his report of 1873 at the head and on later pages of this article, though he did not use the term "cycle" and though he was mistaken in identifying the peneplain of the Highlands with the planation surface of the mountain front.

Systematic Equipment With Standardized Types for the Explanatory Description of Mountains.—The analytical study of all these different highlands and mountains has brought forward good reasons for explaining their existing forms as the product of at least two cycles of erosion, the earlier one of which may have been initiated by the deformation which gave the masses their deformed structure, while the later one was introduced by relatively orderly uplift. It is therefore full time that conscious attention should be directed to a well planned arrangement of the ideal types, which shall be the mental counterparts of these many actual examples; and to the completion of a well developed, systematic series of ideal types, various intermediate members of which are developed deductively in view of the general principles established by analysis regarding two-cycle mountains. The most significant matters to indicate are first, as always, the general structure of the mass; then the stage reached in the earlier cycle before renewed elevation; next the character and amount of elevation; and finally the stage reached in the later cycle after elevation. An elementary graphic treatment of this problem is attempted in my "Practical Exercises in Physical Geography." It may be noted in passing that the term "cycle" finds unexpected justification in those two-cycle mountain ranges, which began in a peneplain very similar to the peneplain in which they will end.

There can not be the least question that the possession of some such series of ideal types, systematically arranged, conveniently named, and thus standardized for easy and immediate use in the description of new regions, greatly strengthens the equipment of a modern geographer, as compared to that of a geographer of the older school. Surely when a modern geographer, thus equipped for mountain exploration and description, returns from a visit to a two-cycle mountain range, he need not, when he is writing for other modern geographers, gradually, inductively, laboriously introduce his problem; he need not even repeat its analysis; he may at once use the results of analytic and systematic study, and draw upon the equipment that such study has furnished for his descriptions of what he has seen. Two-cycle mountains today constitute a well established class, and the types in terms of which they may be described are in some fair degree standardized. To discuss matters of this sort before using them would be, among expert geographers, about the same as demonstrating over again in an essay on stratigraphy intended for expert geologists the familiar principle that two periods of formation and a period of erosion are indicated by an unconformity.

The discussion of peculiar and exceptional cases is of course always in order; but standardized cases can be dealt with more promptly. A modern geographer may therefore in his regional studies make immediate use of standardized type forms of two-cycle mountains when he has to deal with that class of forms, because his types are abundantly supported by widespread observation, warranted by repeated and critical analysis, and conveniently arranged by systematization. For example, he need merely say: "Here is another two-cycle mountain range which reached advanced old age in its earlier cycle, but which is still submature in the present cycle." His readers, similarly equipped with a scheme of standardized types, will immediately understand the essence of what he means. Both writer and readers may then easily pass on to the next subject.

The Monadnocks.—The concept of monadnocks surmounting a peneplain is one of the simplest that is to be encountered in the systematic study of land forms. Residual reliefs of this class are to be conceived as determined by a more or less pronounced excess of resistance, due to some peculiarity of composition or of structure: but it should be understood that various factors, besides those which are indicated by difference of color of geological maps, may suffice to determine the survival of monadnocks in the slow process of inorganic natural selection, which operates during the long continued later stages of an uninterrupted cycle of normal erosion. Differences in the attitude or number of stratification or of foliation planes, in the number of joints and other surfaces of separation, in the texture of mineral grains, and in the degree of consolidation, may all contribute to cause a slightly slower degradation of one part of a single rock formation than of another. Mt. Monadnock itself, the type of this class of forms in southwestern New Hampshire, has been described by Perry[4] as consisting of essentially the same kind of schist as that which constitutes the surrounding uplands which Monadnock surmounts; the survival of the mountain in the cycle of erosion which produced the now ele-

[4] J. H. Perry, Geology of Monadnock Mountain, New Hampshire. Journ. Geol., XII, 1904, 1-14.

vated peneplain of the uplands is therefore explained by him as due to its initially greater mass, as if it were the survivor of an initial divide: but if Mt. Monadnock were really of this origin, other divides in its neighborhood ought to show a similarly strong relief, and they do not: hence I am still inclined to attribute its survival to excess of resistance as determined by something less manifest than difference of composition.

For residuals due to excess of initial mass, Penck[5] has proposed the name *mosore.* Whether any of the residuals of the Front Range highland are of this kind, has not yet been determined. Their distribution seems arbitrary, but it is to be presumed it will be accounted for when the nature of the rocks and their relation to the drainage of the earlier cycle is better understood. In the meantime they will here all be called monadnocks; indeed it may be that the definition of this term should be expanded so as to include both classes of residuals, in view of their similarity of form and of their difficult discrimination.

The monadnocks of the Front Range highlands may in most cases be described by the term "subdued," a term that is peculiarly appropriate for mountains in late maturity or early old age, because it at once suggests the larger forms that they once had, the strong resistance that they have opposed to destruction, their gradual subjugation by the persistent attack of the weather, and the gentle form to which they have been reduced. As in all typical examples of subdued mountain forms, these rounded dome-like masses are covered with creeping waste, and the texture of their dissection is coarse; that is, the ravines by which they are slightly incised are widely spaced. The form of such domes is hard to sketch, because so few well defined lines are to be seen. One of the best examples of a subdued dome is Bald Mountain, B, Fig. B2, which rises above the well defined highlands in the western and higher part of the Boulder district, apparently reaching an altitude of nearly twelve thousand feet, and yet, as seen from the east, Fig. B1, it bears no marks of glacial sculpture, as if its preglacial form had been unfavorable for the accumulation of snow reservoirs, in spite of its great height. It is photographed in Plate I*b*.

In certain granitic districts, the monadnocks exhibit fine-textured, craggy forms, with angular outlines and many bare ledges near their tops, and large boulders of decomposition on their flanks. These rugged masses are still too bold to be called subdued. A good example is seen in Sheep Mountain (10,500 feet), Fig. C1, which rises in strong profiles over the eastern and less elevated part (8,500 feet) of the district northwest of Denver. Some smaller, unnamed, craggy

[5] A. Penck, Geomorphologische Studien aus der Herzegowina. Zeitschr. deut. u. österr, Alpenna, XXXI, 1900, 25-41; see p. 38.

hills in the same district are shown in Fig. C2. Farther south, the irregular form of three unsubdued residuals that surmount the even uplands over the open valley of the South Platte is indicated by their names, Needle Butte, Long Scraggy and Little Scraggy Peaks, Fig. A1. Plate II*a* shows a group of such forms.

The difference between the subdued and the craggy forms appears to be dependent on the number of joints or fissures in the rocks. In the more fissile rocks, the whole surface of the dome-like mass comes to be covered with a slow-creeping sheet of coarse rock waste; bare ledges are hardly seen, except where glacial excavation has taken place. In the more massive rocks, which were granites in all the cases that we noted, weathering enters chiefly by the wide-spaced joints, and leaves large unjointed crags standing between widened crevices. Weathering on the face of the crags results in splitting off rock scales which are soon reduced to gravelly waste. Thus rounded blocks frequently stand up in bold forms and ledges.

Exceptionally strong and mature forms were noted in the Tarryall Range of monadnocks near the upper valley of the South Platte, northeast of South Park, shown in the background of Fig. C3; they seemed more vigorously mountainous than any other non-glaciated summits that we noted, but as they were only seen at a distance of several miles, further account of them is omitted. Pikes Peak, Fig. C5, is one of the largest monadnocks.

The prevailing similarity of altitude among the mountains of Colorado has often been mentioned. In Gannett's Dictionary of Altitudes (1899), there are forty-two summits in Colorado between 13,500 and 14,000 feet; thirty-nine between 14,000 and 14,500 feet, and none higher than 14,500. As far as the Front Range in the central part of the State is concerned, the meaning of this accordance of altitude is not far to seek:—it results first from the reduction of the greater mass of the former cycle of erosion to subdued forms of moderate relief, which seldom rose more than two or three thousand feet over the peneplain that they surmounted; and second, from the simple character of the broad uplift by which the current cycle of erosion was introduced; and to these chief causes may be added a third, namely, a relatively rapid reduction by glacial sapping of any excessive height that the loftiest summits may have had, as will be further shown below. How far this explanation applies in other parts of the State, I am not prepared to assert.

The Valleys.—The valleys by which the highlands of the Front Range are as a rule submaturely dissected vary from very young forms, as in the steep-walled Royal Gorge of the Arkansas River, and from the sub-mature, craggy-sided valleys of various creeks, to the late mature, widely opened valley along certain parts of the South Platte.

The difference of development and of expression is evidently to be referred to differences of rock resistance. The very young gorge of the Arkansas and the wide-open, late mature valley of the South Platte are, however, both exceptional. The steep walls of the Royal Gorge, often slanting 70° or 80°, expose almost continuous surfaces of bare rock, and thus afford a superb natural section of the disordered schists and granites; as in all such cases, the master joints exercise much control over the detailed sculpturing of the rock-face. The graded sides of the South Platte valley, Fig. A1, at its wider parts, have moderate declivities of 12° or 15°. Here the river has a flood plain a few hundred feet wide. The insequent branching of its many little side valleys suggests that if, in the late mature stage here reached, joints and fissures exert any control over their arrangement, the control must be intermittent and imperfect; for there must be many parts of the side-valley lines independent of fissures, and many fissures not developed into valleys.

Most of the normally eroded valleys in the highlands are V-shaped in cross-section, as in Figs. A3 and D1, and Plate II*b*. The streams are roughly graded; boulder-rapids are common, but ledge-rapids are rare. Most valleys are narrow floored, with little or no flood plain; steep-sided, with many irregular alternations between projecting ledges and graded slopes; and sufficiently sinuous for the production of numerous spurs, whose overlapping ends soon close the view along the narrow valley bottom. It goes without saying that the junctions of branch and trunk valleys are at accordant level, except in the upper glaciated regions; for accordant junctions obtain universally in submature, mature and old valleys of normal origin. Exceptions to this rule are here seen only in small, dry gulches, which may "hang" on the hardest rocks ten or twenty feet over the main torrent of a normal valley.

The depth of the main valleys is less than might be expected, in view of the considerable altitude of the highland. Many valleys are incised only to a depth of six or eight hundred feet; a few reach a depth of one thousand feet; this measure is exceeded only in some of the glacial troughs. The apparent depth is increased in certain valleys which happen to lie so near a monadnock that its slope above the highland level is added to the slope of the valley side below the highland, as is the case on the southern side of the valley of Fourmile Creek, Fig. D1, where Sugarloaf and Bald Mountain rise along side of it. (This Bald Mountain is not the same as the one shown in Fig. B1). Not only are the valleys of moderate depth; they are not likely to become much deeper in future, unless in short stretches near their headwaters, for the further deepening of the valleys in the mountains depends largely on the deepening of the valleys on the plains; and inasmuch as these are all already at grade, their further deepening can be accomplished only when the mountain streams bring less load to them; and that is a very remote contingency, hardly to be realized until the mountains themselves are subdued in a late mature stage of the cycle through which they are now passing.

The valleys are seldom wide enough to allow the easy construction of wagon roads; the picturesque road up Middle Boulder Creek being a departure from the rule. The usual habit of the roads of earlier date was to ascend the mountain front and to traverse the highlands; but farther in towards the crest of the range, wagon roads follow the broadened floors of the glaciated troughs. Railroads of later date often enter the gorges from the Plains.

In the Georgetown and Boulder districts, west and northwest of Denver, most of the larger creeks pursue eastward courses, as if they might be consequent on the arched uplift by which the present altitude of the range was produced; but a more plausible explanation regards these creeks as simply revived from the former cycle of erosion. If this be correct, it suggests that the present crest of the range is up-arched along the line of a former divide, which possibly represented a still earlier axis of uplift; but these transcendental questions can not now be resolved.

Two rivers have eroded through-going valleys, which drain areas back of the Front Range; one is the South Platte, which discharges the waters of the lofty intermont plain of South Park, where it has as yet hardly begun to incise its course; the other is the Arkansas, which issues from a deep intermont basin and traverses the Front Range in apparently antecedent fashion: yet the location of this river across the forward part of the range in which the Royal Gorge is incised seems to be related to a saddle of stratified rocks which there formerly lapped over the present mountain crest at a much less altitude than could have elsewhere happened. Indeed the highland in which this gorge is so sharply incised seems to be nothing more than part of the floor of ancient planation, to which the crystallines were reduced before the deposition of the Plains strata, here deformed in an unsymmetrical anticline at the time of monoclinal displacement, but not lifted so high as was usually the case, and now laid bare. There is local evidence in favor of this view, in the presence of patches of the sedimentary beds on the two flanks of the highland, as well as in the relatively even form of the highland at altitudes less than those reached by the highland peneplain elsewhere. When it is remembered that the steep walls of the Royal Gorge indicate an unusual resistance in its rocks, it may be noted that only by regarding the highland adjoining the gorge as a part of the ancient planation surface, less uplifted than usual, can we reasonably account for its moderate altitude.

The tributaries of the highland streams are of typical insequent arrangement, as far as our observation went. This might be expected from the absence of trends in the distribution of the monadnocks. A characteristic feature of the tributary valleys is that they are usually of more mature expression than the main valleys which they join. This may be regarded as a normal, expectable feature; for inasmuch as the action of the weather, by which valley sides are worn back to graded slopes, will be at essentially the same rate all along the valley courses, it follows that, other things being equal, where the streams are largest and cut down their valleys most rapidly, the valley sides will be steep; while where the streams are of small volume, their downward erosion is slower, and the valley sides there may be weathered back to a graded slope about as fast as they are deepened.

The two episodes of renewed erosion, by which broad valleys have been excavated in the Plains forward from the mountains, are not always recognizable in the forms of the valleys in the mountains. Hence it may be supposed that the renewed valley deepening, as permitted by these reviving episodes, has been accompanied by sufficient widening to destroy all traces of the more mature preëxistent valleys. The only distinct exception noted to this rule is in the gorge of South Boulder Creek, Plate III*a*, which issues from the mountains where they are bordered by an exceptionally resistant series of tilted sandstones, almost deserving of the name of quartzites, which form the "Flat-irons" south of Boulder, Plate V*b*, with summits higher than the neighboring highland peneplain. Here the mouth of the gorge is Y-like, the upper part presumably indicating an approach to a mature form, corresponding to the broad peneplanation of the Plains, while the lower part is still narrow and young, corresponding to the episodes of valley excavation in the Plains. Let it be at once added that the cause of these episodes of valley excavation in the Plains is not necessarily to be sought in renewed regional uplifts. The distance to the sea is so great that a very slight decrease in the slope of the graded rivers across the Plains, such as climatic change might produce, could easily, as Johnson[6] has pointed out, suffice to account for the observed revival of erosion.

Glacial Sculpture of the Higher Mountains and Valleys.—The subject here reached is one in regard to which there is still some difference of opinion among geographers and geologists; hence it would be now appropriate to resort to an analytical method of presentation, in order to determine whether the temporary occupation of the valley heads among the higher monadnocks by local glaciers was competent or not to produce the peculiar forms which are there so mani-

[6] W. D. Johnson, The High Plains and Their Utilization, 21st Ann. Rep. U. S. Geol. Surv., Part IV, 1901, 601-768. See page 628.

festly unlike those of the non-glaciated valleys. But those who have become convinced that glaciers are remarkably effective agencies of mountain sculpture may be excused if they do not, on each return to a formerly glaciated mountain range, return also to a statement of the reasons that have led them to regard the highly peculiar forms there occurring as due to glacial erosion.

For my own part, my previous essays have said all that I have to say, for the present, upon the analytical aspect of the subject; and as the features of the higher parts of the Front Range, seen last summer, brought only abundant confirmations of conclusions reached previously and elsewhere, it appears fitting to continue here the regional treatment adopted on the previous pages. I shall, however, occasionally relapse into a somewhat systematic treatment of glacial features, because the employment of such terms as young, mature and old in connection with forms of glacial origin is not yet generally established.

The first point to emphasize in this connection is the three-fold order of statement that is necessary, if one would adopt a thorough-going explanatory treatment for the description of glaciated mountains. A clear understanding of this problem can be gained only by stating, first, in terms of structure, process and stage, the general character of mountain form that was attained in immediately pre-glacial time; second, the amount of work done during the episode of glaciation, both directly by eroding the parts under the ice, and indirectly by sapping the parts above the ice, as well as by deposition of moraines; and third, the work done by normal erosion in postglacial time.

A three-fold order of statement of this kind is, however, not peculiar to the physiographical account of glacial erosion; it is needed wherever existing physiographical forms result from discontinuous processes. For example, in the treatment of the simplest of all kinds of forms, a coastal plain, it is necessary to state first, the form of the sea bottom before uplift; second, the amount and character of the uplift whereby a part of the sea bottom was raised into a land surface; and third, the changes that have since then been introduced by normal and marine erosion. Or in the case of an interruption of a cycle by movement of the land mass with respect to baselevel; it is here necessary to state, first, the form that the region had assumed before the interruption occurred, and this statement can be best made, as usual, in terms of structure, process, and stage; second, the nature and amount of the movement causing the interrruption; and third, the erosional work done in the new cycle that was introduced by the interrupting movement.

So in the geographical treatment of a fault, which is simply a special case of the preceding more general case: first, the form of the district before faulting took place; second, the nature and amount of the faulting, including here the length of the fault, the height of its escarpment at different points along its course, and the relative displacement of the adjoining blocks; and third, the changes due to erosion since faulting. Again, for shore lines; it is essential to state, first, the form that the region had gained before the movement took place by which the land mass was placed in a new attitude with respect to the ocean; second, the nature and amount of this movement, from which the features of the initial shore lines may be stated as a corollary; third, the changes that have been produced by marine and normal agencies since the movement. In all these cases, the importance of the first statement decreases if the forms that it describes are practically obliterated by the changes under the second and third statements; and a twofold order then suffices.

In view of the demonstrated complexity of the glacial period in the Rocky Mountains and its division into at least two glacial epochs, separated by an interglacial epoch of a considerable duration, as appears from studies by Ball, Westgate, Capps and other observers, it would appear to be theoretically necessary here to expand the threefold statement into a fivefold statement; but as far as our observations in the Front Range—and also in the Sawatch Range, west of the upper Arkansas Valley—are concerned, the subdivision of the glacial period into successive epochs is here a geological problem of little geographical import. It seems as if the glaciers of the later epoch merely went on with the work of the earlier glaciers; hence the net geographical consequences of glaciation are much the same as if the two separate epochs had been consolidated into one longer epoch. Closer study may, however, require a change in this simple statement of the case for the Rocky Mountains, as it has already for the Alps. It may be noted in passing that the Rocky Mountain region affords no sufficient evidence in support of the view that glacial episodes were brought on by an elevation of the region, and interglacial episodes by a depression.

The preglacial form of the Front Range highlands and monadnocks may be inferred from the description already given of their present form. The monadnocks must then have been somewhat higher, and the normal valleys shallower and narrower than they are now; but the general quality of form must have been much the same as at present. The higher part of the range must have been then, as now, an up-arched peneplain, surmounted by irregularly scattered subdued monadnocks, usually of large-bodied, coarse-textured, waste-covered form, rising from five hundred to twenty-five hundred feet over the highland, and but slightly incised by their wide-spaced valley heads. True, the more massive granites rose in craggy outlines, but these are not now to be considered, as all the more characteristic features of glacial sculpture that we saw were associated with subdued, waste-covered domes.

Well developed cirques may be counted by the score. The varying relations of domes and cirques are well illustrated in the northern part of the Sawatch Range, as in Figs. D4 and D5. Some of the cirques are small and consume only the lesser part of a dome, as in Plate III*b*; others are huge excavations, leaving only the smaller part of a dome, as in Plate IV*a*. Evidently, the work done by the valley-head glaciers must have been a function of their duration, as well as of their size and slope; hence cirques, like any other forms, ought to be treated with intentional regard for the stage of development that they have reached; a point that has lately been emphasized by Hobbs[7]. It may be noted that the term "glacial cycle," as used by Hobbs, refers to what is here treated as a climatic accident or episode, introduced and closed by a change of climate due to external causes. The phrase glacial cycle, is here reserved for the ideal case of so long a continuance of glaciation under fixed climatic conditions—except for changes of climate with change of altitude due to degradation—that glacial erosion would be carried to its completion, truncating all the higher mountains at the snow line, and thereby causing snowfall to be replaced by rainfall, and glacial erosion by normal erosion, in a manner shown in Fig. 3, and long ago conceived by the active imagination of Tyndall, but by him erroneously applied to the actual case of the Alps.

The largest, steepest and longest-lasting glaciers naturally had their sources in the highest valley heads among the loftiest monadnocks of the range crest; particularly in valley heads on northern slopes, where the effect of sunshine was least, and in valley heads on eastern slopes, where the snow accumulated by drifting over the rounded mountains during westerly gales. The wind appears, as one may judge by the strong development of east-facing cirques, to have been a stronger cause of asymmetry than the inequality of sunshine; and this need surprise no one who observes the strong effect exerted by the west winds today upon the growth of vegetation on the higher western slopes. Systematic asymmetry of this kind has been pointed out in the Sierra Nevada by Gilbert.[8]

The transformation of a normal valley into a mature glacial trough must also be a work of time; hence conscious attention should be given to the different stages of development in which troughs were left when their glaciers melted away. In enlarging a submature,

[7] W. H. Hobbs, The Cycle of Mountain Glaciation. Geogr. Journ., 1910, 146-163, 268-284.

[8] G. K. Gilbert, Systematic Asymmetry of Crest Lines on the High Sierras of California. Journ. Geol., XII, 1904, 579-588.

V-shaped, normal valley, into a mature, round bottomed, overdeepened trough with oversteepened sides, there must necessarily have been successive stages of progress; and if glaciation had been suspended at a halfway stage, an unfinished trough would have been revealed, with many unconsumed spurs, large knobs and hummocks of rock on its sides, and repeated steps and basins in its floor, the latter often being the result of slight differences in rock resistance determined by variation in the number and attitude of joints and other fissures, as well as by changes of composition. Hence troughs as well as cirques should be described in terms of the stage of advance reached by glacial action when the glacial episode was terminated.

The work of postglacial time is small. The basal slopes of the steeper walls in the cirques and troughs are coming to be cluttered with talus, which is creeping forward on the rock floors. "Chimneys" are often opened on lines of weakness in the cirque walls. The tarns in the cirques are usually reduced in size by a fan or delta; the smaller basins and depressions in the trough floors are commonly concealed beneath aggraded waste. But all these changes are of small volume; glacial sculpture still dominates the form where the glaciers worked.

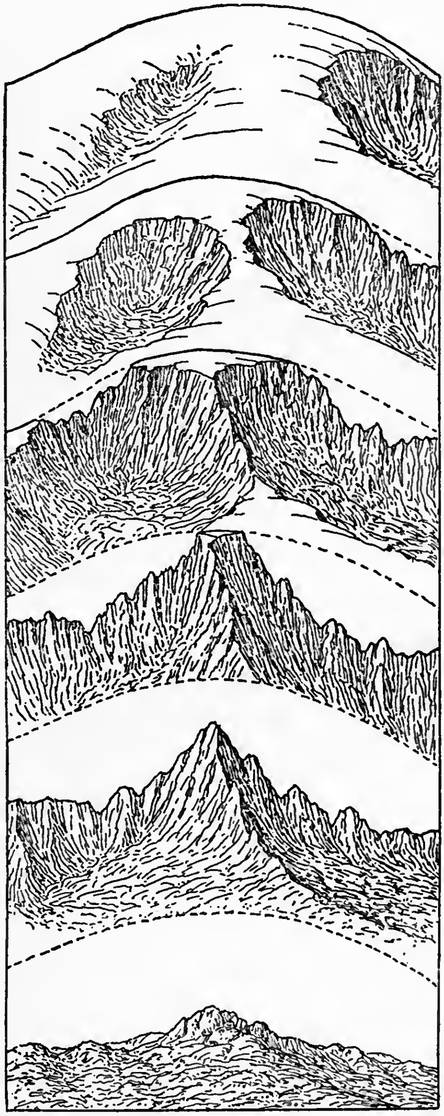

Fig. 3.—Successive stages in the symmetrical development of cirques in a domed mountain.

Domes, Cirques and Troughs.—By good fortune, as far as the manifest exhibition of glacial erosion is concerned, the transformation of normal valley heads into cirques did not usually advance so far as to destroy all traces of the normal monadnock domes; hence the combination of normal and of glacial forms is most striking. By equally good fortune, the change in some cases was so great that no remnant of the dome summit is now seen; the retrogression and lateral enlargement of the glacial heads went on in these cases so far as to change the full-bodied dome into a sharpened peak, with deep, hollow-chested cirques between serrate spurs, leaving normal forms only on the lower flanks of the dome between the diverging glacial troughs.

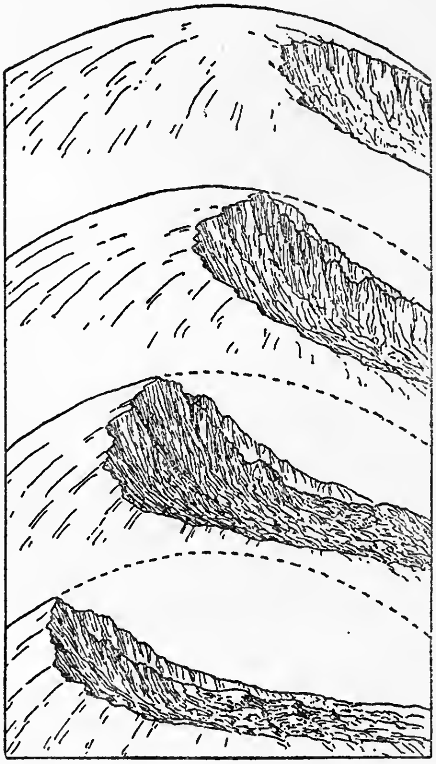

FIG. 4.—Successive stages in the unsymmetrical development of cirques.

By selecting examples of actual forms, or by induction, as in Fig. 3, one may establish a regular sequence of changes from small cirques, between which the greater part of a dome is intact, to large cirques between which no part of a dome is seen; or if analysis and historical review are added to induction, and full confidence is thus established in the explanation of cirques by glacial excavation, one may form an even more complete and systematic series of glacial forms, filling the gaps in the inductive series by appropriate deduction. The use of deduction makes it possible to extend the series farther than observation can reach in the mountains of Colorado, even to the point of consuming the central peak by convergent retrogression of several glaciers, as Richter suggested twelve years ago, thus truncating the dome at about the level of the snow line. Retrogressive truncation may be symmetrically accomplished from all sides, as in Fig. 3; or unsymmetrically from one side only, as in Fig. 4. When a systematic series of forms of this kind is well understood and the names of its several members—for example, young, mature and old—are familiarly established, they are ready for effective use in regional description: thus the progress through several phases of preparatory study—observation, induction, analysis, review, systematization—and their application in the culminating regional phase are well illustrated in treating forms of glacial origin, as well as forms of other kinds.

As an example of the way, indicated above, in which deduction may outstrip induction in the establishment of a systematic series of forms, which follows in general a main line of sequence, but which branches here and there, as desired, on side lines, brief mention may be made of the contrasted consequences of retrogressive erosion by glaciers of divergent and of convergent flow, as illustrated in the fancy sketch, Fig. 5. The maturely retrograded cirques of the divergent glaciers, A, B, C, D, would be expected to head against a single lofty, sharpened peak; their back walls should be separated by short spurs, and their inner floors should be nearly confluent; while their forward parts, separated by spurs of increasing size and normal form, ought to open into

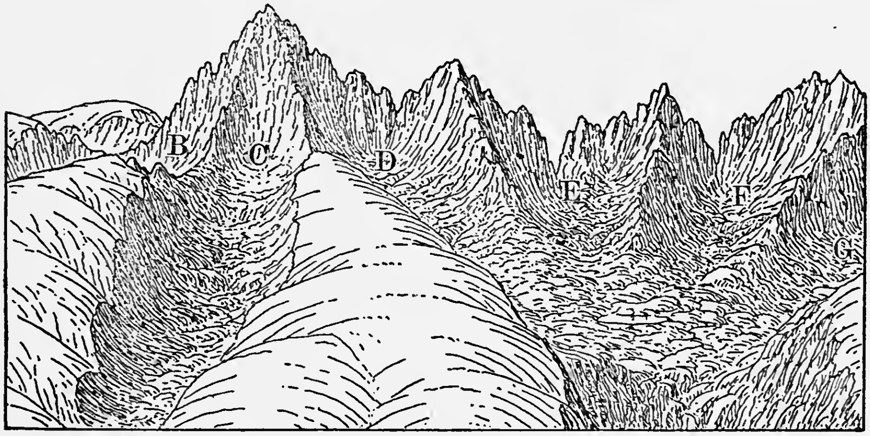

Fig. 5.—Divergent and convergent cirques.

independent troughs of moderate depth. The corresponding cirques of the convergent glaciers, D, E, F, G, heading against deeply notched peaks and ridges, ought to be separated by longer spurs, and to become confluent in their forward floors, just above the head of the strongly over-deepened trough into which they all discharge. This is very likely well known to Alpinists, but I have not seen it concisely stated; it goes beyond my own experience, and as here presented is essentially a matter of inference. Until confirmed by observation, it ought to be regarded as a matter of fancy, not of fact; but even so it may have value in leading to observation and in hastening recognition.

Cirques and Troughs at the Head of the Boulder Creeks.—The best cirques that we saw in the Front Range were at the heads of the branches of the Boulder Creeks. They are easily visited by walking a few miles north and south along the crest of the Continental Divide from Corona station on the "Moffat" railroad, except that accommodations for staying there over-night are very poor. The most striking feature is the strong asymmetry of the crest ridge, Fig. B2, which on the west shows the slopes of confluent, low monadnocks, well subdued in graceful, convex form, waste covered and overgrown with Alpine herbage; but on the east shows deeply excavated, concave cirques with bare rocky walls and barren, moraine-strewn floors, often holding small lakes. Hence these domes and cirques should be described in terms of such a series as is illustrated in Fig. 4, instead of in Fig. 3. The gradual transformation of a broad-topped dome into a serrated ridge between two encroaching cirques of the Middle Boulder group, directly under A, Fig. B2, is shown in Fig. 6. Many of the cirques are compound, in the sense of having small cirques at a higher level opening into larger cirques at a lower level. Some fifteen tarns in the cirque floors in this district are given altitudes

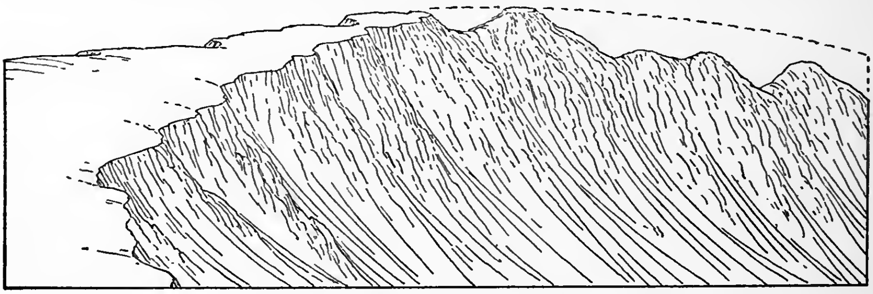

Fig. 6.—Transformation of a broad dome into a sharp ridge, by glacial erosion.

varying between 10,450 and 11,370 feet on the Central City map, U. S. Geological Survey. In a number of cases, as in Fig. B2, the head walls of several laterally confluent, mature cirques have been pushed back beyond the crest of the preglacial domes, so that the Atlantic drainage has gained a little over the Pacific drainage. A few miles to the south, James Peak (13,283 feet), a most interesting example, shows a remnant of a dome crest, Fig. E2 and Pl. IV*b*, with a grassy slope to the north, and huge submature cirques on the west and east; the map of the district indicates a third cirque on the south side. Somewhat farther away to the north, Arapahoe Peak (13,520 feet,) outlined in the background of Fig. B2, is more consumed; its serrated crest has no trace of dome form; a large cirque on its eastern side contains one of the few glaciers in Colorado, of which Lee and Fenneman have given account.[9] Hence, according to a system-

[9] W. T. Lee, The Glacier of Mt. Arapahoe, Colorado. Journ. Geol., VIII, 1900, 647-654.

N. M. Fenneman, The Arapahoe Glacier in 1902, Ibid., X. 1902, 839-851.

atic scheme, the lower monadnocks near Corona would be described as half or more than half consumed by mature cirques on the eastern side; James Peak as a small remnant of a high dome, encroached on by nearly mature cirques on three sides, but retaining a normal slope on the north; Arapahoe as converted to somewhat Alpine sharpness by the excavation of late mature cirques on all sides.

Several well matured troughs lead eastward from the cirques of the Boulder district. One that is drained by the South Fork of Middle Boulder Creek has its group of convergent mature cirques at several levels next north of Corona, partly shown at M, Fig. B2. The view down the trough into which these cirques discharge, as seen from the top of one of the cirque walls, Fig. E3, shows it to be maturely developed with a catenary cross-section, for the description of which the term U-shaped is altogether inappropriate. Its course is of long and gentle curvature, its floor is nowhere entered by well defined lateral spurs. The train on the Moffat road, on approaching the range crest, runs for part of a mile in a cornice along the upper part of the high southern wall of the trough, whence, if one is not nervous, one enjoys an exceptionally fine view of the blunt trough head and of the stream that cascades down into it from the lowest cirque floor. About three, and four and a half miles from its head, this trough is joined on the north by the similar troughs of Jasper Creek and North Fork, which come from a fine group of submature and mature cirques, deeply carved in the crest of the range. The village of Eldora, reached by a narrow gauge line from Boulder, is farther down the main trough. Judging by the height at which boulders are perched on the trough sides, the ice must have been a thousand feet thick there. Lateral moraines are suspected high on the south side of the trough and are probably the cause of two little lakes, shown on the Central City map. The moraines seem to descend to lower and lower levels eastward, but were nowhere seen of great size. About eleven miles eastward from the cirques above the trough heads, the open trough, in which the Middle Boulder glaciers united, narrows and ends at an altitude of 8,200 feet, and is continued by the normal submature gorge of Middle Boulder Creek.

The group of mature or late mature cirques excavated in the eastern slope of the range crest next southward from Corona station, some of which are shown in the foreground of Fig. B2, discharge into the deep and mature trough of South Boulder glacier; the trough narrows and ends at an altitude of 8,000 feet, without any well defined terminal moraines, about eight miles from its head, and is continued by the normal valley of South Boulder Creek, which soon becomes a steep-sided submature, V-shaped gorge of decidedly irregular course, as in Fig. A3. The distal part of this trough is aggraded and partly occupied by a marshy meadow, partly by low drift hills and terraces; it is called Boulder Park, and is occupied by the village of Tolland. The trough deserves, on the whole, to be described as mature, but there are several good-sized unconsumed rocky knobs on its sides and floor. Its walls truncate several spurs in triangular facets, and leave the ravines between the spurs hanging high above the trough floor and partly inclosed by lateral moraines. A large branch trough, known as Mammoth Gulch, heading in the eastern cirque of James Peak, Fig. E2, comes from the southwest and opens several hundred feet above the main trough; many well defined moraines occupy this hanging trough near its mouth. The Moffat road passes through Boulder Park and then returns on its northern wall in a double loop, Fig. C6; the unweathered rock in the cuts on the side of the glaciated trough, and the deeply weathered rock waste, in cuts outside of the limit of glacial action, are strikingly contrasted. A remarkably fine mature trough on the western side of the Sawatch Range is shown in Plate V*a*.

The absence of large terminal moraines in the distal part of the Boulder troughs is significant of the thorough work of the glaciers in comminuting the eroded rock so finely that nearly all of it could be carried away by the outflowing streams. The moraines represent only a very small fraction of the excavated material; perhaps about a hundredth part. On the other hand, the glaciers that descended from the Sawatch Range eastward into the open intermont basin of the upper Arkansas Valley, formed terminal moraines of great size, three pairs of which are beautifully illustrated in drawings by Holmes in one of Hayden's reports.

The Trough of Clear Creek.—The mature trough of the Clear Creek glacier in the Georgetown district presents several features of interest. The main trough, trending north-northeast, divides at its (southern) head into two subequal branches; one (that of South Clear Creek) from the south, the other (that of Clear Creek) from the westh; each of these hangs above the main trough floor, and in the mouth of each of them a connecting gorge is cut, thus exemplifying the rule announced by Penck and Brückner as to the greater depth of a main trough, formed by the junction of two equal branches. These hanging trough mouths were explained some years ago by Crosby[10] as the result of a fault; but as no indications of a fault scarp are to be seen on the slopes of the inclosing mountains, and as it would be singular that a fault should cut two tributary troughs just where they unite to form a main trough, and displace them so as to produce typical "hanging" relations, the explanation by

[10] W. O. Crosby, The Hanging Valleys of Georgetown, Colorado. Amer. Geol., XXIII, 1903, 42-48.

unequal glacial erosion seems preferable. Georgetown lies at the upper end of the main trough floor. The narrow gauge railroad from Denver continues up the western branch trough to the village of Silver Plume, and in order to make the necessary ascent at the hanging mouth of the branch trough, the track turns on itself in the famous "loop." A heavy landslide from the south wall is passed just above the "loop"; it seems to have formed a lake, now aggraded into a meadow, on which Silver Plume lies near a large, unconsumed rock knob of the north wall. From here a mountain railway ascends the south side of the trough in a series of switch backs, and turns around the promontory that divides the two branch troughs, thus disclosing fine views into both of them and down the main trough; then slants up the northern wall of Leavenworth Gulch, a hanging southwestern branch of the southern trough, for a dozen miles, and finally zigzags up the normal eastern slope of Mt. McClelland (13,423 feet), from the top of which, Fig. 7, the visitor has a

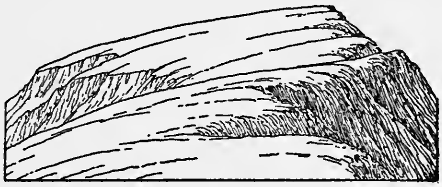

Fig. 7.—Mt. McClelland, an unsymmetrically consumed dome.

grand sight of the great cirques on the northeastern side of the double Grays (13,341 feet) and Torreys (14,336 feet) mass, Fig. E1. The walls and floors of these cirques are much encumbered with slide rock. The northern spur of Mt. McClelland, Fig. D3, is exceptional in having a steeper rocky slope on the west, and a less steep graded slope on the east; this is because the western side was undercut and steepened in the deepening of the glacial trough from Grays and Torreys Peaks. A small cirque seen to the north, across Clear Creek trough, is shown in Fig. D2.

Mt. Evans (14,330 feet) is a striking feature of the view to the southeast from Mt. McClelland. It was evidently once a full-bodied, complex dome, but it is now a hollow-chested wreck, greatly consumed by seven huge cirques, of which one opens to the west, and one to the north; its form is suggestively indicated by the contours of the Georgetown, Colo., topographical map. It is worth noting that a small side valley hangs high on the south side of Leavenworth Gulch, which hangs over South Clear Creek trough, and this in turn over the main Clear Creek trough, thus making a four-storied succession.

Below Georgetown the main trough, trending northeast, is remarkably well developed; the walls are somewhat ragged, yet simple and spurless; many small side valleys hang high above its floor; connecting ravines are slightly cut below the hanging valleys, and fans are spread in the main trough; but all these features weaken ten miles below Georgetown, after the trough turns eastward, where it seems to end at an altitude of 7,900 feet; here the creek flows in a narrow valley of normal appearance, soon to be joined by the more trough-like valley of Fall River, which comes from the northwest, heading in the southern cirques of James Peak. The combined waters, still called Clear Creek, flow eastward and have an open, trough-like valley for some five miles below their junction, and here the town of Idaho Springs is situated. To my surprise Ball's description and the geological folio of the Georgetown district do not indicate that this trough-like valley has been glaciated, although the view of it from a passing train strongly suggested a glaciated form. If glaciated, its ice probably came from James Peak, ten or twelve miles distant.

The Mountain Border.—What will be the appearance of the border of a mountain mass, in which the fundamental crystalline mass has suffered planation before a heavy series of weaker sedimentary strata was deposited upon it, and in which the compound mass was then divided by a pronounced north-south monoclinal displacement into a higher western area (the Mountains area) and a lower eastern area (the Plains area); then worn down to a peneplain which crossed from the crystalline rocks west of the monocline to the stratified rocks east of it; then uplifted long enough ago for the weaker rocks to be again peneplained while the harder rocks are only submaturely dissected?

Such a mountain border must be as rectilinear as the monocline that it follows, and almost as steep as the dip of the monocline; it must consist of a series of triangular or trapezoidal facets all standing in line, but separated by the notches of many superposed consequent valleys and ravines; somewhat the worse for wear near the top, somewhat protected by overlapping members of the stratified series near the base; its height not at all dependent on the much greater height of the monocline, but on the amount of the last uplift and on the resultant depth to which the weaker strata of the plains are now removed. Such a mountain border is in fact a fragment of a huge inorganic fossil, an ancient surface of planation, long preserved by being buried under later deposits, after the manner of organic fossils; then uplifted, attacked by erosion, its upper part destroyed, its middle part laid bare, its lower part still remaining buried. Its smoothness in the Boulder district is emphasized by Fenneman.[11]

Where the basal covering strata are unusually resistant, they hold fast to the old planation surface, as in the remarkable "Flatirons," shown in Plate V*b*, between North and South Boulder Creeks, suggesting the type shown in the farther part of the front block of Fig. 1. Where a resistant formation occurs a thousand or more feet up in the covering strata, it will now rise as a subsequent monoclinal ridge a half a mile or a mile forward from the mountain base, notched here and there into "hogback" form by the larger consequent streams, and inclosing a series of subsequent valleys, along which the smaller consequent streams from the mountains will be diverted by subsequents until they join the larger consequents and flow out by the notches, as shown in the nearer part of the front block of Fig. 1. Many excellent illustrations of the outstanding ridges are reproduced in Holmes' inimitable drawings in the earlier reports of Hayden's Survey. Where the covering strata are all weak, there will be neither clinging "flatirons" nor outstanding "hogbacks," a new peneplain will truncate all the monoclinal strata forward from the uncovered planation surface of the mountain border, as happens along the Front Range border for a short distance south of Palmer Lake, north of Golden, and at various other points.

The embayments of the mountain front at Manitou and Canyon City, already mentioned in connection with the subdivision of the highland into several districts, deserve more space than can be given them in this already over-long essay. They are significant as exhibiting in part of their contour the replacement of the monocline by an oblique fault, trending northwest-southeast; here the foothill subsequent ridges, instead of systematically following the mountain base at a rather constant distance, run obliquely against it and are truncated by the fault line. This is particularly well seen in the Manitou embayment, where the many and well developed subsequent ridges of red sandstone, which in the district of their strongest expression form the "Garden of the Gods," a mile or two farther south abut against the base of the Pikes Peak highland and end abruptly. A view of this significant relation is given in one of Holmes' drawings (Hayden's Survey, Report for 1873, 1874, 200). Both embayments are mapped in Darton's account of the Arkansas Valley.[12] The

[11] N. M. Fenneman, Geology of the Boulder District, Colorado. Bull. 265, U. S. Geol. Surv., 1905, p. 54.

[12] N. H. Darton, Geology and Underground Waters of the Arkansas Valley in Eastern Colorado. Prof. Paper 52, U. S. Geol. Surv., Washington, 1906.

ancient surface of planation near Manitou has been well described by Crosby.[13]

The tilted attitude of the strata near the mountains immediately gives the impression that the mountains owe their height above the plains to the monoclinal uplift by which the tilting was produced; but as soon as the peneplain of the highland is recognized in its proper relation to the mountain front, this first impression must be given up. The height gained by monoclinal tilting has been lost by peneplanation; since then, both the mountains and the plains have been broadly uplifted, the mountains a little more than the plains; and the present difference of altitude along the border of the range is due simply to the erosion that the weaker strata of the plains have suffered, whereby they have been much more worn down than the part of the uplifted peneplain that is composed of harder rocks.

Marvine's Early Work on the Front Range.—It was this mountain front, so striking and typical an example of its kind, which first suggested the idea of superposed consequent drainage; for here Marvine, returning in 1873 as a member of Hayden's Survey to the scene of Whitney's excursion of 1869, wrote: "The channels of drainage . . . [on the border of the Front Range] were directed solely by the structure and characters of the upper rocks, and when they gradually cut down through these and commenced sinking their cañons into the underlying complicated rocks, these cañons bore no relation whatever to their complications. . . . . Penetrating the formerly covering sedimentaries, the cañons commenced sinking into the lower and more complicated rocks, with directions impressed upon them by the latest uplift and the overlying rocks, and bearing no constant relation to the structure of the lower ones in which we now find them . . . in a broad sense, the drainage is from the main mountain crest eastward, independent of structure. . . . The subaqueous erosion, in smoothing all to a common level, destroys all former surface expression of geological character, and the present erosion has not yet been in progress sufficiently long to recreate the lost features."[14] Powell afterwards referred to this passage when he introduced the terms, consequent and superimposed, the latter term afterwards being shortened into superposed.

It was in relation to the ancient planation surface of the mountain front that Marvine, first of all observers, published the idea of the essential obliteration of mountains and hills by normal erosion, although he, like others of his time, seems to have looked to marine abrasion

[13] W. O. Crosby, Archaean-Cambrian Contact near Manitou, Colorado. Bull. Geol. Soc. Am., X, 1899, 141-164.

[14] A. R. Marvine, Report in Ann. Rept. of the U. S. Geol. and Geogr. Survey Terr., Washington, 1874, p. 145.

as the agency by which the final planation was produced. He wrote: "The ancient erosion gradually wore down the mass to the surface of the sea, and while previous to this it [erosion] was no doubt directed by the structure, yet the mass was finally levelled off irrespective of structure or relative hardness of its beds by the encroaching ocean, which worked over its ruins and laid them down upon the smoothed surface in the form of the Triassic and other beds" (l. c., 144). Although the first line quoted gives hardly more than a hint of a great principle, it is significant that subaerial erosion was there recognized as capable of wearing down a mass of deformed crystalline rocks "to the surface of the sea," and not simply into hills and valleys, as was thought and taught at that time.

In common with other observers, Marvine recognized the evenness of the Front Range highlands, but he went beyond his contemporaries in trying to explain it. He described the highlands as "a region of pine-sprinkled surfaces . . . . large areas are frequently undulating or level, forming beautiful park-like regions . . . . there is a remarkable uniformity in the height of these ridges. Their tops are frequently quite level or gently rounded; while standing on one, the general level, which seems indicated in their tops, is very striking" (l. c., 89). In explanation of this feature, he looked back to the same planation surface as that recognized in the even front of the range; no one at that time conceived the peneplanation of the highland surface as having taken place in a cycle of erosion following instead of preceding the monoclinal deformation of the compound mass. Marvine's statement was: "It is but recently that the upper rocks have been completely removed from the summits of the mountain spurs, the ancient level of subaqueous erosion being still indicated by the often uniform level of the spurs and hilltops over considerable areas, and large plateau-like regions which become very marked from certain points of view" (l. c., 145). The important point to note here is that Marvine had formed a mental scheme by which an intelligible understanding of the forms of the Front Range could be worked out. True, we must now regard his scheme as erroneous in certain respects; nevertheless, the effort to give rational explanation for all the forms of the mountainous highlands was a great step in advance of the methods of his time. That a young geologist —Marvine was then twenty-five years of age—should in 1873 have already so fully accepted the responsibility of explaining the forms of the surface, as well as the structures of the undermass, reveals the originality and analytical power of his mind, as well as the keenness of his observation.

Opinions regarding glacial erosion were undefined forty years ago. Rock scorings and moraines are repeatedly mentioned in the reports of the Hayden Survey, but it is seldom that cirques and troughs are treated as being due to other than ordinary erosional processes. If glacial erosion was considered at all, it was as likely as not given an extravagant measure, as when Hayden said, regarding the intermont basin of the upper Arkansas Valley: "It is probable, also, that this great space was at no very ancient period filled with one vast glacier, which doubtless performed the greater part of the grinding up of the rocks and the wearing out of the valley" (l. c., 48; also 1876, 51); yet the same writer, after clearly recognizing the great amphitheaters or cirques as characteristic features of the higher mountains, seems to explain them by a "gnawing process, as it might be called," which has "been going on for ages, so that in many places the crest is a single sharp ridge between the amphitheaters on either side." Each mountain stream "rises in a sort of amphitheater, which has been formed by the breaking down of the sides of the gorges by the water and ice in the fissure, and the melting of the snow sweeps the fragments slowly down into the gulch" (1875, 44). "That the wearing out of the depressions [amphitheaters] may have been more rapid in former times, I do not doubt, perhaps during glacial or post-glacial times" (1875, 45). "Although the evidence is clear that these amphitheaters have been carved out of the massive granite, no forces are now in operation to carry away the fragments of rock that are annually loosened from the walls by water and ice, but they gather on the slope, forming a talus of great magnitude" (1875. 56).

The unsymmetrical crest of the range in the Boulder district, sketched in Fig. B2, attracted the attention of more than one member of Hayden's Survey. Marvine says of it: "From Arapahoe, for twelve miles directly south to James Peak . . . . the crest presents a very uniform ridge rising but little above timber line, and for five miles near the southern portion scarcely varying two hundred feet in altitude. As at the north, the eastern face of this ridge is precipitous, falling in great cliffs to a series of amphitheaters which make up the front, each with its bank of snow lying up against the base of its rocky walls. Some of the rounded spurs reaching eastward between the amphitheaters, afford a means of access to the ridge. . . . The western slope from this ridge is of a very different character from the eastern slope. Though of course having many of the characteristics of a rugged, mountainous region, yet, as compared with the east slope, it has no precipitous front, but its massive westward spurs fall in rounded, gently moulded slopes, not separated by deep cañons" (l. c., 86, 87). The only explicit statements that I have found in his report regarding glacial erosion are contained in the quotation at the beginning of this paper, and in the following lines: "Starting from the eastern base of Gray's and Torrey's Peaks [see Fig. E1 in this paper], and curving around northward, is a most profound and regular glacier-carved gorge, with sweeping, precipitous sides towering up on the east side to the rather even-topped summit [see Fig. 7 of this paper] of McClellan Ridge" (l. c., 148).

The report from which the extracts here given are quoted, is one of the few that Marvine produced. Hayden wrote of it: "The energy and devotion to the work displayed by Mr. Marvine merit the highest commendation, and the results so admirably brought out in his report . . . are but promise of the future" (l. c., 4): a future that was most unhappily cut short by his death in 1876.

The Problem of Intersecting Peneplains.—Physicists have found it desirable to give the special name, entropy, to a certain

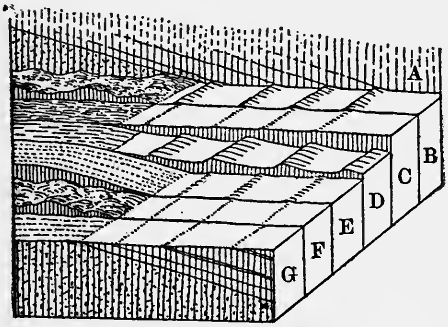

Fig. 8.—Intersecting peneplains.

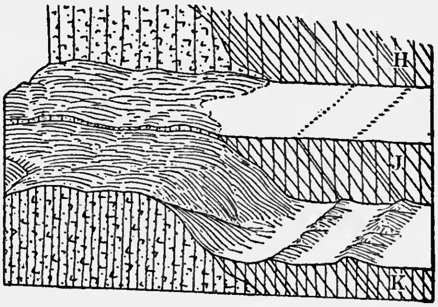

Fig. 9.—Peneplains intersecting at a large angle.

involved conception, because they so often have occasion to refer to it; thus they avoid much circumlocution. Physiographers have not yet given a special name to the combination of several peneplains, as seen in the highlands and the front of the Front Range, and in the piedmont plains, although one phase or another of such a combination is a common occurrence, and a name for it would frequently be useful. One of my students has suggested that the combination should be spoken of as that of "intersecting peneplains." Their varying relations are shown in Fig. 8. The essential element of structure is a compound mass, consisting of resistant rocks below, and of less resistant rocks above, separated by a surface of unconformity, the double mass being tilted, as in section A. The chief variable elements of structure are the contrast of resistance between the lower and upper rocks, and the smoothness and inclination of the surface of unconformity. Contrasted resistance and a smooth surface of unconformity inclined about 30° are represented in this figure. The essential elements of later erosion are an approximate or perfect planation of the tilted compound mass, as in blocks B and C; the variable elements of later erosion depend in part on the nature and amount of the elevation by which the worn-down mass, B or C, is introduced into a new cycle of erosion, and on the stage reached in this cycle. After simple uplift of moderate measure, block D shows a late mature stage of erosion in the weaker strata and a partial stripping of the surface of unconformity; block E shows a new peneplain worn on the weaker strata, and the complete stripping of the surface of unconformity, while the hard-rock highland remains little changed; block F shows an aged plain on the weak strata and a late mature dissection of the hard-rock highland; block G repeats block C. Fig. 9 is a variation of Fig. 8, showing an uneven surface of unconformity, a steeper tilting of the compound mass, and a greater uplift after truncation. The border of the highland as here developed is uneven, chiefly because the stripped surface of unconformity is uneven. It is evidently possible to conceive a large number of variants on these simple examples.

The object of here introducing the scheme of intersecting peneplains is to point out a better method of presenting the problem of the mountain border than that of the first paragraphs under this heading, six pages back. The particular case of the Front Range border was there entered abruptly, without systematic preparation. This is inadvisable, because the reader then has the actual mountain border and its hypothetical explanation both before him at the same time. It is better to treat the two separately. Let the hypothetical case be taken first, and let its presentation be systematically expanded so as to include various styles and stages of the problem, such as are shown in Figs. 8 and 9. After many variants have thus become familiar, the actual case may be taken up. It then suffices to say: the border of the Front Range corresponds to block D of Fig. 8, except that it is dissected by many superposed consequent ravines and valleys, and that a monoclinal ridge frequently stands in front of it, as is better shown in the front block of Fig. 1.

The Need of Systematic Preparation for Regional Work.—This example may serve as a final illustration of the high value of systematic preparation for regional work. The evident difficulty in the way of such preparation is the great variety of land forms and the consequent necessity of elaborate systematic discussion, if the ideal counterparts of all actual forms are to be known before they are seen. But such completeness of preparation is not essential: the point is rather that systematic preparation should be carried much farther than it usually is, if an expert geographer is to gain an equipment that shall at all compare with the equipment that is expected of a proficient botanist or zoologist. If the underlying principle—the principle of first systematically elaborating a good number of variants under a hypothetical case, by making reasonable changes in its variable elements, and then stating that the actual example of land form under discussion corresponds to variant G or M or Q—is made clear and familiar by preparatory training, it may be applied in special cases, as need arises, even if these cases are not already resolved by previous study. For example, there is no question that the description of the Front Range border could have been briefer and more effective, if the problem of intersecting peneplains were generally recognized and introduced in the systematic treatment of land forms, as presented in our text-books; or again, there can be little question that the subject of this essay, the Front Range of the Rocky Mountains in Colorado, could have been treated more briefly and effectively if the general problem of two-cycle mountains and a good number of its variants were the common property of all geographers; but such is not the case. The question then arises: is it best to open each of these problems with an abstract treatment of their ordinary variant values, or to begin at once by a statement of the case in hand? In view of the fact that this essay was not intended to form part of a systematic course of instruction, but was written as an independent regional treatment of a mountainous district for expert readers, the second method was chosen; but I am by no means persuaded that the choice was well-advised.

The constant inspection of method, here adopted, may be fatiguing to some readers, but in the present stage of the study of land forms inspection of method is highly important. It might well constitute a larger part of the discussions in the meetings of geographical societies than is ordinarily the case. An analogy may illustrate this point. Let it be supposed that in the present stage of the study of mineralogy, every year witnessed the publication of many diverse, inaccurate and inadequate descriptions of new minerals; under such conditions, would it be best for mineralogists to continue to publish inadequate, inaccurate and diverse descriptions of still more new minerals, or to address themselves to the discussion and development of better methods of describing the minerals already imperfectly known? The latter course would evidently be preferable. A corresponding course is preferable also in geography. For my own part, I should like nothing better than to see abundant, conscious experiments in geographical description; for example, a description of the Front Range or of some similar range in strictly empirical terms, from which all explanation is excluded; or a description in strictly explanatory terms, but on some other plan than that of structure, process and stage, here adopted. It is by such conscious experimentation and by free discussion of its results that the object of this Association, "the cultivation of the scientific study of geography in all its branches," can be best attained.

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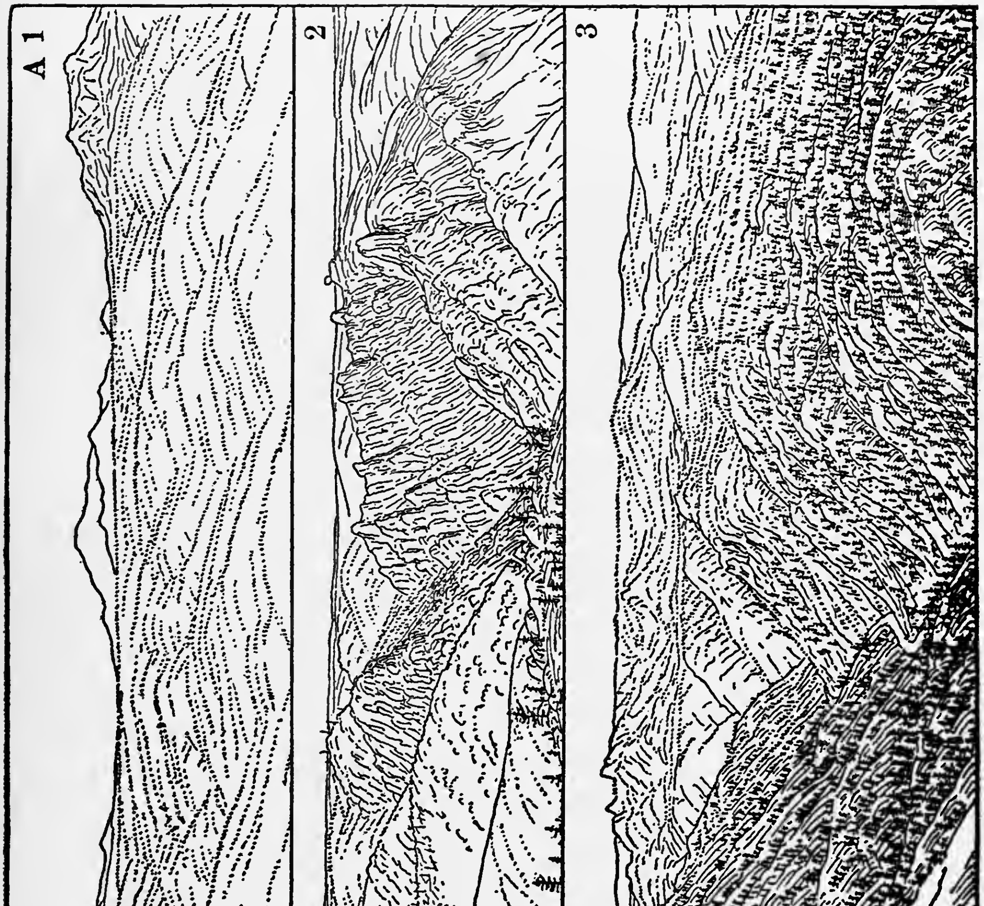
Explanation of Figure A

A 1. View southward across the late mature valley of the South Platte at Buffalo, showing the even skyline of the granitic highland at an altitude of about 9000 feet. Long Scraggy Peak on the left, with Devil's Head or Platte Mountain behind it; Little Scraggy Peak on the right, leading to Tarryall Mountains (see background of Fig. C 3). Pikes Peak in mid-background. See page 51.

A 2. View of granitic highland west of Palmer Lake, looking west; altitude about 9000 feet. The granite has a predominant east-west jointing, which determines details of form on steep, ungraded, rocky slopes, but which has no apparent influence on the irregularly branching courses of the submature insequent valleys. See page 42.

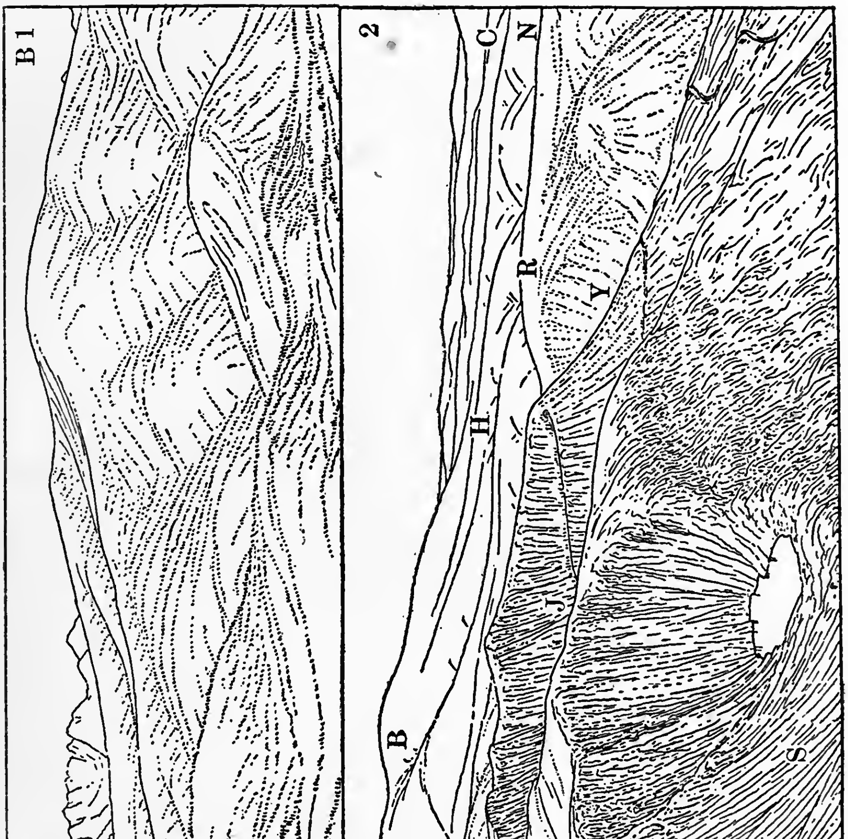
A 3. Canyon of South Boulder Creek, about five miles west of the mountain front, looking northwest. The unlifted peneplain is seen on the left, and also in a nearly level upland over the submature valley in the center of the sketch. The smooth skyline above this upland is that of an even-crested monadnock. The sloping surface on the right is regarded as being worn down in the current cycle somewhat below the surface of the uplifted peneplain. See page 51.


A 1
2
3

Explanation of Figure B

B 1. Bald Mountain (12,000?), a smoothly graded, subdued monadnock, slightly dissected by normal valley heads, three of which in the right foreground descend rapidly into the young submature valley of Lefthand Creek, eroded during the current cycle; looking west from near Gold Hill station, between Sunset and Ward; on the left (southwest), the dissected highland (altitude 10,500–11,000?) known as Chittenden Mountain (C, Fig. B 2); in the distance, the sharpened summits of Mt. Arapahoe (13,520), with its east-facing cirque, in which lies a small glacier. See pages 41, 49, 60.

B 2. View northward along the crest of the Front Range (12,000 feet), here forming the Continental Divide, near Corona station, O, Moffat Road. The railroad is also seen on the right, winding into the cirques of Yankee Doodle, Y, and Jenny Lakes, J, after which it passes out of sight along the south wall of Middle Boulder trough (see Fig. E 3), which heads in the cirques, M, of mid-distance, and discharges, N, between Bryan Mountain, R, and Caribou Flats, C. Bald Mountain, B, and Mt. Arapahoe, A, in the distance; the former not glaciated, the latter strongly glaciated. See pages 41, 60.


B 1
2
A
B
C
H
N
R
Y
J
M
O
S

Explanation of Figure C

C 1. Sheep Mountain (10,500 feet) surmounting the rolling highland (8,000 feet) south of South Boulder Creek, which flows in a young valley hidden by the foreground ridge; looking southeast. See page 49.

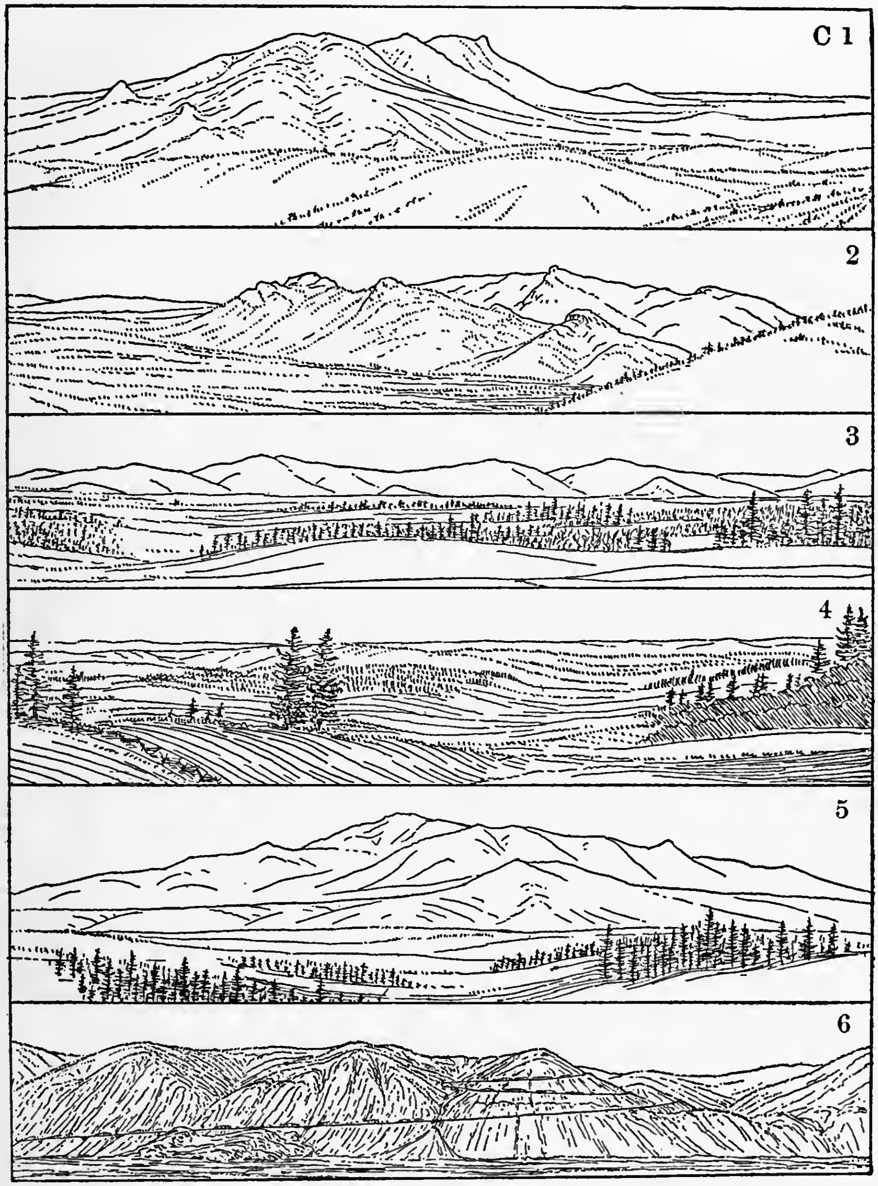
C 2. Craggy granitic monadnocks surmounting the highland (7,500-8,000 feet) between South and Middle Boulder Creeks; looking northeast. See page 50.

C 3. The gravel-covered highland (10,000 feet) of the South Platte district; Tarryall Range in the distance, looking northwest. See pages 43, 50.

C 4. The same highland (10,000 feet), looking northeast. The farthest sky line shows the district sketched in Fig. A 2; it is separated from the middle distance by Manitou Park, a northwest-southeast valley excavated on a down-faulted strip of Plains strata. See page 43.

C 5. Pikes Peak (14,108 feet) surmounting the gravel-covered highland, as seen from near Divide station, Colorado Midland RR., looking southeast. See pages 43, 50.

C 6. The north side of South Boulder glacier trough, here called Boulder Park, as seen from Tolland station, Moffat R.R. The railroad follows up the flat aggraded floor (8,800-9,000 feet) of the trough from east to west (right to left); then turns back, ascending the trough side in zigzags, and passing on to the cirques, shown in Fig. A 2. Morainic ridges clinging to the side of the trough are indicated between the first and second turns of the railroad, as here shown; and also in an embankment that shuts in a side valley, farther on the right. See page 62.


C 1
2
3
4
5
6

Explanation of Figure D

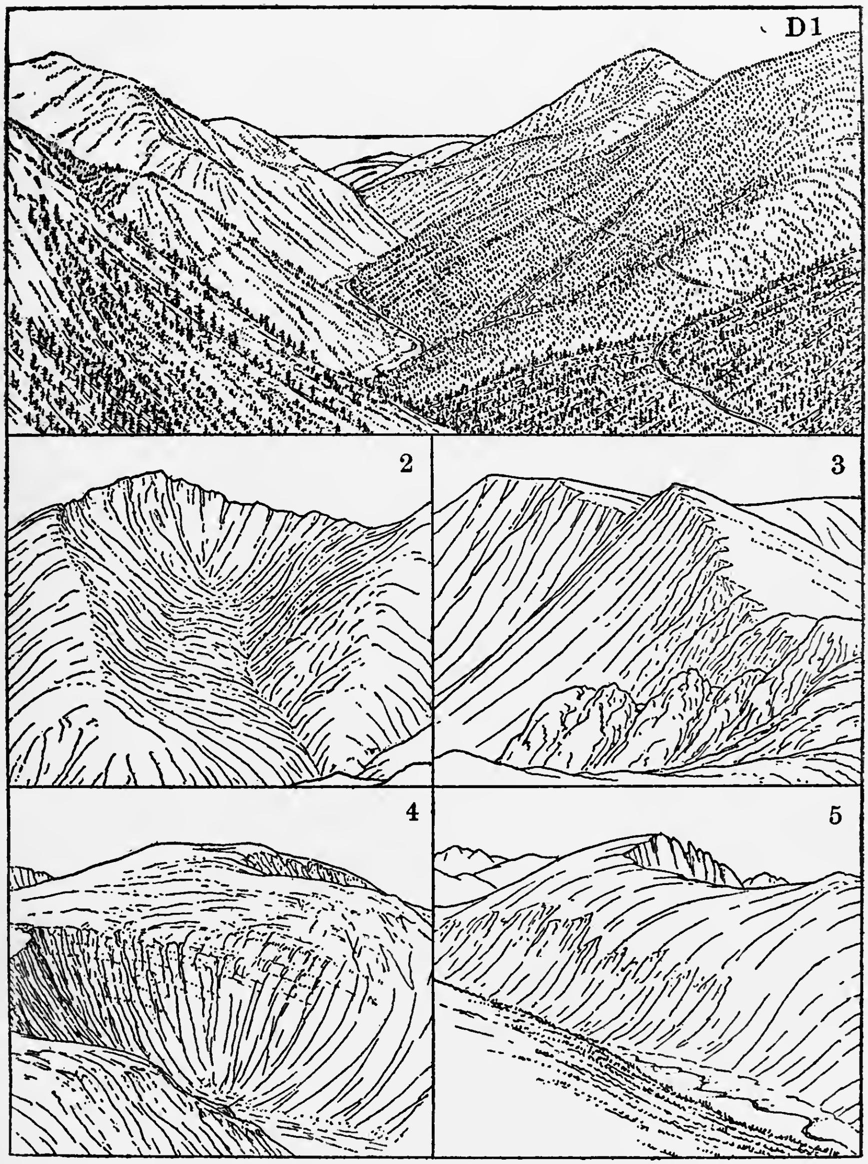
D 1. Looking eastward, down the normal early-mature valley of Fourmile Creek. The highland level is not seen, because of monadnocks on the valley border: on the right are Sugarloaf and Bald Mountain (the latter, partly shown, is not the same as Bald Mountain of Figs. B 1 and 2.) The sky line of the plains is in the distance. A narrow gauge line ascends this valley from Boulder to Sunset (hidden behind foreground spur): there the line divides; one branch turns back on the south side of the valley, rounds Bald Mountain and descends to Eldora in the trough of Middle Boulder trough, Fig. E 3, or below N, Fig. B 2; the other turns back on the north side of the valley, passes northwestward over the highland and reaches the town of Ward, near the northeastern base of Bald Mountain, Fig. B 1. Both of these towns are in the tungsten mining district. See page 51.

D 2. A small cirque high on the north side of the west branch of Clear Creek trough, Georgetown district, as seen from Mt. McClelland. See page 63.

D 3. The unsymmetrical northern spur of Mt. McClelland, with a normally graded slope on the east and a steep glacially undercut slope on the west. See page 63.

D 4. A glacially dissected dome, otherwise of normally subdued form, in the northern part of the Sawatch Range, between two branches of North Fork of Lake Fork, looking north. The cirques were occupied by glaciers 5 and 6 of Capps' map. See page 56.

D 5. Another example of the same kind in the same locality, a little farther north, between North Fork of Lake Fork, and a south branch of Homestake Creek looking north. The cirques were occupied by glaciers 7 and 11 of Capps' map. See page 56.

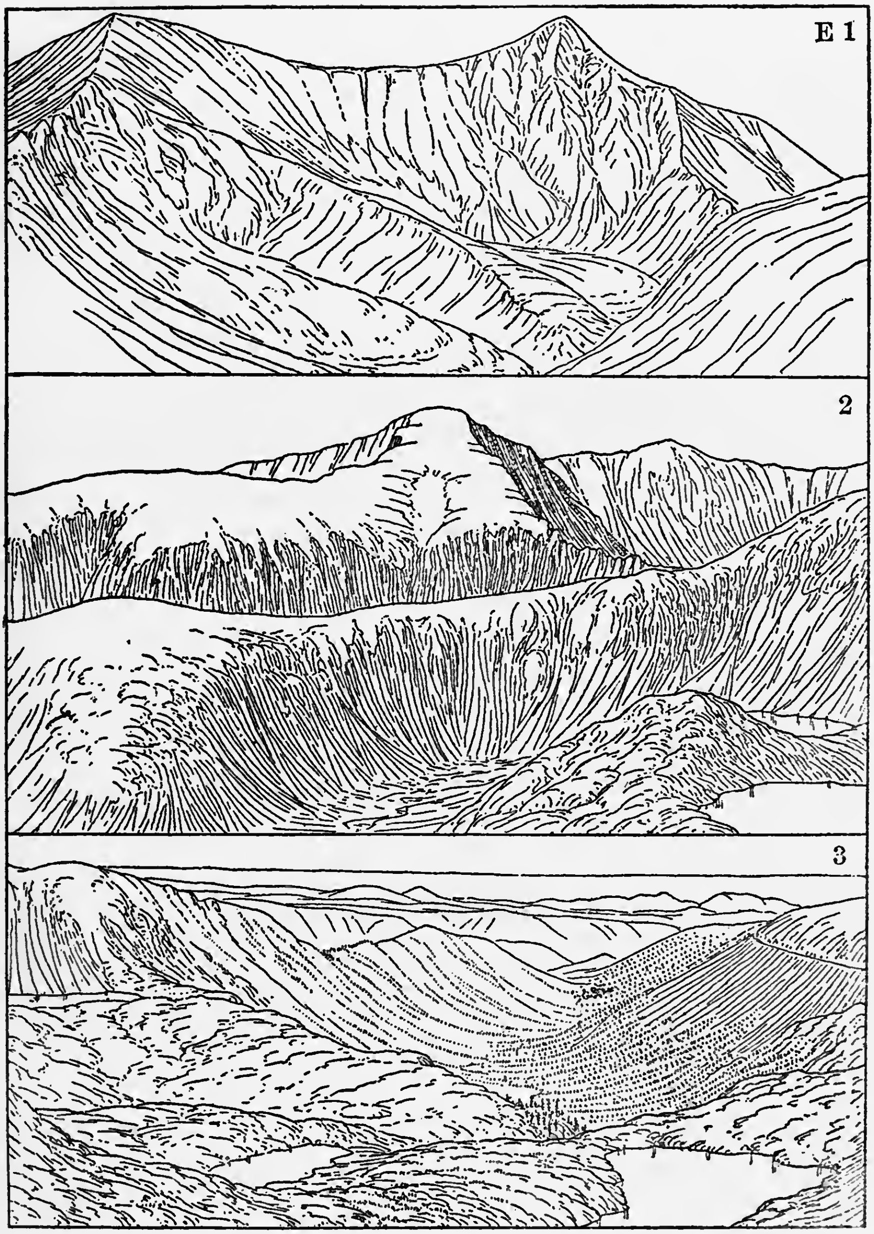

D1
2
3
4
5

Explanation of Figure E

E 1. Grays (14,341 feet, on left) and Torreys Peaks (14,336 feet, on right), with waste-covered cirque walls and floors, looking west. See page 63.

E 2. James Peak (13,283 feet), as seen looking south from crest of Front Range, near Corona station, Moffat Road (Fig. B 2). Cirques of head branches of South Boulder Creek in foreground and mid-distance; cirque of Mammoth Gulch (branch of South Boulder Creek) on the east of the peak; and of Jim Creek, flowing to the Grand-Colorado system, on the west. See page 60.

E 3. View looking eastward from top of cirque wall, over M, Fig. B 2, down the maturely overdeepened and widened trough of Middle Boulder Creek, showing its catenary, or round-bottomed-V cross-section. Eldora lies in the farther part of the trough floor. The Moffat Road is seen near the top of the trough wall on the right. Bald Mountain and Sugarloaf (see Fig. D 1) rise over sloping highlands in center of sketch; the ocean-like sky line of the plains is seen in the far distance. See page 61.


E 1
2
3

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GEOGRAPHY IN THE DEVELOPMENT OF THE ALASKA COAL DEPOSITS*

ALFRED H. BROOKS

CONTENTS

The Commercial Value of Coal Deposits.—The ultimate importance to the human race of every ton of recoverable coal, no matter what its geographic position or geologic occurrence, admits of no argument. An evident corollary to this proposition is that every effort should be made to assure to mankind the maximum use of all the energy stored as coal. Though the recent literature on the value and proper utilization of our coal supply is voluminous, much of it is largely made up of sweeping generalizations, and there is an almost entire lack of searching analysis of the fundamental problems of economics which are involved.

Efficient recovery of mineral fuel and the most complete utilization of its contained energy obviously belong in the domain of technology, but the more fundamental problem as to whether it is to the best interests of mankind that a given coal field should be drawn upon now or at some time in the future, can only be answered by studying its geographic relations and, to a lesser extent, its geology. Obviously, this thesis involves the assumption that it is the function of the state to control the utilization of its natural resources. Assuming that governmental control is to be exercised, it is pertinent to inquire where a natural market for the product of a given coal field exists, or whether mankind would benefit by deferring its exploitation.

Probably a safe method of arriving at a conclusion as to the present importance of any given coal deposit is to determine its present monetary value, that is, the monetary value for development and not the value as a speculation for future development. The determination of such value involves the consideration of many factors, some of which

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are only imperfectly understood. An attempt will be made, however, to discuss the principles which govern the economics of mineral fuel supply and to apply these to the Alaska coal fields.

The commercial valuation of any particular coal deposit is usually based on data which can be grouped under four headings, namely: (1) Quantity and quality, (2) cost of mining, (3) cost of transportation, (4) markets. Such a grouping admirably serves the purpose of the mining engineer whose object is to determine the present money value of any coal property or of an extensive field. All these factors will also enter into any broader discussion of the importance of any coal field or group of fields to mankind, but the economist, in contrast to the engineer, will make a somewhat different grouping and possibly arrive at a more fundamental analysis of the problem.

The Factors Determining the Economic Value of Coal.—As I see it, the more important factors which determine the valuation to mankind of coal deposits fall into two general groups, which can be termed geographic and geologic. Of these the first is by far the more important. It includes the position of the coal on the earth's surface, hence its availability relative to population and industries, present and prospective, to other coal fields, and to other kinds of fuel. Given the market, almost any coal deposit can be mined, while without the market—either because of the competition of cheaper fuels or absence of population and industries—even a high-grade coal which is readily accessible can not be commercially developed.

Of the geologic factors overweight has usually been given to the chemical and physical properties of the coal. These items, while necessary for making a comparison of various coals in the same market, are in a general way becoming less important. The internal combustion engine has, for example, made available the energy of even the poorest class of lignites. It is not improbable that technical advances may soon break down the line between coking and non-coking coals. The following table is intended to set forth the factors controlling the value of coal deposits, using the term value in its broadest sense.

The Importance of Geographic Position.—The geographic position of the coal is evidently of first importance. Many coal deposits in the world, and notably some in Alaska, are so inaccessible that they can be regarded as having no present economic value, and in many instances it is difficult to forecast when such coals may become a part of the available supply. This is dependent on (1) population, (2) industries, and (3) exhaustion of other sources of fuel supply. The geographic relation of the coal deposit to population is evidently an all-important factor in its valuation and is involved in the question of its accessibility. The same holds true of its relation to industries, both present and prospective. It will also be evident that the position of the coal relative to other resources is an important factor in determining its value. This is notably true in relation to iron ore, but also holds to a lesser degree with respect to other metalliferous deposits. Any resources which attract industries and population must lead to railway construction and, all combined, will enhance the value of a coal field.

- Factors controlling the economic importance of coal deposits:
  - Geographic:
    - Position relative to transportation routes.
    - Position relative to other natural resources.
    - Position relative to other sources of power.
    - Position relative to present and future industries.
    - Position relative to present and future population.
  - Geologic:
    - Dimensions.
    - Structure.
    - Position relative to earth's surface.
    - Relative position of coal beds to each other.
    - Physical character of associated beds.
    - Chemical composition.
    - Physical properties.
    - Presence or absence of gas or water.

Of equal, if not greater, importance than those factors previously discussed is the position of the deposit relative to other sources of power. Under this heading should be considered competition with water powers, with other coal fields, and with other mineral fuels, such as gas and oil. To be entirely consistent, other possible sources of energy, such as the sun, the tides, and the wind should also be discussed, but this would lead into the realm of speculation rather than to tangible results.

THE GEOLOGIC ELEMENTS IN COAL VALUATION.—The geologic elements in coal valuation will here be only briefly touched upon. These deal chiefly with (1) dimensions of the deposit, (2) fuel values, (3) geologic conditions which affect method and cost of extraction. The first of these needs no explanation. The second has to do with the chemical and physical composition of the coal, which determines its fuel value. It has already been pointed out that recent advances in technology indicate that the chemical and physical properties in the future will be of decreasing importance to the valuation of coal. Much has been written about the economic effect of the exhaustion of the Pennsylvania anthracite deposits. Such exhaustion is no more to be deplored than that of the equivalent in heat units of other varieties of coal in similar advantageous geographic position; indeed, the exhaustion of the Pennsylvania and West Virginia coking coals would be a far more serious matter. Anthracite is now used for no purpose for which bituminous coal could not be substituted. It is not impossible that eventually similar relations may hold between lignitic and bituminous coals.

Among the important factors affecting the cost of extraction is the depth of the coal beneath the surface. This is of almost equal importance with geographic position in determining the value of the coal. Coal can be mined under methods now employed, to depths of about 4,000 feet. It is possible that, when the more accessible coals are exhausted, means will be devised to mine coal at even greater depths. Here, again, the geographic factors which determine the market for the coal will also determine the depth to which it can be profitably mined. There are other geologic factors, such as position of beds, deformation, character of roof and floor, and presence or absence of gas and water, which greatly affect the cost of mining. Conditions may so enhance the cost of mining in any given field that the product can not compete with that of other fields where the conditions favor cheaper extraction. Here again, the geographic position may determine availability, since the above factors must be considered with reference to competition.

It will be evident from the above that, while the geologic factors may, and often do, control the present value of any individual property, the geographic factors dominate the economics of a coal field or of a group of fields. In other words, if there be a sufficient market, almost any coal deposit can be mined, while without market, no coal deposit is worth mining. The importance of the geographic factors is emphasized in the valuation of coal fields which are difficult of access. This involves the consideration of growth and movements of population and the development of new industries and new sources of energy, as well as possible routes and means of transportation.

THE COAL PROVINCES OF ALASKA.—One measure of the relative importance of the Alaska coal fields is obtained by comparing the quantity of fuel with that of better-known regions. It has been estimated that Alaska contains probably 150,000 million tons of coal.[1] This is about four and one-half per cent. of the total estimated tonnage of the United States and its possessions and a little less than fifteen per cent. of the coal in lands which are still in government ownership. It is about a third more than the original coal supply of the State of Pennsylvania.

In view of the fact that Alaska is almost continental in its dimensions and that the coal fields are very widely distributed within the Territory and that much of the coal is of a low grade, these broad comparisons are very misleading. It becomes necessary to qualify any statement in regard to total quantity by considering what part of this total supply is available for present use. For this purpose the Alaska coal fields can be conveniently divided into three economic provinces based on geography. The first is the Pacific slope, which comprises the mountainous area drained to the Pacific Ocean. This province as a whole is readily accessible and its resources can be considered an asset of the present generation. It contains about forty per cent. of the known coal resources of Alaska, besides valuable deposits of metals and considerable areas of arable land, all of which can be opened up by railways. (See Fig. 1.) Some of this coal is of high grade and located favorably for export.

The central region includes the area lying north of the coastal mountain basin and is drained to Bering Sea by the Yukon and Kuskokwin rivers. It includes about thirty-five per cent. of the known coal, besides important gold deposits and considerable arable land. To reach this region by railway from open ports on the Pacific will require four hundred to six hundred miles of railway. The coals are of a lignitic character and under no conditions which can now be foreseen could they be mined for export. The coals of these fields, therefore, have value only for local use—a value which is enhanced by the other mineral resources and by the relative scarcity of other fuel.

The third province comprises northern Alaska, draining into the Arctic Ocean. This includes about twenty-five per cent. of the known

[1] Brooks, Alfred H., Alaska coal and its utilization. Bull. U. S. Geol. Survey, No. 442, pp. 53-55, 1910.

coal, much of which is of a high grade. This part of Alaska is almost entirely isolated, as it is too far from open ports on the Pacific to permit of railway connection, and its rivers are locked in ice for all but two months in the year. Most of this field is unexplored, and the stated estimate of tonnage is probably far below the actual tonnage. There is good reason to believe that its coal supply may exceed that of all the rest of Alaska but, whatever it may be, the coal has no value unless as an asset to future generations.

It appears, therefore, (1) that the Pacific slope coal is the most valuable of the Alaska coal supply to the present generation, for it can be exported, (2) that the coal of the central province has value only as local population and industries develop, and (3) that the coal of the Arctic slope will not be drawn upon until that future time when the more accessible coals of the world approach exhaustion.

The Pacific Slope Coal Fields of Alaska.—A discussion of the development of Alaska coal fields will, therefore, be concerned chiefly with those of the Pacific slope. These coals are the only ones in the Territory which are available for the growing population of the western side of the North American continent and are, therefore, of national as well as local importance.

The estimated reserves of the Pacific slope fields is 60,000 million tons, much of which can be readily made available by the construction of railways. This tonnage is about five per cent. of the total coal tonnage still in government ownership in the western states. These Alaska deposits include considerable high-grade steaming and coking coal, as well as a large quantity of lignite. The geologic occurrence of the high-grade coals of the Pacific slope of Alaska need not be presented in detail, for it will suffice to say that they are in many places not so unfavorable as to prevent exploitation.

The position of these coals relative to transportation is favorable. There are large quantities of lignitic, with some sub-bituminous coals, which are on or close to tidewater. The fields of high-grade coals can be reached from open ports on the Pacific by railways from thirty to two hundred miles in length. From the coastal terminals of these railways to Puget Sound ports the distance is about twelve to fourteen hundred statute miles and about two thousand miles to San Francisco.

Alaska Coal and the Pacific Coast States.—These coals are therefore available for the use of the Pacific Coast States, with their growing population and industries. The five million people in this section are the natural customers for that surplus of Alaska's high-grade coals which can not be locally consumed, yet must be mined to warrant the establishment of the mining industry on a profitable scale. In other words, as Alaska now uses only about one hundred thousand tons of coal annually, an export trade must be established to warrant the large investments needed to open up the coal fields.

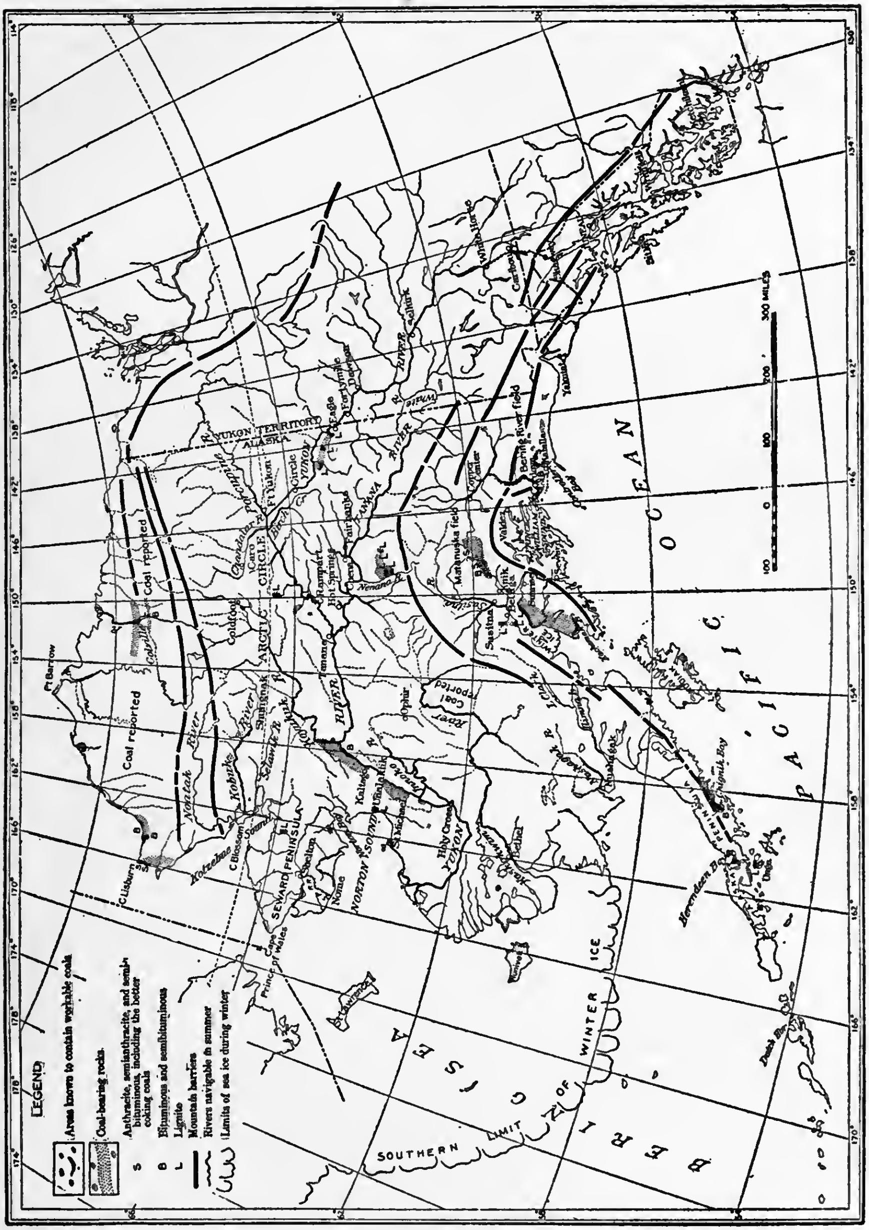
LEGEND
Areas known to contain workable coals
Coal-bearing rocks
Anthracite, semianthracite, and semibituminous, including the better coking coals
Bituminous and semibituminous
Lignite
Mountain barriers
Rivers navigable in summer
Limits of sea ice during winter
SOUTHERN LIMIT OF WINTER ICE
BERING SEA
PACIFIC OCEAN
YUKON TERRITORY
ALASKA
ARCTIC CIRCLE
SEWARD PENINSULA
NORTON SOUND
Coal reported
Pt Barrow
Nome
Fairbanks
Matanuska field
Bering River field
Valdez
300 MILES

FIG. 1.

At present, the industries most needing the Alaska coal are those of the Territory itself. These include primarily the whole transportation system, both railway and steamer, the mining industry and, to a lesser extent, the fisheries. Given cheap fuel, all these industries would rapidly develop, while without it they must lag. More important to the nation as a whole are the future needs of coal for the metallurgical industries of the Pacific seaboard. It has been estimated that this province now consumes over a million tons of raw and manufactured iron annually. Only a small part of this is supplied from local sources, the balance coming from the Eastern States, the Rocky Mountain States, and from foreign sources, including European countries and Asia. This long haul involves an economic waste of fuel and materially increases the cost to the consumer. With cheap coke there is no reason why the Pacific seaboard should not smelt its own iron ores. Other industrial uses need not be mentioned, but include manufactures as well as commerce.

The position of Alaska coal in relation to other natural resources has already been referred to. Metalliferous deposits are widely distributed in the Pacific slope region of Alaska. To develop them the coal is needed. Iron ore occurs in the Pacific Coast States and probably in Alaska, and could be used if coke were available. The opening of the coal fields will attract a population which, in turn, will lead to the development of Alaska's latent agricultural resources. It is by no means impossible that the world may draw on Alaska for a part of its meat supply, for the Territory includes the most extensive unoccupied grazing lands on the continent.

The position of the Aslaska coals in relation to other sources of power is the most important, as it involves the question of competition. Disregarding possible future sources of energy, the competition will be with (1) water power, (2) other mineral fuels. Water powers will here be only briefly considered.

There are many undeveloped water powers in the Pacific States and Alaska, and these could be made to furnish energy which might compete with that which could be obtained from Alaska coal. Eventually, however, recourse must be had to the mineral fuels, as the water powers are not sufficient to meet the demands of future industries. Therefore, the competing mineral fuels are probably the most important element in the problem of markets for the Alaska coal.

Examination of a map of North America showing distribution of coal indicates clearly that the Pacific seaboard of the continent is but poorly supplied with this mineral fuel. As distant land transportation of coal, especially over high divides, is always uneconomical and usually commercially impossible, it will be evident that Alaska coal fields are a natural source of fuel to supply the west coast population and industries. This is emphasized by considering the available tonnage. The states of Washington, Oregon, and California have an estimated aggregate of 22,000 million tons of coal reserves, to which should be added, say, 4,000 million tons for the coal of the British Columbia coast. The total of these is little more than a third of the coal supply of the Pacific slope of Alaska. There is known to be some coal in the Pacific drainage slope of Mexico, but this is probably not in sufficient amount materially to change these ratios. Evidently, therefore, Alaska is the only adequate source of supply of North American coal for the Pacific seaboard. The element of quality as affecting strength against competition is on the side of Alaska coal.

Coal Supplies in Foreign Countries.—Turning now to the coal supply of other lands bordering the Pacific. The South American countries have insufficient coal for their own use and are drawing heavily on England. Australia is well supplied with coal, though most of it is not of high grade. Her mines are furnishing coal to South America and even to California. China's coal fields, though of enormous extent, are for the most part unavailable because of the lack of railways. When her teeming population turns to industries requiring fuel, the coal is likely to be needed at home. It is a significant fact, however, that a shipment of Chinese coals has recently been received at San Francisco. Japan, though an exporter of coal, has none to spare, as her reserves are small.

It is evident, therefore, that the lands which, from the standpoint of commerce are tied together by the Pacific, do not promise to become serious competitors with the Alaska coal. The opening of the Panama Canal will change the situation. Then the eastern coals—by water transportation only about six thousand statute miles to California, with an assured return cargo—can probably compete with the Alaska coal. This great engineering feat will change the boundaries of economic and geographic provinces. In considering the broad problems, however, it would appear unwise to ship coals from near the centers of population to the west coast at the expense of the fuel used, and any such movement can hardly persist under the operation of rational economic laws.

Alaska Coal vs. California Oil.—If Alaska is the natural source of fuel supply for the several million people of the western border of the continent, it is pertinent to inquire why the Territory does not furnish this fuel, but is drawing coal for its own use from other parts of the Pacific province at an economic loss. One reason for this lies in our unfortunate public land policy which I do not propose to discuss. The other is the growing production of fuel oil in California. The first has entirely prevented the development of the Alaska coal fields; the second has made the need of it less pressing. If oil fields had the same permanency as coal fields, the Alaska coal fields would have their greatest value at some distant time in the future. Experience in other fields has shown that the oil has only ephemeral importance in the industries and that it is only a matter of time when recourse must be had to coal. During the period of maximum production of an oil field, coal is often driven out of its natural market. For example, California oil is now used on steamers running to the Alaska ports which should be the coastal terminals of coal-hauling railways and is even carried three thousand miles to the Yukon, where it is used on river steamers which, by every economic consideration, should be using the abundant local supply of lignitic coal. Every effort should be made to check such evident economic loss. In time, of course, oil will increase in value, and will then only be used in near-by markets.

Summary.—The above considerations indicate that the coals of the Pacific slope of Alaska are geographically so located as to be the natural source of fuel for the western border of the continent. The supplying of this province with coals transported from long distances means the ignoring of the geographic factor and involves an economic loss. On the other hand, this is being rectified, and the present increasing demand of this province for mineral fuels is now being met by the petroleum of the California fields. The geologic conditions of the occurrence of petroleum are more favorable to exploitation than are those of coal. Geographically the California oil is favorably situated, and its physical character makes its transportation less affected by the geographic factor of distance than is coal. As a result, the abnormally rapid increase in output of California oil will soon prevent any considerable importations of coal from distant provinces and in this way prevent the economic losses to which attention has been directed.

The question naturally arises whether it is sound economics to save the Alaska coal at the expense of encouraging the abnormally rapid development of California oil, which is the more valuable fuel. It is not, however, proposed to discuss here the question either of the possibility or the justification for a governmental check on this oil production.

It is evident from the foregoing that there are two main sources of mineral fuel for the western border of the continent, namely, California oil and Alaska coal. The former is being drawn as rapidly as the means of development permit; the latter is undeveloped. Both geographic and geologic conditions favor the California oil. An ideal economic policy would be to draw on both sources of fuel for this geographic province, and not save one at the expense of the other.

Annals of the Association of American Geographers
Volume I, pp. 95-100, Plates VI-VIII

A GEOGRAPHIC STUDY OF THE MESA VERDE

WALLACE W. ATWOOD

CONTENTS

About thirty-five miles southwest from the base of the San Juan Mountains and near the southwestern corner of Colorado there is a maturely dissected mesa, bordered by an abrupt escarpment, which rises from one thousand to two thousand feet above the adjoining lowland. The upland area is of sufficient elevation to receive an annual rainfall which will support a covering of grass and a scattering of scrubby cedars and piñons, and thus the name Mesa Verde, a green table, was long ago suggested.

The Origin of the Mesa Verde.—In origin the mesa is closely related to the geomorphic changes which have affected the San Juan region of southwestern Colorado, and the details in the outline of the mesa, in the bordering escarpments, and in the canyons which subdivide the mesa, are dependent upon local geologic conditions. The Mesa Verde is but a portion of a widespread plateau, which has been dissected by streams flowing southward and southwestward from the San Juan Mountains into the San Juan River, and thence to the Colorado. The mesa and plateau surfaces appear to be portions of a late Tertiary peneplain. That peneplain probably extended northeastward over a portion of the neighboring areas where now there are mountain ranges, and far to the southwest over the Colorado Plateau district. The relationship of the surface of the mesa to the San Juan Mountains is strongly suggested by a scattering of beautifully worn gravels, which must have come from the San Juan Mountains and traveled southwestward in stream courses long before the present valleys were developed. With the uplift which closed the cycle of erosion, when this broad area was reduced to a peneplain, the San Juan Mountain area rose as a dome and the surrounding area as a slightly inclined plain. The upper surface of the Mesa Verde slopes gently to the southwest. The streams were invigorated and the uplifted and deformed peneplain was dissected. The areas of softer rocks were first reduced and the remaining upland areas were thus defined as relief features. These relief features have been slowly yielding to the agencies of weathering and stream erosion to the present time.

The Dissection of the Mesa.—A hard layer of sandstone has preserved portions of the Mesa Verde, and the weathering of soft underlying shales has maintained the precipitous marginal escarpment. On the north, east, and south are the valleys of the Rio Mancos and its tributaries. On the west is the Montezuma Valley. The smaller streams tributary to the Rio Mancos on the south side of the mesa have worked headward until, in some instances, they have reached the escarpments bordering the mesa on the north and northwest. These escarpments, in turn, have been gradually retreating southward as the soft shales have been worn away, and huge blocks of the hard overlying sandstone have fallen. In those instances where the headward growth of the valleys has reached to the margin of the mesa, the upper ends of the valleys are being gradually cut off by the retreat of the marginal escarpment. The surface of the mesa is to-day, therefore, very little like a tableland, for the canyons which have been cut into it have left but narrow strips of upland bordered on either side by the nearly vertical faces of the canyon wall (Pl. VI*a*). As there is little or no water on the mesa at present, it is more common to see the stream courses dry than to find flowing water in them. The heads of the canyons are box-like (Pl. VI*b*), and the waters enter them as cascades or falls. The extension of the canyons northward into the mesa must be by the under-cutting at the falls and the gradual recession of the falls up stream.

The Cliff Dwellers of the Mesa.—The mesa top suggested to certain primitive people who formerly lived in the southwestern portion of the United States, an easily protected site for their homes. The upland could be reached only at a few points, and at those points with great difficulty. The approach of unfriendly peoples could be watched from the rim of the mesa or from outlook points on the rims of the canyons, and attempts made to scale the bordering escarpments or approach the homes through the canyons from the south could be anticipated by the dwellers on the mesa or by those in the great alcoves near the heads of the canyons. These people became the Cliff Dwellers. They built some of their homes and many watch towers on the remnants of the upland surface of the mesa, but most of their houses were built in the canyon walls. The ruins of these homes may still be found to the number of several hundred, scattered about through the area now set aside as the Mesa Verde National Park and southward over the remaining portion of the Mesa Verde. The more remarkable of the buildings are near the heads of certain of the canyons which end just south of the southern limit of the Park. The Park authorities, however, by an act of Congress, have been given control over this region of unusual dwellings which added to the territory under their jurisdiction a bordering strip five miles in width. The alcoves which were selected for homes were worn out of the canyon walls by the agents of weathering at less resistant points in the sandstones. The dwellings are not in the underlying soft shales, but near the bedding plane between two of the great sandstone layers which form the capping of the mesa. The overhanging ledge sometimes extends as much as one hundred feet beyond the inner margin of the cave in which the home was built.

The Character of the Houses.—Fragments of the sandstone, after some little trimming and shaping, were used by these peoples in the construction of their homes and laid one upon the other with mortar or plaster made of the underlying clay. The homes were built from the floor of the cave to the ceiling. In some instances, there are three, and in a few instances even four stories. The floors were made by placing cedar boughs from wall to wall. These cedar boughs were usually allowed to protrude beyond the walls and sometimes served as a support for platforms or balconies (see Pl. VII*a*). The rooms are usually not more than eight or ten feet in diameter and many of them are much less than that. Many of them are without light from the outside. The dark rooms have been interpreted as granaries or storage rooms.

A few of the inner rooms in which human bones, and in some instances mummies have been found, have been interpreted as burial rooms, and it is believed that these people, after embalming their dead, stored them away in the inner recesses of their great dwellings. Among the rooms in the dwellings there are certain circular ones which have been called kivas, and these have been interpreted as ceremonial rooms (see Pl. VII*b*). These rooms were covered over and entered from above by ladders, or through subterranean passageways. The kivas had cold air flues for ventilation, an altar, a large central fireplace, small niches in which the sacred grain was stored, and a little off the center a small circular opening about eight inches deep and four inches in diameter, which has been interpreted as a connection with the under-world which might be used when desired by those conducting the sacred services. The ceremonial rooms were sometimes rectangular; they were always well made and exceedingly strong. There were several such kivas in each dwelling and they were always in the outer portion or foreground of the little village (see Pls. VII*b* and VIII*b*).

The Products and Implements of the Cliff Dwellers.—Almost every room in the dwellings has been blackened by the soot which came from the fires used for heating or cooking. There were open fireplaces in which the people prepared their simple foods and about which they may have baked certain of the pieces of pottery. Scattered about in the rooms and in the large open space back of the

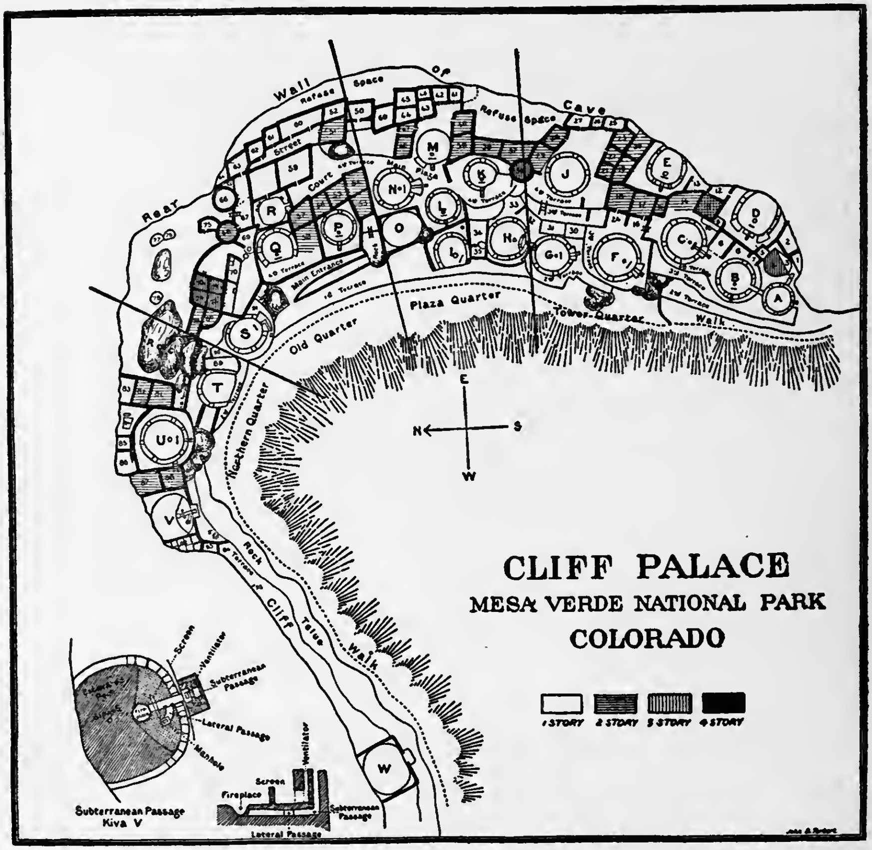

Fig. 1.—Sketch Plan of Cliff Palace.
From the Annual Report of Superintendent of Park, 1909.

rooms, where the caves have but little height, there are thousands and thousands of corncobs. Great heaps of corncobs have been found by those who have been engaged in repairing the dwellings. The corncobs were small, about the size of pop corn cobs, and it is of special interest to learn that these people raised maize in this region where now there is but one spring known, and where it would be impossible to raise grain without some elaborate method of storing the rainfall and using it through the dry season by means of irrigation ditches.

From the few relics found about the dwellings it is evident that cotton also was raised. Some game was killed, and both the cotton and the skins of animals were used for clothing. The leaves of the corn, and the leaves and cords of the yucca served in the making of sandals. The abundance of plastic clays and the necessity of vessels for carrying water led these people to be good pottery makers, and among the dwellings to-day there are many bits of ancient pottery. Occasionally a bowl or a spoon or a cup is found in the débris.

The corn was ground in large bowl-shaped stones, hollowed out for that purpose. Many of the grinding stones and bowls are still in good condition and are now preserved for the inspection of visitors. About the ruins little flint arrow-heads, used presumably for shooting small game, may be found, and at many places on the upland areas of the mesa similar arrow-heads have been picked up. Stone axes and stone knives have also been found, but no implements of metal. The Cliff Dwellers used the grasses and leaves of the yucca, the leaves of the corn, the twigs from the willows, cedar boughs and trunks, stones, clay, cotton, and the skins of wild animals. They presumably lived in peace and in an exceedingly simple way.

The Cliff Palace.—In the largest of the dwellings, the Cliff Palace (see Pl. VIII*a* and *b*), there are over three hundred rooms (Fig. 1). A great circular tower occupies the central position in the dwelling, and at one end is a rectangular tower, four stories high, interpreted as the home of the chief. Over twenty kivas border this dwelling in the foreground, and behind the rooms which were closed in there is a large open space, which may have been used as a playground for children or a safe retreat during an attack, or as general storage space.

Near each dwelling on the mesa there must have been a spring. There are indications that many such springs did exist. The one which is now flowing is near the head of one of the forks of the Navajo Canyon, where the Spruce Tree House is located. The dwellings at the Spruce Tree House and Cliff Palace have been somewhat repaired by representatives of the Smithsonian Institution, but this work has been so well done that the homes still appear as ruins. The débris has been cleared away and a much better idea of these ancient homes can now be obtained than before this work was done. There remain several of the dwellings which are almost inaccessible or unsafe to visit until some work of repair shall have been done.

The Geographic Conditions at the Time of Occupation by the Cliff Dwellers.—The origin of the mesa is seen to have been closely associated with the physiographic history of the region. Its form and the details in its architecture are due to the controlling geologic conditions. Its isolation made it attractive to a peaceful people who wished a quiet home out of the reach of unfriendly nomadic tribes. The alcoves which the Cliff Dwellers selected for their homes were due to the differential weathering of the varying formations of the mesa. The stones used in building homes were obtained from the formation immediately at hand; the clay used as mortar immediately underlay the sandstone. The scarcity of water determined the location of the homes near the springs, and compelled the people to conserve the water supply. The necessity for carrying and conserving their water supply led these people to make various kinds of water vessels and to become good pottery makers. The scarcity of level land made it necessary to cultivate small portions on the upland and on the canyon bottoms. The aridity of the climate made the food supply a difficult question for these people. The corn which they raised was small and stunted. The wild game was presumably small and scarce. Cotton was raised in but relatively small quantities.

The Present Conditions.—Since the Cliff Dwellers inhabited the Mesa Verde, the climate has evidently become even more arid, and the mesa could not to-day support the population which it must once have supported. The single spring would limit the inhabitants to one or at most two of the hundreds of dwellings scattered about on the mesa and in the canyons. The almost complete absence of wild game on the mesa would add to the difficulties.

The Age of the Ruins.—The lack of definite legends among the Indian tribes of the Southwest of their relationship to these ancient Cliff Dwellers seems to indicate that these homes were deserted many hundreds of years ago, and the absence of any metals about the homes suggests the same conclusion. The relationship of this entire record to the geologic history suggests that the Cliff Dwellers inhabited this region at a time much less removed than the present from the last period of glaciation in the mountains, and the question may perhaps be raised, may we not find some evidence in the homes of these ancient peoples that will indicate that they inhabited portions of our Southwest country during the last glacial epoch in North America?

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TITLES AND ABSTRACTS OF PAPERS PRESENTED TO THE ASSOCIATION FROM 1904 TO 1910, INCLUSIVE

Philadelphia, 1904

Bailey Willis.
Some Physical Aspects of China.

F. E. Clements.
The Interaction of Physiography and Plant Successions in the Rocky Mountains.—Read by Title.

E. Huntington.
The Seistan Depression in Eastern Persia.

L. Stejneger.
The Distribution of the Discoglossoid Toads, in the Light of Ancient Land Connections.

A. P. Brigham.
The Development of the Great Roads across the Appalachians.

R. W. Pumpelly (by invitation).
Physiography of the Northern Pamir.

R. S. Tarr.
Some Instances of Moderate Glacial Erosion.

D. W. Johnson.
The Distribution of Fresh-Water Faunas as Evidence of Drainage Modifications.

H. C. Cowles
The Relation of Physiographic Ecology to Geography.

R. A. Daly.
The General Accordance of Summit Levels in a High Mountain Region: the Fact and Its Significance.

I. Bowman (by invitation).
Partly Submerged Islands in Lake Erie.—Read by Title.

Cyrus C. Adams.
The Improvement of American Maps.—Read by Title.

R. E. Dodge.
The Journal of Geography and Its Purpose.—Read by Title.

F. E. Matthes.
The Study of River Flow.

L. G. Westgate (by invitation).
The Geographic Features of the Twin Lakes District, Colorado.

N. H. Darton.
Geologic Expression in Contour Maps.—Read by Title.

H. F. Reid.
The Forms of Glacier Ends.—Read by Title.

F. P. Gulliver.
Muskeget, a Complex Tombolo.

Wm. Libbey.
The Physical Characters of the Jordan Valley.—Read by Title.

W. M. Davis.
A Chapter in the Geography of Pennsylvania.—Read by Title.

G. K. Gilbert.
Moulin Sculpture.

G. W. Littlehales.
A New and Abridged Method of Finding the Locus of Geographical Position, and Simultaneously Therewith the True Bearing.—Read by Title.

New York, 1905

Presidential Address—W. M. Davis.
An Inductive Study of the Content of Geography.

A. H. Brooks.
The Influence of Geography on the Exploration and Settlement of Alaska.

J. Walter Fewkes.
The Sun's Influence on the Orientation of Hopi Pueblos.

Martha Krug Genthe.
Valley Towns of Connecticut.

E. O. Hovey.
Geographical Notes on the Western Sierra Madre of Chihuahua.

R. De C. Ward.
Climate and Disease: How They Are Related?—Read by Title.

A. P. Brigham.
Lake Loen (Norway) Landslip of January, 1905.

Emory R. Johnson.
Political Geography as a University Subject.

Cyrus C. Adams.
Map Making in the United States.

Cleveland Abbe.
A Modified Polar Projection Adapted to Dynamic Studies in Meteorology.

Isaiah Bowman.
Hogarth's "The Nearer East" in Regional Geography.

R. M. Brown.
Notes on the Mississippi River Flood of 1903 and on the Floods of Other Years.

Henry G. Bryant.
Notes on Some Results from a Drift Cask Experiment.

N. M. Fenneman.
An Example of Flood Plains Produced without Floods.

D. W. Johnson.
Map Studies for Engineering Students; The Classification of Contour Maps on a Physiographic Basis.

Wm. Libbey.
Physical Geography of the Jordan Valley.

Lawrence Martin.
Observations along the Front of the Rocky Mountains in Montana.

A. Lawrence Rotch.
Proofs of the Existence of the Upper Anti-Trades.

R. S. Tarr and Lawrence Martin.
Observations on the Glaciers and Glaciation of Yakutat Bay, Alaska.

P. S. Smith.
Practical Exercises in Physical Geography.

F. P. Gulliver.
Home Geography.

J. Russell Smith.
The Place of Economic Geography in Education.

Martha Krug Genthe.
Some Remarks on the Use of Topographic Maps in the Schools.

D. W. Johnson.
Drainage Modifications in the Head Waters of the Chattahoochee and Savannah Rivers.

W. M. Davis.
Physiographic Notes on South Africa.

NEW YORK, 1906

Presidential Address—Cyrus C. Adams.
Some Phases of Future Geographical Work in America.

William Churchill (Introduced by Cyrus C. Adams).
Insularism and the Nesiote Type.

A. L. Rotch.
The Circulation and Temperature of the Atmosphere at Great Heights above the Tropical Atlantic.

Charles C. Adams.
The Evolution of the Isle Royal (Lake Superior) Biotic Environment.

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The Opening of the Indian Territory.

Isaiah Bowman.
The Deserts of Peru and Chile in South American History.

E. N. Transeau.
The Need of Evaporation Data in Plant Geography.

Wm. Libbey.
Problems of the Panama Canal.

W. J. McGee.
The Prospective Conquest of the Mississippi River.

Angelo Heilprin.
Guiana and Venezuela, as a Field for Geographical Exploration, With Some Observations on a Recent Visit to the Essequibo Wilderness.

G. W. Littlehales.
The Nature and Purpose of the Chart Publications of the Navy Department, and Their Geographical Extent.

E. O. Hovey.
The Isthmus of Tehuantepec.

Alfred H. Brooks.
Railway Routes in Alaska.

H. L. Bridgman.
The International Polar Congress at Brussels.

E. Huntington.
Influence of Changes of Climate upon History.

R. De C. Ward.
The Meteorology of the North and South Polar Areas.

W. M. Davis.
Place of Coastal Plains in Systematic Physiography.

W. J. McGee.
The American Deserts and Their Reclamation.

W. M. Davis.
Geography as Defined by Hettner.

F. P. Gulliver.
The Orientation of Maps.

A. P. Brigham.
Geography for College Entrance.

Collier Cobb.
Hatteras Island and Its Shifting Sands.

D. W. Johnson.
The Texture of Topography.

W. M. Davis.
The Eastern Slope of Mexico.

H. E. Merwin.
Land Forms as Plant Controls.

Cleveland Abbe.
A Study of Airy's Projection by Balance of Errors.

A. W. Grabau.
Classification of Marine Life Districts.

Chicago, 1907

W. M. Davis.
Memorial of Angelo Heilprin.

Isaiah Bowman.
Geographic Relations in Chile and Bolivia.

The regional geography of the deserts of Chile and Bolivia, the great interior basin of western Bolivia, and the humid windward slopes of the eastern Andes.

Eugene Van Cleef (Introduced by J. Paul Goode).
Is there a Type Cyclonic Storm?

A study of the cyclones and anti-cyclones of America for a period of ten years, with the purpose of determining type storm paths and to arrive at some clue for more definite forecasting.

J. Paul Goode.
An Electrical Compensator for the Foucault Pendulum.

An electrical device by which the retardation due to resistance of air and friction of bearings is compensated for, permitting continuous vibration.

Wallace Craig (Introduced by Chas. C. Adams).
The Flatness, Aridity and Severe Winter of North Dakota in Relation to the Life of the Region.

The three conditions named are dominant geographic conditions in North Dakota; they affect all forms of life. The object of this paper is to show that the results produced by these conditions upon the various forms of life, such as plant, bird, mammalian, Indian, pioneer, and civilized life, are strikingly analogous.

For example, the chief adaptation to an unobstructed, flat topography is great travelling power; this is seen in plants (wind-blown seeds, especially the tumble-weed); birds (strong fliers); mammals (swift runners); plains Indians (nomadic); pioneers (also nomadic, *e. g.,* in "prairie-schooners"); and civilization (the flat surface makes possible railroads without curves or grades, good wagon roads and, especially, wonderful farming machinery). A secondary effect, resulting from this travelling power, is seen in the formation of large societies; the plants form extensive associations; the birds, immense flocks; the mammals, immense herds; the plains Indians, great social organizations; the pioneers, boundless ranches, with immense herds of cattle; civilized man, large fields and immense farms, with further results, such as great caravans of harvesters, etc.

Henry C. Cowles.

The Relation of Snow and Ice to Mountain Timber Lines.

Mountain timber lines have been commonly referred to temperature as a controlling factor. As a matter of fact, timber lines are much less definite physiognomic features than is commonly supposed and, so far as they actually exist, they are to be accounted for by a complex of causes, among which the direct influence of temperature is comparatively inconsequential. Trees readily thrive at the coldest known places in the world, if other factors favor them.

Among the factors that determine the presence or absence of trees are snow and ice. In the mountains, trees are commonly scattered or absent altogether, where snow remains for a large portion of the year. Grasses and other alpine herbs can become established without difficulty, where tree life is impossible. These facts explain why trees are often scarce in cirques, and why trees commonly ascend much higher on exposed ridges than in protected valleys. Similar phenomena are to be seen in front of glaciers and along their sides.

E. N. Transeau.

The Successional Relations of the Cold Spring Harbor Vegetation.

A classification of the plant societies found in the vicinity of Cold Spring Harbor, Long Island, and their relation to evaporation.

Victor E. Shelford.

The Distribution of the Tiger Beetles, and Its Relation to Plant Succession.

The study of breeding habits is the first essential in animal ecology. Animals breed only within a very limited range of conditions. Habitat selection in correlation with environmental processes: erosion, deposition, plant succession, etc., is one of the great factors in dispersal and isolation.

Plant ecologists find that forests develop through a series of stages all directed toward a climax climatic type. Different tiger beetles are found in the different stages of forest development, *Cicindela sexguttata*, in the white oak, red oak and hickory. This forest is now distributed over the Eastern United States as far west as eastern Kansas. Dr. Cowles tells us that with the planation of the eastern plateau, this type of forest, which in the plateau area occupies the uplands, will be succeeded by the beech and maple west to the Mississippi and Illinois Rivers. *C. sexguttata* and its associates will, by this process, be in part driven from the beech and maple area and in part isolated in situations where the dense beech and maple conditions, encroaching from all sides, will set up a rigid and definitely directed selection. Such selection will, perhaps, result in the production of new habits and new characters.

C. R. Dryer.

Philosophical Geography.

Strabo (A. D. 19) regarded geography as an important branch of philosophy or the general theory and explanation of things. Its place in modern philosophy was assigned by Kant (1802) as that part of our experience which is concerned with the order of phenomena coexistent in space. Bain says the foundation of geography is the conception of occupied space.

Consequently, facts of location, direction, distance, area and distribution belong exclusively to geography. Distribution is not simply static, as shown on a map, but dynamic as the result of terrestrial activities. Hence geography becomes a science which investigates the general laws of distribution of every class of phenomena on the earth (Neumann, Hettner, Mill, Keltie).

From an evolutionary point of view, features and phenomena are products of their environments (Davis, Redway).

The geographic argument or enchainment (Richtofen, Mackinder). Relations of Geosphere, lithosphere, hydrosphere, atmosphere, biosphere and psychosphere to one another.

Geographic dualism: (1) Relation of all other spheres to lithosphere (Mill); (2) to bio-psychosphere (Davis); (3) to psychosphere (McMurry and others); (4) to atmosphere.

Geography a synthesis of phenomena in all spheres (Ritter, Geddes, Unstead).

Mark Jefferson.

The Distribution of Population.

C. W. Hall.

The Conservation of the Upper Mississippi River.

A brief sketch of the present reservoir system of the U. S. Government at the head waters of the Mississippi River was given, the need of additional storage, as an advantage to manufacturing interests and navigation, pointed out, and a general plan for increasing the present reservoir system suggested.

The change in the run-off conditions of the region is due to the great extension of the system of farm-swamp. Drainage now being developed in thus briefly discussed.

Ellen C. Semple.

Oceans and Enclosed Seas.

F. V. Emerson (Introduced by C. F. Marbut).

The Geographic Distribution of Slavery in Missouri.

R. H. Whitbeck.

Geographic Influences in New Jersey.

C. R. Dryer.

Glacial Economics and Sociology; a Study of a Western New York Town.

The Town of Victor, Ontario Co., N. Y.; location and area. Physiography: crossed by a massive range of kames and moraines with associated drumlins, which give an unusual variety of landscape and soil. Range cut by a glacial river valley affording passage for roads.

Drainage and climate: aboriginal occupants; Seneca-Iroquois villages destroyed by the French in 1687. Settlement by New England people in 1787. Forests cleared and farms fully occupied before 1820.

An agricultural community: crops and domestic manufactures.

Roads and markets: Erie Canal and plank roads; railroads; macadamized roads and electric interurbans.

Population almost constant in numbers, but changed in composition. New England stock largely replaced by Irish immigrants. Schools and churches. Probable changes from advent of suburban and manufacturing population.

F. Carney (Introduced by R. S. Tarr).

Springs as a Geographic Control in Humid Climates.

In arid and semi-arid lands, springs are an important control; while exerting a less striking control in humid regions, they have. nevertheless, an ample influence because of the more general activities of these regions.

The localities discussed are found in Ohio within the area comprised by the outcropping formations of the Pennslyvanian period.

Lawrence Martin.

Glacial Highways in Alaska.

In Alaska certain highways across glaciers have been of great importance in reaching gold fields, high mountains, etc., and have been traversed in a single season by hundreds, in several cases, and in one case by thousands of prospectors. One large town of Alaska owes its location to the proximity of a deep water harbor to such a glacier highway. The favorable geographic conditions which determine these highways were discussed and the necessary glacial conditions to make human movement and transportation possible described.

W. M. Davis.

Geography of Devonshire and Cornwall, England.

The Devonshire-Cornwall district is of deformed or mountainous structure, but its time of chief deformation is so ancient that its original strong relief has been destroyed in successive cycles of erosion. In a Tertiary cycle the district was reduced for the most part to a peneplain, surmounted as in Dartmoor by broad, low domes of the more resistant rocks. Since then, an uplift of a few hundred feet has introduced a new cycle of erosion in which all stages of topographic development are represented, from narrow valleys of early youth in the most resistant rocks, to open lowlands of well advanced old age in the weakest rocks. A recent depression of moderate amount has submerged the open lowlands, converting them into shallow seas; and has drowned the narrow valleys, converting them into branching bays. On the shore line thus produced, the sea has cut young, ragged cliffs. Conditions of settlement and occupation may be concisely referred to the physiographic sub-districts.

Wm. H. Hobbs (Introduced by R. S. Tarr).

On the Expansion and Contraction of the Lake Superior Region.

Samuel Wiedmann.

The Physiography of Northern Wisconsin.

Lawrence Martin.

The Physiography of the Lake Superior Region.

A brief review of the topographic provinces in the region about Lake Superior; their age, form, characteristics, and relationships. The region was described in terms of the several periods of planation, the burial and resurrection of the old topography, the extensive glaciation, and the subsequent tilting in the Lake Superior Basin, with some consideration of the present attitude of the shore lines of the ancestors of Lake Superior.

G. E. Condra.
The Geography of the Sand Hills Area of the Great Plains.

A. Keyser.
Agriculture in Western Nebraska and Eastern Colorado.

N. A. Bengston.
Recent Change of the Missouri River.

C. F. Marbut.
Soils of the Ozark Region.

W. W. Atwood.
The Lakes and Cirques of the Uinta Mountains.

The cirques on the north and south slopes of the Uinta Mountains were developed under somewhat different geological conditions, and their present dimensions seem to be intimately related to those conditions. The dimensions of the cirques were one of the chief controlling factors in the development of the glaciers. The lakes of the Uintas are grouped in great amphi-theatral basins near the crest line and may be classified under several heads. Among them are rock-basin lakes, drift-basin lakes, lakes due to stream-ponding (frequently arranged in chains), lakes in tributary valleys blocked by lateral moraines in the main, in basins between lateral moraines and the canyon walls, and in basins between lateral moraines from adjoining canyons just above the junction of these lateral moraines and the formation of the medial moraine. The utilization of the lake waters and the stages in the destruction of the lakes were also considered.

N. M. Fenneman.
Physical Geography in Public Schools.

W. M. Davis.
Exercises in Physical Geography.

R. S. Tarr.
The Use of the Wet Laboratory in the Teaching of Physiography.

Brief statement of kinds of laboratory work commonly used in physiography instruction. Advantages and disadvantages of each kind. The need felt of additional laboratory methods has led to the introduction of a wet laboratory at Cornell University, for use both with elementary classes and for research by advanced students. Description of this laboratory and its equipment. Illustrated description of some of the experiments performed, and brief outline of possibilities. Discussion was invited as to the desirability of such work both in the university and in the secondary schools.

J. Paul Goode.
A College Course in Ontography.

Outlines of a course in the principles of geography, with the purpose of emphasizing the inter-relation of life and its physical environment. Essentially an elementary course in plant, animal and human ecology.

W. M. Davis.
Uniformity of Method in Geographical Instruction and Investigation.—Round Table Conference.

Baltimore, 1908

Presidential Address—G. K. Gilbert.
Earthquake Forecasts.

J. W. Goldthwait.
Accumulation of Inherited Features in Shore Lines of Elevation.

The straight, freshly cliffed shores of the Great Lakes, especially in the southern part of the Great Lake region, offer good illustrations of what has been called the mature stage of the shore cycle.

When the present shore line is studied in the light of past history, it is found that the present cycle was instituted by the falling of the lake level from an earlier, higher stage; and that preceding this were several other stages, each higher than the later one. A comparison of the present shore line of Lake Michigan, for instance, with its immediate ancestors, the Nipissing and Algonquin shore lines, shows that the present one inherited nearly all its maturity from these which preceded it. Likewise, comparing the Algonquin shore line with the higher, earlier beaches of Lake Chicago, and comparing them with each other, one finds that each shore line inherited a noticeable degree of development from its predecessor. This principle is believed to obtain very generally in the shore line topography of the Great Lakes.

The recognition of inherited features as such is considered to be as desirable in the study of shore line topography as it is in the study of incised meanders and other features among rivers.

W. H. Hobbs (Introduced by R. S. Tarr).
On the Elements of the Surface Sculptured by Valley Glaciers.

This paper is a discussion (1) of the relief forms which result from the occupation of a mountain region by glaciers of the Alpine type, and (2) the stages in the process of change to glaciers of the Piedmont type through climatic variations.

O. D. von Engeln.
Existing Glaciers of the Western Hemisphere.

F. E. Matthes.

The Topographer's A B C of Land Forms.

An attempt to classify land forms according to a scheme of practical value to the topographer. Beginning with the continent as the largest unit, several successively smaller sub-divisions are recognized. The lowest and simplest of these is the "topographic district," an area of uniform topographic character. The detail forms or "topographic units" which enter into its composition (the forms with which the topographer chiefly deals) are shown to represent various genetic families or "topographic groups." Each "group" contains one or more critically important forms or "index forms." Again, topographic units may occur in different orders of magnitude and in different modes of arrangement, thus producing different kinds of "topographic texture." The types present, the shape and character of the separate units and the topographic texture, together determine the "topographic character" of a district.

Each concept was briefly outlined and illustrated by maps and sketches.

C. T. McFarlane (Introduced by A. P. Brigham).

How May the Teaching of Geography in Elementary Schools be Improved?

Wm. H. Hobbs.

On Apparatus for Instruction in the Interpretation of Maps.

(a) A description of simple apparatus which has been used with success in initiating students into an appreciation of the relief expressed upon topographic maps. (b) Apparatus for instruction in the preparation of geologic maps and sections from the observational data.

H. G. Bryant.

Some Practical Results of the Ninth International Geographical Congress.

A. P. Brigham.

Three Gatherings of Geographic Interest.

Brief notes on the Ninth International Geographical Congress, the Meeting of the Linnean Society of London on the fiftieth anniversary of the announcement of Natural Selection by Darwin and Wallace, and on the Oxford University School of Geography.

L. A. Bauer.

Status of the Magnetic Survey of the Earth.

A general statement was made as to the progress to date of the magnetic operations by the Department of Terrestrial Magnetism of the Carnegie Institution of Washington and other organizations, for the accomplishment of a general magnetic survey of the Earth within a period of ten to fifteen years. The general plan of work being followed by the Carnegie Institution was described and the future work, especially on the oceans, set forth.

E. D. Leffingwell (Introduced by H. C. Cowles).
A Reconnaissance in the Arctic Slope of Alaska.

H. Gannett.
The Climate of Cuba.

A. L. Rotch.
The Temperature at Great Heights Above the American Continent.

For the first time in America the temperatures are known at heights between 7,000 and 16,000 meters. These data were obtained from 72 *ballons sondes* sent up from St. Louis in 1904-7 by the staff of the Blue Hill Observatory, under the writer's direction. A discussion of the observations by Mr. Clayton appeared in the Annals of the Harvard College Observatory and in the present paper certain important results only were stated. These were: (1) the non-periodic changes from day to day which extend to the greatest heights reached; (2) the seasonal changes which, though progressively retarded, extend to a height of 12,000 meters or more; and (3) the relatively warm stratum, which lies above 13,000 meters, to an unknown thickness.

E. Huntington.
The Climate of the Historic Past.

In a previous paper before the Association evidence was presented which seems to show that changes of climate have occurred in central Asia and that they have been of a pulsatory nature. Further study shows that similar evidence is found in the far east and the far west of Asia, and also in various parts of America. Some idea may thus be gained as to the extent of changes of climate in latitude and longitude. It appears that they bear certain marked resemblances to the epochs of the glacial period, on the one hand, and to Brükner cycles, on the other hand. Recent data as to the nature and degree of the changes of the glacial period and as to the extent of variations in climatic conditions during short periods at the present time, give a basis for a rough estimate of the extent to which the climate of the historic past varied from that of the present. They also afford some important suggestions as to the causes of climatic variations.

J. R. Smith.
The Origin of Civilization Through Intermittency of Climatic Factors.

H. A. Smith (Introduced by A. P. Brigham).
The National Forest Policy.

H. Gannett.
Some Results of the Recent Census in Cuba.

Mark Jefferson.
The Anthropography of Great Cities.

The distribution of population-density within great cities is under geographic control. The greatest density encompasses the business center where are many non-residential buildings. Beyond this, population becomes less dense to a grade of ten thousand to the square mile, which is taken as suburban. The anthropographic city thus includes all adjacent territory populated more densely than this, regardless of political boundaries. There result anthropographic values of the population of great cities that are comparable. Geographic limits to a city's expansion immensely add to the maximum density within it, as shown by New York and Chicago with higher and lower densities than London, Paris, Berlin or Vienna. Attention was given to the causes and epoch of great cities, with a glance at the population of imperial Rome.

A. P. Brigham.
The Capacity of the United States for Population.

R. H. Whitbeck.
Geographical and Other Influences Affecting the Pottery Industry of Trenton, N. J.

Contrary to general belief, Trenton potteries depend very little upon local clay. Only a coarse quality used for "saggars" is found near Trenton. All of the clay used for white ware comes from a distance—Southern States and England. The flint and spar come from other states, and from Canada. Coal comes from a long distance. The freight on the coal is more than the first cost of the coal. Trenton enjoys no advantage over dozens of other places in cost of fuel, nearness to raw materials, freight rates, or even markets. Nearness to markets is, however, one of Trenton's advantages over East Liverpool, her chief rival. This advantage shows itself in Trenton's ability to deliver goods to Eastern markets more promptly, rather than so much more cheaply.

The momentum of an early start, the early collecting of skilled labor, largely from England; the natural tendency of later immigrant potters to locate in a pottery center already established, and the reciprocal tendency of pottery manufacturers to locate new plants where a supply of skilled labor already existed, are probably more important factors in building up Trenton's pottery industries, than are purely geographical influences.

F. Carney.

Geographical Influences in the Development of Ohio.

Physiographically, Ohio is the doorway joining the East and the West. Between the natural routes, the Ohio River and Lake Erie, was first constructed a "National Road," and later several trunk railways. These water thoroughfares on the north and south, connected early in the last century by canals, now by a network of railroads, stimulated the isolated rich farm lands and grazing areas, made marketable the supply of coal, salt, clay products, etc., and attracted industries. Ohio's situation in reference to the ores of the upper Great Lakes and the Appalachian coals, combined with the shipping facilities of its trunk lines, will give it a still higher position in the list of manufacturing states. Until recent years, the development of Ohio has been associated largely with internal causes; henceforth, external factors will be important.

Isaiah Bowman.

Trade Routes in the Economic Geography of Bolivia.

The paper outlined the principal sources of trade, the geographical distribution of trade products, and the unique disposition of the mountains and drainage systems of Bolivia which at present make the apparently round-about route via the Pacific more economical than that to the Atlantic. Some discussion of the railway then building about the falls of the Madeira was introduced, and of the new railways of the plateau system; the water power of the eastern Andes in relation to railway traction and the absence of coal in the Republic was discussed.

G. D. Hubbard (Introduced by R. S. Tarr).

The Influence of the Precious Metals on American Exploration, Discovery, Conquest and Possession.

The quest of the precious metals drew the Spanish inland and persuaded them to wander widely in North and South America, without making many permanent settlements. The lack of fixed settlements gave them no adequate hold on the country. The English, finding the Spanish in the south, and the French in the north, took a middle place. With no wealth real or reported, inland or even in the mountains, to detract from their purpose, they developed flourishing permanent settlements along the coast.

California gold induced more exploration of routes and passes across the mountains and high plateaus in one summer, than had ever been made before. Little known trails were improved, straightened, lowered or carried by more watering places, and in many places new ones were formed. Routes across Mexico and Central America were found. Prospectors went out through every valley and gulch and learned the land. Scientific exploration and mapping have been directed and accomplished in accordance with the discovered distribution of the precious metals.

N. H. Darton.

The Stream Robbery on Which the Belle Fourche Reclamation Project is Based.

In the development of the drainage of the plains lying north of the Black Hills, certain peculiar conditions have made natural drainage basins, while stream robbing has afforded a water supply for the reclamation of a large area of semi-arid land.

F. B. Taylor.

A Remarkable Glacial River and its Modern Representative.

F. P. Gulliver.

Delta Form and Structure of the Thames River Terraces, Connecticut.

The terraces of the Thames River in eastern Connecticut are from fifteen to twenty feet above sea level at New London, forty to fifty feet at Montville, seventy to eighty feet at Brewster's Neck and near Trading Cove, one hundred to one hundred and twenty feet at Norwich, two hundred to two hundred and forty feet at Willimantic, and two hundred and fifty to two hundred and eighty feet near Danielson.

A casual inspection of the surface forms of these terraces would suggest that they were formed as river terraces after the retreat of the ice. This was Dana's idea in regard to them, as published in 1880.

The structure, however, is delta structure, which was well shown by the cuts made at the Navy Yard north of Groton when the New York, New Haven and Hartford Railroad built its line from New London to Norwich in 1897.

J Paul Goode.

The Requisites of a School Wall Map.

Round Table Conference: Geography for Secondary Schools; by R. E. Dodge.

Boston–Cambridge, 1909

Presidential Address—W. M. Davis.

The Italian Riviera Levante.

Mark Jefferson.

The Dominant Factors in the Geography of America.

Geography was contrasted to physiography as essentially leading to human consequences. Mt. McKinley or the Colorado Canyon are important physiographic features. Not so geographically. The word factor is selected to denote elements that act on men widely and cogently. The study leads to a contrast of Latin America, generally poorly developed, tropic plateaus, dry, poor in easily worked lumber, rich in precious metals that are easy to find—and English America, well advanced in production, industry and culture, and consisting mainly of a well-watered region, forested and supplied with abundant iron and coal.

Isaiah Bowman.

The Regional Geography of Long Island.

The physiography and geographic position of Long Island have been dominating influences in the distribution and activities of the people. The human responses are of particular interest in that the effect of insularity is still clearly visible, though the island was settled early in colonial times and is today partly occupied by the largest urban center in America. The history of Long Island as shaped by geographic influences; the forest types of Long Island showing the influence of soil and water supply; the development of the summer business; the growth of Brooklyn and Long Island City; communications, etc.

R. M. Brown.

The Change of Response Due to a Changing Market.

The growth of cities and towns is dependent on the market, but acts within the limits of its physiographic advantage. The discussion was focused on the conditions in Sutton and Worcester, both in Massachusetts. These towns were founded under the same stress for meadow land; Sutton has not changed. Worcester has put her fields to another use. This change in the latter town was the result of a situation which allowed her to reach the markets of the world. In any city and in most manufacturing establishments, a changing market must always be faced. A further illustration is taken from the history of New Bedford, Mass. Once a flourishing whaling port, its market for oil was removed in the fifties by the competition arising from the petroleum wells of Pennsylvania. The population began to decrease. The whaling industry rapidly declined. The slight beginnings of cotton manufacturing had been promising, the people of the city faced the newer conditions and the city in a few years changed completely its mercantile character.

F. B. Taylor.

The Michigan and Erie Canal, an Indispensable Link in the Most Important Canal in the United States.

After stating briefly the oppressive economic effects of the "long haul" by rail upon the twelve North Central States (population more than 26,000,000), with reference to seaboard and foreign trade in bulky freights, the relief to be obtained by transportation in large canal barges and barge fleets on deep canals was briefly set forth. The fact was pointed out that within the borders of the United States there are only two possible routes for trunk line, deep waterways from Chicago to the sea: (1) southward to the Gulf of Mexico by way of the drainage canals and the Illinois and Mississippi Rivers, and (2) eastward to the Atlantic through the Great Lakes, the Erie Canal and the Hudson River. The Gulf route is 1,600 miles long; the Great Lakes route via Straits of Mackinac is 1,400 miles. By the building of the proposed Michigan and Erie Canal from Toledo through Fort Wayne to Chicago, the length of the latter route will be reduced to 1,000 miles, which is the same as the distance from Chicago to New York by rail.

J. B. Woodworth (Introduced by W. M. Davis).

An outline of the Physiography of the Highlands of South Brazil.

The southern highlands of Brazil comprise three well defined geological terranes, each with a characteristic relief, and to a large extent differentiated by soil, climate, and peculiarities of the human occupation. The coastal belt, including the Sierra do Mar region, is one of crystalline schists and igneous associates, the geographical character of which was described. Westward of the once largely planated surface of this belt, a levelled and slightly dissected zone of paleozoic sediments, including a westward dipping cuesta of Devonian sandstones, occurs, forming the so-called "campos" of South Brazil. Westward of this region is a dissected cuesta of basaltic flows. The paleozoic tract is the seat of agriculture and the site of growing colonies of immigrants. The trappean (Triassic) area is difficult of access, with lingering remnants of hostile aborigines in possession of portions of the district whose topography is unfavorable to civilization. The character of the drainage, vegetation, and the existing economic conditions of the region were briefly stated.

F. P. Gulliver.

Hydraulic Grading, Commerce and Population of Seattle, Washington.

The phenomenal commercial development of Seattle, the great deepwater port of the Northwest, has caused a most stupendous cutting down of hills and filling up of flats, costing many millions of dollars.

Eugene Van Cleef (Introduced by W. S. Tower).

Climatic Influences in the Economic Development of Australia.

A discussion of the main features of the Australian climates and their intimate relation to the economic development of the country. A series of charts and diagrams were presented to show the distribution of rainfall, flora, fauna, and population. The effect of variability of rainfall on the prosperity of the country was discussed, with the idea of indicating the extent to which Australia is controlled by climate alone.

R. M. Harper.

A Natural Prairie on Long Island.

In the western third of Long Island there is an area of about fifty square miles of dry land which was originally treeless. This prairie is mentioned in a few historical and descriptive works, and a few botanists know it as a good collecting ground, but its existence has been almost entirely overlooked by modern geographers. About one-fifth of the area still retains its natural vegetation, and the fact that the plants are nearly all native species, confirms the historical evidence that such places at least have never been deforested or cultivated.

The generally level surface of the prairie is interrupted by a number of broad, shallow valleys, most of which are dry. The soil is about a foot of loam and tough sod, underlain by coarse sand and gravel of unknown depth. The herbaceous vegetation covers the ground pretty closely, and is fairly rich in species. A few trees and shrubs are scattered over the eastern portion.

The cause of the treelessnees of this isolated eastern prairie is as much of an unsolved problem as is that of the better known western prairies. Some of the western theories will fit the Long Island conditions, and some will not.

The preservation of so much dry land in a state of nature in a county which has three hundred inhabitants to the square mile, seems to be due to several causes, some of which are obscure. But the growth of New York City is bound to obliterate this prairie before long, and no time should be lost in studying it in all its aspects.

R. M. Brown.

Maximum, Minimum and Average Hydrographs of the Mississippi River.

This paper presented charts containing the absolute maximum, absolute minimum and average hydrographs, covering a period varying from twenty to thirty years, of the Mississippi River at Hannibal, Mo., the Missouri at Hermann, Mo., the Mississippi at St. Louis showing the deviation from the composite, the Ohio at Cairo, and finally the Mississippi at Memphis. A brief discussion of the salient points shown on these charts was undertaken.

A. L. Rotch.

The Use of Pilot Balloons to Determine Atmospheric Currents.

Angular measurements of free balloons may serve to ascertain the direction and velocity of the air currents at different heights. This has been done in Europe, for several years, but in America only at

Blue Hill Observatory since the summer of 1909. Rubber balloons about 80 centimeters in diameter, filled with hydrogen, which expand as they rise, are observed with theodolites at the ends of a base 1,234 meters long. From the azimuth and altitude at successive minutes, the trajectory of the balloon may be calculated, or, knowing the velocity of ascent, the horizontal velocity and direction at any height can be determined from observations at one station.

On October 8, 1909, a balloon was followed for one hour and ten minutes, during which time it rose to 18,300 meters, the greatest height at which atmospheric currents are known to have been observed in America, and 3,000 meters above the highest clouds that have been measured at Blue Hill. On the previous day, under similar weather conditions, nearly the same trajectory was followed by a balloon, the drift at the highest levels in both cases being but little faster than near the ground and from the east-northeast, an unusual direction and a small velocity for the upper currents in this latitude.

R. De C. Ward.

A Model of the Temperatures of Boston.

Mark Jefferson.

Temperature Representation.

The temperature scheme still current in elementary schools, making countries hot, cold or temperate, is too crude and inaccurate for modern use. On the other hand, the progress of the temperature in a number of lands is so complex that it can only be clearly comprehended with the help of a number of curves of average, typical and actual conditions. Schools and the general public can not and will not go so far, but they are ready for more information than is at present offered them. The complexity referred to usually has under it some governing character that can be approximately expressed in simple terms. The proposition here is to classify months as hot, mild or cold, by their average temperature, well agreed on division points being 50° and 60°F. We should then say Boston had two hot months and six cold, Calcutta ten hot months, San Francisco all months mild, and Buenos Ayres four hot months and the rest mild.

F. E. Matthes.

Scientific Topography.

L. A. Bauer.

Magnetic Explorations, Carnegie Institution of Washington, 1909.

During 1909, special expeditions were organized and satisfactorily concluded, one embracing a trip through China and terminating in India, another in southern Asiatic Russia, two in Africa, one in Canada to James Bay, and one each in Central and South America.

Furthermore, a special vessel has been constructed for a magnetic survey of the oceans, called the "Carnegie," which entered on her first cruise August 21, 1909. The speaker accompanied her from St-John's, Newfoundland, to Falmouth, England, and gave a general account of the trip and of the practical results obtained.

D. C. Bower.

The Magnetic Expedition Through China.—Abstracted by L. A. Bauer.

R. A. Daly.

Relative Erosive Efficiency of Ice Caps and Valley Glaciers.

A large ice cap and a typical valley glacier of equal thickness, must normally have very different powers of erosion. The ice cap, bearing its own snow-field, flows outward on all, or nearly all, radii. Owing to topographic conditions, the valley glacier, is the product of strong concentration of flow for the ice draining its snow-field. Therefore, the velocity of a valley-glacier is often many times greater than that of the radially outflowing ice-cap which exists under similar climatic conditions. Bottom erosion is, accordingly, much faster under the local sheet than under the ice cap. This principle is used to explain the great contrast of interior British Columbia (ice capped during the Pleistocene) and the neighboring zones of locally glaciated mountains, with respect to degree of glacial excavation. Incidentally, it will be noted that abrasion or rock-grinding is the dominant factor in this erosion.

R. S. Tarr and Lawrence Martin.

Geographical Aspects of Alaskan Glaciation.—Read by Title.

Geographical aspects of Alaskan glaciers and glaciation were presented, including their functions as barriers to trails and railways, controls of plant and animal life, highways to prospectors and to mountain climbers, scenic features, now to be seen from boats, trains and automobiles, sources of ice supply for refrigerators, concentrators of placer gold, obstacles to coal and copper mining and transportation and in making or destroying town sites, and modifying stream, lake and fiord highways.

A. P. Brigham.

An attempt at a General Classification of Geography.

A. H. Brooks.

A New Relief Map of Alaska.—Read by P. S. Smith.

D. W. Johnson.

The Hanging Valleys of the Yosemite.

The tributaries to the Merced River in the Yosemite Valley appear to have been graded with reference to a main stream which was from

2,000 to 2,500 feet higher than the present Merced. The extensive over-deepening of the Merced River, indicated by the hanging valleys, may have been due in part to acceleration of the river consequent upon uplift of the Sierra block; but comparison with other tributary valleys in the region, a consideration of the process of valley widening in jointed rocks, and the general form of the Yosemite Valley, support the theory that the over-deepening was largely produced by glacial erosion. The peculiar notch often found in the lip of a hanging valley at one side of the present course of the stream, and generally interpreted as a gorge abandoned by the stream which cut it, demands a different explanation in different cases; some are stream cut, while others are due to weathering along joints and have never been occupied by streams. The existence of both types is compatible with extensive glacial erosion of the main valley.

F. P. Gulliver.

Shore Line Notes—Southern California.

1. Elevated former shore lines: Santa Monica; San Pedro; San Clemente; San Juan; La Jolla. The extension of these shore lines on the Santa Monica Mountains and in the region of Los Angeles.
2. Santa Catalina depression.
3. San Diego Bay and Coronado Bay-bar.
4, Blocked valleys near Oceanside and Del Mar.
5. Santa Barbara region.
6. Mature shore line of the present cycle.

The relation of these shore line features and their occupation by man was discussed.

S. W. Cushing (Introduced by W. M. Davis).

The Coastal Plain of Maine.

E. W. Shaw.

The High Terraces of Western Pennsylvania.

R. H. Whitbeck.

The Present Trend of Secondary School Geography.—Read by Title.

F. Carney.

Religion as a Factor in the Development of America.

The association is quite obvious in the colonial stage of our history; since then it has been less direct but no less effective. Organizations that encourage habits of industry and saving, that foster culture, that maintain the stability of the family and promote morality, are factors in material progress.

O. L. Fassig.

The Mean Monthly and Annual Rainfall of Porto Rico.—Abstracted by W. M. Davis.

A. P. Brigham.

The Organic Side of Geography, Its Nature and Limits.—Round Table Conference.

Pittsburg, 1910

Presidential Address, Henry C. Cowles—The Causes of Vegetational Cycles.

Round Table Conference: The Purposes of Geographic Instruction and the phases of the subject best adapted to these purposes; Rollin D. Salisbury.

Walter S. Tower.

The Problem of a Classification for Ontography.—Read by Title.

To develop a systematic arrangement for the items of ontography is the chief problem in geography. A logical system would be of value: (1) to geography as a science; (2) in the development of ontography; and (3) in the comparative study of the subject.

Any comprehensive grouping must be based on the important factors to which responses are made, as: climate, land forms, and soil. The breadth of application of these different factors should determine the grouping. A system of classification based on these principles illustrates the problem.

N. M. Fenneman.

The State Geological Survey Educational Bulletin.

The Purposes of Geological Surveys.—The avowed purposes of state geological surveys are generally industrial. Probably no state legislature exists which would vote the necessary money with this motive omitted, and many of them would entertain no other. In accordance with the purposes explained in the laws which authorize them, state survey reports are usually addressed to men interested in lines of business based on the facts discussed, either the direct participants in such enterprises, or legislators who must regulate them, or that part of the public which in some way is financially interested.

It happens occasionally that in establishing a survey, "science" is mentioned specifically, usually in some such language as is used in the law of West Virginia, evidently copied by Illinois. This calls for the consideration of "such other scientific and economic questions which shall be deemed of value to the people of the State." The law of Ohio makes specific mention of the collecting and describing of fossils. This is among the privileges *permitted* to the state geologist. The next clause says, however, that "no expenditure shall be incurred under this head that is not expressly ordered and provided for by the general assembly." People outside of Ohio may choose to see in this provision an indication of indifference to pure science. On the other hand, Ohioans may find cause for pride in a legislature which dreamed of such a possibility and actually contemplated without dismay that a state might appropriate money for the express purpose of collecting and describing fossils.

Without specific instructions and doubtless often without conscious purpose, the writers of some state reports have, as if by instinct, suited their style and to some extent their content to that larger constituency which has neither education in geology nor interest in the industries based on it. In 1876 a law of Wisconsin pertaining to the final report of the state geologist, provided for one volume suited to "the needs of the schools of the State and the masses of intelligent people who are not familiar with the principles of geology; said volume to be written in clear, plain language with explanations of technical terms, to be properly illustrated with maps and diagrams and to be so arranged as to constitute a key to the more perfect understanding of the whole report." It is difficult not to suspect in these instructions the hand of the master geologist himself to whom they were supposedly addressed, and who soon after gave to the State and the English speaking world that wonderful text-book known as Geology of Wisconsin, Vol. I (Survey of 1873-79).

A later survey in Wisconsin has as a part of its work the preparation of a series of distinctly educational bulletins. This plan is also followed by the present Illinois Survey. It is this type of bulletin, its functions, method and content, with which the discussion is now concerned.

The Purposes of Survey Bulletins.—The purpose of such a publication is avowedly to bridge a gap between the professional paper and the public intelligence; to be a kind of inclined plane leading up to the technical and industrial reports. The Survey wants a larger constituency and usually larger appropriations. It may enter the field of education, not so much because education needs help as because *it* needs help, but the immediate direction of the work soon gets into the hands of university professors and thenceforth it becomes an adjunct of the school quite as much as of the Survey.

The choice of audience to whom the bulletins are addressed has, however, resulted in restricting such efforts almost wholly to the geologic phases of the science. It is likewise true that most of the distinctly physiographic reports, up to the present time, have been written with the thought of their possible educational use, so that in present practice the terms educational bulletin and physiographic bulletin are not far from synonymous.

Following lines of least resistance, there is a very natural tendency towards the forms and methods and even the content of the older official reports which had a different purpose. It is highly desirable that the writers of educational bulletins should be freed from this influence and should develop a mode of treatment specifically adapted to their own purposes.

The Treatment of Surface Features.—No better method has yet been found of treating surface features than the successive consideration of three elements,—structure, process and stage, the existing topography being regarded as the resultant of these. The author of this simple formula has, for the sake of emphasis, abbreviated the names of these elements until they are only in part descriptive, but their usefulness as mnemonics is thus increased.

Whatever the word "structure" may connote to a geologist, the physiographer must omit from consideration all structural features which have no effect on the surface, either in the style of its relief, its drainage pattern or on the character of its soil. Physiography must consider all structural facts affecting these elements and, narrowly speaking, no other. Only by way of illustration and not enumeration, may be named the division of rocks into strata, the thicknesses of these and their differences in porosity, etc., also the manner in which they have been cracked and deformed. This often involves a considerable study of the physical character of the rocks concerned, but in this portion of his field the physiographer must often be content to use the result of other men's labors.

The proper treatment of this phase of a physiographic subject may differ little from that contained in a general geologic report. Naturally it will be briefer, but the essential distinction lies not in its brevity but in its selection and presentation of facts which have a bearing on surface features. This does not give to physiography the undignified character of a superficial treatment or smattering. It has dignity so long as it is concentrated toward a *purpose* and loses it whenever it drags in irrelevant material "for the sake of completeness." The real purpose of physiographic discussion is to describe and explain the *surface*.

Under "process" should be discussed all the work of atmosphere, water and ice so far as it is concerned in making the topography of the area treated. The brief mention of co-ordinate processes by the same agents but not illustrated in the area may serve *to give a setting* to the points discussed.

This discussion of processes lies at the very center of the author's purpose. It probably interests the largest number of people. It is interesting on its own account and standing alone, but without it the other chapters have no significance. Some of the processes are often omitted from physiographic treatises and left to other phases of geology; for example, some of the modes of weathering. In this case the constitution of physiography should be interpreted broadly. No phase of earth study is so well fitted as these surface processes to arouse the interest and stimulate the observation of the average person, young or old. The writer of an educational bulletin may well afford, therefore, to give much space to discussion and to abundant illustration of all processes concerned in the alteration of the surface which he treats. There is small chance that in so doing he will bring in irrelevant material or crowd out something more important.

Any adequate discussion of the processes which affect topography must take account of the resulting forms, a matter which most people find absolutely uninteresting except when interpreted in terms of process. This involves a treatment of one or more kinds of cycles, according to the nature of the area.

Before the completion of the general discussion here demanded, most of the topographic features of the area will have been mentioned by way of illustration, some of them perhaps many times, but it may still be necessary to give a systematic classification of the various topographies in the area, elucidating each as the result of certain processes working on certain structures, until the evolution of topography has reached a certain stage.

The suggestions here made are meant to embody *principles* rather than *rules*. However, should they be followed as rules, the resulting treatment would embrace first, a chapter which might be called geological, treating of the underlying rocks and their structure as here defined; second, one or more chapters dealing with processes now at work, making, unmaking and remaking the earth's surface; third, an areal description in terms of the elements discussed in the previous chapters.

If physiography began and ended with that which concerns topography and soil, the treatise might end here. It would thus have more unity of theme and treatment than it could possibly have with any further expansion. Up to a very recent time it was the only phase of geography participating in higher education in America. It is now practically the only phase which can draw on public money for the study of limited areas, and those who expend such moneys are generally quite as sympathetic with other phases of geography. As a practical matter, therefore, the educational bulletin may as well be broadly geographic as narrowly physiographic, though in all such bulletins thus far produced, the latter phase has been predominant.

THE SCOPE OF A GEOGRAPHICAL BULLETIN.—If the educational bulletin is to enter the larger field of *geography* it must treat, in addition to the things above named: (1) Climate; (2) Animal and Vegetable

Life; and (3) Habitation; the last named involving industries and thus demanding a somewhat fuller treatment of mineral and other natural resources than that suggested above as appropriate to the geologic chapter.

Given topography, soil and climate, the native flora, and the fauna, are always in greater or less degree the natural effect. These, like the climate, are determined partly by the mere accident of location within a vast zone; but the influence of local conditions will generally not be far to seek. The elucidation of these is highly appropriate to an educational bulletin. Almost the same may be said of crops.

Human habitation and mode of life take their place in the same category. So far as the conditions are common to a larger area, the local bulletin is not responsible for their treatment, but almost all localities which are likely to be made the subject of such studies will show interesting elements of human response, involving comparisons and contrasts between nearby localities.

Oliver L. Fassig.

The Climate of Porto Rico—Presented in Abstract.

General Characteristics.—The most characteristic feature of Tropical climates is the regular recurrence of similar phenomena from day to day throughout the year. The strong contrasts in temperature, which mark the seasons of the north, with the accompanying variations in the abundance and character of plant life, are conspicuous by their absence in the Tropics. The periodic recurrences in plant and animal life are determined more by rain or the absence of rain than by marked changes in temperature. The contrast between day and night conditions are more marked than the seasonal contrasts. The irregular changes in the weather, such as storms, cold waves, hot waves, etc., which largely control weather conditions in the United States, are so infrequent in the lower latitudes as to cut but a small figure in making up the average of weather conditions. Next to uniformity in the Tropics we have the factor of abundance; abundant heat, rather than excessive heat; abundant moisture, both in the form of a high humidity and of rainfall; and abundant and perennial plant and animal life.

The island of Porto Rico is primarily an agricultural country. Each succeeding year witnesses an increasing acreage in sugar, tobacco, coffee, citrous fruits and pineapples. The geographical position of the island within the trade wind belt, combined with its high elevation above the sea level, mark it as one of the most favored regions within the Tropics.

While the physical features of the island seem never to have been accurately charted, the more conspicuous outlines of topography and hydrography are fairly well known. Seen from a distance, the island gives the impression of a confused mass of short mountain ranges, having in the main an east-west trend. Closer examination reveals a well-defined ridge, the Cordilleras, extending across the full length of the island, parallel to, and from ten to twelve miles from, the south coast, its eastern end following for a short distance the northeast trend of the coast line. In the northeast portion of the island there is a smaller group of mountains, the Luquillo Range, also with an east-west trend, and with peaks slightly higher than those of the main range. These two mountain ranges form the principal watershed which separates the series of short streams, which flow southward into the Caribbean Sea, from the series of comparatively longer and more numerous streams flowing in a general direction northward into the Atlantic Ocean. The longest of the streams, Rio de la Plata, does not exceed forty-five miles. Numerous spurs diverge from the main ranges, mostly from the north side, forming a complex system of narrow ridges, and of deep valleys, through which hundreds of small streams carry the waters of an abundant rainfall rapidly to the sea. The south slope of the main divide is decidedly more precipitous than the north side. From Guayama Pass southward to the coastal plain the descent is about one hundred feet per kilometer; northward the rate is about fifty feet per kilometer. The main divide has an average elevation of about 2,500 feet, with peaks rising to a maximum, in the Luquillo Range, of about 3,500 feet, while the elevations of the main spurs will vary from 1,500 feet to 2,000 feet. The lowlands are found only in a narrow belt bordering the coast, the broadest stretches not exceeding four or five miles in width.

TEMPERATURE.—Porto Rico, in common with all islands within the areas swept by the northeast and southeast trade winds, has a warm, but equable and comfortable climate. The small extent of the island, with its moderate elevations above sea level, insures a uniformity of temperature characteristic of marine climates in all latitudes. The series of carefully made daily observations of the United States Weather Bureau in fifty selected localities upon the island cover a period of more than ten years, a period sufficiently long, in the Tropics, to include all the variations in temperature likely to be experienced in any portion of the island.

A record covering a period of more than ten years at over fifty selected stations shows a mean annual temperature for the island, combining the records at all stations, of 76 degrees; during the coolest month of the winter season the average is 73 degrees, and during the warmest month of summer it is 79 degrees. The variation of the mean annual temperature has very restricted limits, having varied only about one degree above and below 76 degrees in the past ten years.

The average temperature during the month of February, which shows the greatest variation, has fluctuated only between the limits of 76 degrees and 72 degrees.

The above values represent average conditions for the island as a whole, coast stations and mountain stations combined. The figures will vary somewhat with elevation and other topographic conditions. For the towns situated upon the narrow coastal plain encircling the island the average annual temperature is 78 degrees, the average for January 75 degrees, and for August 81 degrees; at inland stations the average annual falls to a minimum of 72 degrees, with 69 degrees during January and 75 degrees during August. The lowest temperatures are naturally those experienced along and near the summit of the main divide, at elevations varying from two thousand to three thousand feet; here the mean annual temperature falls below 72 degrees. At Aibonito the mean temperature for the year is 72 degrees, with a January mean of 67 degrees and a mean for August of 76 degrees. The highest mean temperature for August in five years was 77 degrees, and the lowest January mean was 66 degrees.

AFTERNOON AND EARLY MORNING TEMPERATURES.—While the mean daily temperature does not vary greatly from month to month, the difference between the afternoon and early morning temperatures, or the daily range, as it is called, is comparatively large, larger as a rule than in more northern regions. At stations on the immediate coast, like San Juan, or on the smaller islands of Culebra and Vieques, the diurnal range is controlled by the uniform temperature conditions of the surrounding ocean, and is quite small, ten or eleven degrees. At inland stations the mean daily range varies from twenty to twenty-five degrees. At stations along or near the coast the afternoon temperature rises to an average of 84 degrees in the winter months, and to 89 degrees in the summer months, while the early morning temperatures fall to 73 degrees in the summer and to 66 degrees in the winter seasons. At stations farther inland, in the hills and mountains, the average daily maximum is about 87 degrees in the summer months and 81 degrees in the winter months, while the average daily minimum is 68 degrees in summer and 61 degrees in winter.

The highest temperatures recorded during the past ten years in Porto Rico do not differ greatly in different portions of the island. At the more elevated inland stations the range is between 90 degrees and 95 degrees, while along the coast and in the valleys they range from 95 degrees to 100 degrees. Only on three occasions in the past ten years has a temperature exceeding 100 degrees been recorded at any of the forty-odd stations on the island.

There is a greater variation in the early morning temperatures. At the stations near the coast and at most of the interior stations the lowest reported temperatures range between 50 degrees and 55 degrees; at stations on the immediate coast, which are more under the influence of the uniform ocean temperatures, the minimum rarely falls below 60 degrees; at higher stations in the mountains the minimum frequently falls to 45 degrees, and has been as low as 43 degrees at Aibonito, at an elevation of two thousand feet, and probably lower at greater elevations along the summit of the main divide.

RAINFALL.—The average annual rainfall for the entire island is 76.00 inches. This value is based upon the records for forty-four stations, covering a period of twelve years. The annual amounts vary greatly from year to year, and in geographical distribution. In 1901 the average amount for the island as a whole was 93.72 inches, and in 1907 but 64.18 inches. The variations in geographical distribution are even greater. In the Luquillo Mountains, where rainfall is heaviest, the average annual amount exceeds 135 inches, with a maximum in 1901 of 169 inches. Along portions of the south coast the average annual amount is less than 40 inches, with a minimum, at Aguirre in 1907, of 21 inches. At stations along and near the south coast the average annual rainfall is about 45 inches; along the north coast the average is about 65 inches. Along the west coast the rainfall is greater, the annual fall being 75 inches, while along the east coast and at inland stations the average increases to 85 inches. These variations in the annual rainfall are due to differences of elevation and to the trend of the mountain ranges with reference to the prevailing winds.

The most striking feature of the rainfall distribution is the contrast between the heavy and perennial rains north of the main divide and the light and irregular rains of the south side coastal plain. Over the north side, comprising over two-thirds of the entire island, an abundant rainfall may be counted upon in all seasons of the year, and protracted droughts are of rare occurrence; along the south coast the rainfall is not only comparatively light, but unevenly distributed throughout the year, and periods of several months with little or no rain are frequent.

There are no well-defined wet and dry seasons on the island. The winter rains are comparatively light, with a minimum in February at practically all stations. From February there is a steady increase in the average monthly amounts through May. From May to November the differences in the average monthly amounts for the entire island are small. The maximum generally falls in September along the east coast, in October along the south coast, in November along the north coast, while in the mountains of the interior the time of maximum occurs in one of the summer months or as early as May. The seasonal distribution of rainfall shows a steady increase, for the island as a whole, from 11 inches in winter to 26 inches in autumn, with 16 inches for the spring months and 23 inches for the summer months, making up the total of 77 inches, in round numbers, for the average annual rainfall of the island.

The rains of Porto Rico, while frequently very heavy, are usually of short duration. The average duration of a shower is probably not more than ten or twelve minutes, although on many occasions a series of intermittent showers will extend over a period of an hour or two. During the passage of a tropical hurricane, or when one of the more extensive North Atlantic storms passes eastward along a more southern route than usual, the period of continuous rainfall may be extended to several hours and even throughout the day, or there may be several successive days of unsettled weather with frequent showers. But such storms are of comparatively rare occurrence.

While heavy rains occur with comparative frequency, they form but a small percentage of the total number of rains during the course of the year. A tabulation of the rainfall records at forty-four stations during a period of ten years shows the following relative frequency of stated amounts:

33 per cent. of all rains measure 0.10 inch or less.
50 per cent. of all rains measure 0.20 inch or less.
75 per cent. of all rains measure 0.50 inch or less.
90 per cent. of all rains measure 1.00 inch or less.

Rain occurs over some portion of the island practically every day in the year; it is probable that the month of February is the only month of the year having occasional periods of three or four days without some rain somewhere within the island. For the island as a whole, rain occurs on the average of 169 days in every year. Along the southern coast the average annual number varies from 75 to 100; along the western and northern coast, and generally in the interior, the average number of days with rain is about 175, and along the eastern coast the number exceeds 200. On the eastern slope of the Luquillo Mountains rain occurs on an average of nearly 300 days per year.

Humidity.—The feeling of lassitude which is common to warm, moist climates is to a great extent dissipated in Porto Rico by the persistent flow of the trade winds throughout the day and night, supplemented by the daily play of the land and sea breezes. While the large amount of moisture in the atmosphere becomes oppressive during periods when the winds fail, it is extremely favorable to the growth and development of vegetation throughout the year. The high percentage of humidity also prevents the large and rapid fall of temperature during the night, so characteristic of drier climates. There are no official humidity records available for the drier inland stations of the island, but the observations at San Juan are typical for the entire coast. The variations in the average humidity from month to month are not large. The average for the entire year is 78 per cent.; during the driest month, March, it is 75 per cent., and during the most humid months, October and November, it is 81 per cent.

Sunshine and Cloudiness.—While days with rain are frequent, and the rains are frequently heavy, there is an abundance of sunshine throughout the year in all portions of the island. An inspection of the record of the comparative frequency of clear, partly cloudy, and cloudy days will show a remarkable preponderance of clear and partly cloudy days over cloudy days. The record for San Juan, where hourly observations have been carefully maintained from sunrise to sunset for five years, shows on the average 139 clear days, 158 partly cloudy days, and 68 cloudy days per year.

The Trade Winds.—The trade winds, aided by the daily recurrence along the coasts of the cool, invigorating sea breeze, constitute a beneficent provision in the Tropics for counteracting the enervating effects of a high temperature combined with a large amount of moisture in the atmosphere. This is clearly shown during the occasional periods of a few days when the trades fail and light, variable winds prevail, accompanied by sultry and oppressive weather.

The area of high pressure, while permanently located in the North Atlantic, shifts its position within limited bounds from month to month and from year to year, causing variations in the prevailing direction of the trades; at the same time there are variations in the gradient of pressure, or the difference in pressure, between the center and edges of the high area, causing variations in the velocity of the trades. In Porto Rico the variations in the direction of the wind during the course of the year are from northeast to southeast, with a decided predominance from the east-southeast. The only variation from east-southeast (regarding monthly averages only) is likely to occur in July, August and December, when the prevailing direction is more nearly east, and in October, when it is prevailingly southeast.

The average velocity is remarkably constant in Porto Rico, the average hourly velocity from month to month at San Juan not varying more than one mile from the average of 11 miles for the entire year, excepting in July, when it rises to 13 miles per hour, and in October and November, when it falls to 8 or 9 miles.

Tropical Storms.—Porto Rico is comparatively free from storms of all kinds. During the summer months a mild type of thunderstorm occurs with more or less frequency, but these storms seldom attain the intensity common to most portions of the United States during midsummer, and they attract little attention from the visitor from the north. The more destructive local storm of the type known as the tornado is almost unknown in the Tropics. In the middle latitudes, and particularly in the northern United States, cyclonic storms pass across the country from west to east in all seasons with such frequency as completely to dominate the daily weather conditions; there is a constant succession of approaching, passing and disappearing cyclones. They vary in intensity from shallow barometric depressions, which move quietly across the country producing only light winds and gentle showers, to storms of the greatest violence and of great geographical extent, at times covering more than half the area of the United States.

The Tropics are singularly free from these cyclonic disturbances during the greater portion of the year, and there is a monotonous recurrence of similar weather conditions, interrupted only by light to heavy showers of short duration, or by the occurrence of a mild type of thunderstorm, or squall. During the months of July to October, however, that portion of the trade-wind belt containing the West India Islands and the Caribbean Sea is subject to occasional visits from one of the most destructive types of cyclonic storms—the West India hurricane. These storms are similar in form and general character to the Temperate Region cyclones, but differ from them in being more restricted in area and in moving more slowly. Their general direction is from east to west, within the Tropics, being carried along with the general westward drift of the atmosphere. They recurve generally in the Gulf of Mexico, or over the Bahama Islands, and then move northward and northeastward, either across the United States, up the east coast or over the Atlantic Ocean, and can not be distinguished from the Temperate Region cyclones.

The recorded storms of this character during the past four hundred years number about four hundred and fifty, or an average of a little more than one per year. While they are liable to occur at any time from July to October, over eighty per cent. of those recorded during the past forty years have occurred in the months of August, September and October. Porto Rico has been singularly free from the severer types of these storms. Only on three occasions in forty years did the center of a hurricane pass over the island, all of these in the month of August—namely, in August of 1891, 1893 and 1899. By far the most destructive of these storms was that of August 8, 1899. The storm of September 12, 1898, passed very close to the south coast.

These storms originate, or first appear within the field of view, in the neighborhood of the Windward Islands, move in a direction between west and northwest at the rate of about ten or twelve miles per hour, and then recurve to the northward and northeastward, increasing their velocity as they get into higher latitudes. The comparatively slow movement of these storms in the Tropics is a fortunate circumstance, as it enables the official forecaster, after once locating the center and determining the direction of movement, to give ample warning of their approach in the western waters of the Caribbean Sea and in the ports of the Gulf Coast.

Robert De C. Ward.

The Economic Climatology of São Paulo Coffee District, Brazil. —Read by Title.

The results of a study made during the summer of 1910, in Brazil. The fact that Brazil produces about three-quarters of the world's coffee crop gives the São Paulo District a peculiar interest. The conditions of climate and soil are exceptionally favorable, both for the cultivation of the coffee, and for its preparation for market. This paper deals with the most important characteristics of the climate, and shows in what ways coffee production is controlled by the climate.

F. E. Matthes.

Criteria of Topographic Delineation.—Read by Title.

Could the physiographer and the topographer agree on a set of definite criteria governing the delineation of relief on maps, they might together help to advance the art of topographic mapping from its present nondescript status halfway between engineering and science, to that of graphic art of the highest value to physiography and geology.

The palaeontologist, when dealing with sculptural forms or details of surface modeling, relies extensively on pictorial representations, even though he commands an elaborate terminology. It is suggested that the physiographer do likewise and depict his physiographic species and the manner of their relations by means of judiciously prepared maps, and thus do away to a large extent with the often long and tedious introductory chapters descriptive of the feature or area studied. It is necessary, however, before he can hope to succeed in this, that the principles involved in such topographic portrayal be first formulated and agreed upon. Topographic delineation has thus far proceeded upon a more or less haphazard basis and is consequently still somewhat uncertain in its results. Most maps in use today are either inadequate for the expression of the desired features or else too ample, and consequently in either case unsatisfactory for the physiographer's purpose, to say nothing of being uneconomic to produce.

A number of criteria are therefore proposed for the selection of scale, contour interval and other topographic devices; for the consistent generalization and omission of subordinate details on successively smaller scales; for the proper use of "topographic license" so-called, and many minor matters that affect the capacity for expression and the truthfulness of topographic maps.

Lawrence Martin.

Glaciers in Prince William Sound, Alaska.[1]

[1] Published under a different title in National Geographic Magazine, Vol. XXII, 1911; pp. 537 561.

The National Geographic Society's 1910 expedition found seven glaciers advancing simultaneously in College Fiord, as well as Columbia Glacier and several others in adjacent parts of Prince William Sound. Barry Glacier has retreated nearly 3½ miles, and Surprise Glacier 1¼ miles since 1899. Tiger Glacier has melted back about seven miles since 1794, and many other glaciers have retreated variable amounts. Several earlier glacial oscillations are dated by tree growth and an attempt is made to show that one of the earlier advances may be due to avalanching during an earthquake in 1880, rather than to variations in climate.

W. M. Davis.

The Front Range of the Rocky Mountains in Colorado.—Printed in full herewith.

E. W. Hilgard (Introduced by W. M. Davis).—Presented in Abstract. The Mississippi Delta.

This paper explains the peculiar "bird-foot" extremity of the Mississippi Delta as consisting not of silt immediately deposited from the river load, but of a tough clay derived from mud lumps that rise in the river channel from a peculiar clay layer beneath.

John L. Rich (Introduced by R. S. Tarr).

Recent Stream Trenching in the Desert of Southwestern New Mexico—a result of removal of vegetation cover.

In Southwestern New Mexico, in the neighborhood of Silver City, all the stream valleys outside the more rugged mountains show recent stream trenching of the alluvial valley fillings. This trenching is universal in large and small valleys alike and is so widespread in its occurrence that for an explanation we must look to some general condition affecting the entire region. Physiographic evidence shows that the trenching is due directly to an increase in the maximum volume of water coming down the valley in times of flood; historical evidence, that it has been accomplished since the settlement of the region. An analytical study leads to the conclusion that the trenching is due to the removal of the vegetation cover by too close grazing.

Douglas Wilson Johnson.

Shoreline Changes in the Scituate-Marshfield (Mass.) Region.—Read by Title.

That portion of the Massachusetts shoreline extending from Scituate Harbor on the north to Marshfield Neck on the south, consists of drumlins in various stages of destruction by wave erosion, and narrow beaches or bars which connect the drumlin remnants and separate the ocean from areas of salt marsh. Past changes and the present form of the drumlins and beaches are briefly described; special attention is given to changes in the shoreline effected by the "Portland Storm" of 1898, and to the resulting invasion of the salt marshes by higher tides than formerly. It is shown that many features usually attributed to coastal subsidence were produced by the change in the form of the shoreline.

G. B. Roorbach (Introduced by W. M. Davis).

Some Shoreline Changes at Winthrop, Mass.

The Winthrop Region, east and north of Boston Harbor, consists of a nearly continuous chain of drumlins and connecting beaches from Deer Island to Point of Pines. The drumlins that face the ocean are being rapidly clipped by wave action and are found in all stages of destruction from those scarcely nipped at their extremities to mere heaps of boulders, the only remains above water of drumlins that have been completely truncated by the waves. A comparison of old and recent surveys shows that the shore cliffs have receded in recent years at a rate not less than nine inches per year, and it is shown that the rate was probably much more rapid in the past than now. Some of the drumlins, as Cherry Island and Nix's Mate, have had their destruction completed within historic times. An attempt is made to compute the length of time that has been required to effect the destruction of the headlands and thus to give some indication of the amount of recession of the shoreline since glacial times.

Shirley Gut, heretofore regarded as a channel kept open by tidal scour, is shown to have been gradually closing, being now no more than one-quarter the width it had in colonial days when used as a ship channel.

The evidence in regard to changes of level indicates considerable subsidence at a remote date, followed by long periods of relatively slight movement. During recent years subsidence has been renewed.

Stephen R. Capps (Introduced by W. M. Davis).

Rock Glaciers in Alaska.[2]

Rock glaciers are masses of fragmental rock which originate in glacial cirques and extend from these down the stream valleys. The flows are glacier-like in form and position, but occupy positions in which the climatic conditions no longer favor the accumulation of glacial ice. Their surface markings, and the conditions at their front edges, give strong evidence of slow and long continued movement. They differ in appearance from true glaciers in the absence of perennial snow fields at their heads, in the lack of crevasses, and in their failure to show anywhere massive glacial ice. The movement is believed to be due to interstitial ice formed by the penetration and freezing of water from the surface, the contained ice imparting to the whole mass a sort of glacial movement.

[2] Published in the Jour. Geol., Vol. XVIII; pp. 359-375.

Robert De C. Ward.

A Visit to the Coffee Plantations of Brazil.—Read by Title.

A description of the São Paulo coffee district by the writer in the summer of 1910.

E. W. Shaw (Introduced by Charles C. Adams).

The Infertility of Southern Illinois.

Though the southern and northern halves of Illinois are very similar, both being flat and both having been glaciated, the southern half is relatively unproductive. A belt of hills, in part unglaciated, lies along the Mississippi and Ohio and, though it is subjected to severe erosion, it yields as heavy crops as the interior lowland. While the warm discussion concerning the relative importance of the organic and inorganic contents of the soil is in progress, the following may serve as an additional working hypothesis. The hilly counties bordering the Mississippi and Ohio bear thick accumulations of marly loess. The territory lying back from the rivers is covered with a mantle of glacial till overlain by a sheet of fine material 10-20 feet thick, which seems to be an inland phase of the loess though differing from it in being more plastic, less calcareous, and non-fossiliferous. The resulting soil may properly be spoken of as "sour" or acid. Such soils seem to remain in a very finely divided state, whereas calcareous soils seem to be more granular. Perhaps then the ultimate reason for the infertility of most of Southern Illinois has been the sorting of the loess material by the wind (supposing the loess to have been derived from the flood-plain), and the carrying of the finer, less calcareous particles inland where they now yield a white, impervious, acid soil. Another view is that the soil is poor because of the advanced age and leached condition of the underlying Illinois glacial till. This gives us nothing to look forward to but a similar barrenness for the northern half of the State when the Wisconsin glacial till shall have reached old age. However, if the loess is accountable for the infertility, we may expect to see the sowing of ground limestone prove a sovereign remedy and the northern half of the State to retain its fame as a corn belt.

Otto E. Jennings (Introduced by H. C. Cowles).

The Plant Geography of the South Shore of Lake Erie.

The writer, during the last ten or eleven years, has had the opportunity of devoting considerable time to field work in botany along the southern shore of Lake Erie, particularly in the vicinity of Erie, Pa., and Sandusky, O., and much has been accomplished towards an ecological classification and correlation of the vegetation of the two regions.

The Origin of the Surface Features.—With the subsidence of old glacial Lake Warren to the present Lake Erie it is likely that up to within a comparatively few centuries there was nothing like Presque Isle in existence in the Erie, Pa., region and also that the present mainland around Sandusky, O., extended continuously for a considerable distance to the northeast and east and included the present islands of Kelley and Put-in-Bay. With the differential tilting of the basin of Lake Erie, the land in the Sandusky region has been rather rapidly receding, and marked changes in the vegetation, the successive ecological formations keeping pace with the physiographic changes. In the Erie region proximity to the outlet of the lake has prevented any marked changes in the height of the water relative to the land, such as characterize the Sandusky region, but much beach débris in the form of sand and gravel has been shifted to the eastward along the south shore of the lake and from some cause has been built up into a peninsula about seven miles long and known as Presque Isle. In the Sandusky region the peninsula of Cedar Point has been built partially across the mouth of Sandusky Bay by a secondary swing of the main west-east current and in both Cedar Point and Presque Isle there has been a regular series of physiographic changes as new land has been formed on one side of the peninsulas, while the oldest land has been again washed away or submerged.

The Vegetation Formations.—In the formation and retention of new land on the peninsulas studied, vegetation has had an important part, and with new land established, vegetation soon reacts upon the habitat in such a way that there a uniform series of vegetational formations can be seen as one passes from the younger to the older land-areas. This succession of vegetation has been worked out for Cedar Point by Professor Moseley, while more recently the author has done the same for Presque Isle. The building up of a bar off-shore by a severe storm, especially during a period of high water in the lake, is often followed by a further segregation of the water behind the bar into a lagoon. Into such a lagoon cottonwood and willow seeds are soon blown and, accumulating around the banks of the lagoon, are soon buried by shifting sand where they sprout and eventually form a hedge more or less completely surrounding the lagoon. As this hedge grows, sand is accumulated, and finally the cottonwoods may be found holding in place a ridge of considerable height. However, if new land is formed lakeward at a comparatively rapid rate, as towards the eastern end of Presque Isle, the lagoon will soon be left so far inland that indrifting sand will not be sufficient to fill the basin of the lagoon and to form a ridge around the bank in the cottonwood hedge, and the lagoon will, with advancing age, show a very interesting series of vegetational formations, as the reaction of the plants upon the habitat becomes more and more effective. In old lagoons, as around the Chimney Ponds on Presque Isle, probably not far from six hundred years old, the concentric belts of vegetation are usually as follows, counting from the deeper part of the basin towards the banks: (1) Chara Association; (2) Pondweed Association; (3) Waterlily-Spatterdock Association (*Decodon-Persicaria*); (5) Buttonbush-Cornel Association (Thicket on wet bank); (6) Sumach-Alder Association (Thicket on moderately moist bank); and (7) around the basin a White Elm-Red Maple Association (Forest on moderately moist soil). Before such a vegetational structure as this is reached there are often developed more or less extended areas of marsh and wet meadow in front of the advancing thicket and forest formations.

On the sand-plain the vegetation may pass through the following series of associations: (1) *Artemesia-Panicum* Association (Sage-Bunch Grass); (2) *Arctostaphylos-Juniperus* Association (Bearberry-Red Cedar Heath); (3) *Pinus* Association (White Pine Forest); (4) *Quercus* Association (Black Oak Forest); and perhaps eventually either a Hemlock or a White Elm-Red Maple Forest.. This succession, however, is confined to the more northern portion of Presque Isle, while the southern portion, with finer-grained sand and less exposure to north and west winds is characterized by a succession in which the Heath and Pine stages are represented by the *Myrica* Association (Waxberry Thicket) and the *Prunus serotina* Association (Black Cherry Forest). For an extended and detailed account of the vegetational associations and successions and their relation to the physiographic conditions of Presque Isle and Cedar Point, reference should be made to the author's papers in the *Carnegie Museum Annals* and in the *Ohio Naturalist.*

Charles A. Davis (Introduced by H. C. Cowles).

Salt Marshes, A Study in Correlation.—By permission of the Director of the Bureau of Mines.

Description of Salt Marshes.—Salt marshes have long been regarded as solved problems by geologists, physiographers and biologists, and the classic writings of Shaler on the subject of their formation have apparently so impressed themselves on the interested public that no consideration has been devoted to the problems which they present in the quarter of a century since his papers appeared.

In the following discussion, attention will be given only to the salt marshes of New England, and salt marshes are here understood to include those flat, poorly drained parts of the coastal region which are overflowed at such frequent intervals by saline tidal waters that their vegetation is affected by the salt content of the water. Those whose surfaces are so near the level of the mean high tide that they are covered by the majority of high tides, are considered typical salt marshes, and are of most frequent occurrence, although every gradation from fresh water swamps and marshes, through brackish types, can be found.

The typical salt marsh of New England is a very flat, poorly drained plain, the surface of which is covered by a very characteristic vegetation of a few species of salt-tolerant, or salt-requiring plants, the most abundant of which are grasses. Sometimes the monotony of the surface is broken by slight elevations forming "islands," which may be covered by trees and shrubs. The tidal waters penetrate the marshes and run away from them through tortuously meandering channels, locally termed "creeks," which frequently are continuations of streams rising in the uplands, but which receive many tributaries having their origin in the marsh itself and are cut by the action of the tide, apparently chiefly in its outward rush.

The Formation of Salt Marsh Peat.—Sometimes, extensive areas of salt marsh in New England are separated from the sea by narrow sand or shingle beaches of the barrier type, but there are also very many instances where no such barriers exist. The barrier beach, however, is sufficiently common between marshes and sea and the relationship between beach and marsh apparently so obviously genetic, that the two features have become intimately associated with each other in the minds of most physiographers who have given the matter any thought, and the hypothesis of Shaler seems never to have been questioned. Briefly stated, this hypothesis assumes that salt marshes have been built up by sedimentation in the shallow basins or lagoons formed by barrier beaches cutting off portions of the sea, assisted and attended by the growth of certain seed-plants, beginning with those growing in water and ending with the types growing at the present surface of the marshes.

If this hypothesis explains the facts, a section of a salt marsh in Eastern New England should be as follows, taking, for convenience, the strata in the order of their assumed deposition:

(1) At the bottom marine sands, silts and muds, containing marine fossils, extending to within twenty to thirty feet of the surface.

(2) Marine silts and muds, rich in the remains of shallow water mollusks and of eelgrass (*Zostera marina* L.), up to nine to twelve feet.

(3) Above this a silt stratum four to six feet thick, containing few plant remains and locally large numbers of shells of mollusks now living between tide marks on the flats.

(4) A stratum of wet, blackened mud, three to five feet thick, filled with roots and the large underground stems of a coarse salt marsh grass, known locally in New England as "salt thatch" (*Spartina glabra* Muhl., var. *alterniflora*—Loisel—Merr.).

(5) Superposed on this and capping the section, a thin layer, rarely as much as a foot thick, of salt marsh turf, would be found.

In making sections in many typical salt marshes, from the top to the underlying till, or other bottom material, over a wide range of coast line, and examining with care many samples from them, no deposit has yet been found which presents such a sequence of strata as that outlined, nor have any of the features which must be considered typical, in the hypothetical section, been found in any real one. Eelgrass remains, except for the rare occurrence of fragments of leaves, clearly drift material, are entirely wanting in every specimen examined, and marine shells are also rare.

Character of Sections to be Seen in Salt Marsh Peat.—In place of this kind of section, fresh water marsh or forest beds are often found on sand or modified till and these are overlain by a greater or less thickness of the peculiar and easily recognized turf, which is formed only at the surface of the typical salt marshes. In some cases, the salt marsh turf is found to make up the entire thickness of the deposit, down to the silty or muddy bottom, and this is true for depths which extend to ten, twelve or even to eighteen feet or more from the surface. In more than one instance this kind of deposit has been found on the seaward side of the present ocean beach, extending to below the low tide level. It is evident, therefore, that some other hypothesis than Shaler's must be used to explain the facts such as these, or more facts must be collected, and the whole so correlated that they can be brought into harmony with the theories developed to explain them.

In the course of the work on which this paper is based, the attention of the writer was early attracted to the vertical distribution of the plants making up the flora of salt marshes, and it soon became evident that this was significant, and conformed to laws well known to students of plant distribution. It is easy to demonstrate that the surface of a salt marsh is a very unfavorable habitat for seed plants, for it is wet and practically undrained, water covers it for a longer or shorter time at frequent and regular intervals, and this water contains a considerable amount of salts in solution, some of which, notably sodium chloride, are strongly toxic to most seed plants when present in excess of a low limit of tolerance.

A single unfavorable factor of growth excludes from a given habitat most species of the seed plants of a given region, and two such factors still farther limit the number of species, while three may reduce the habitat to a desert. It is apparent, on consideration,, that such a process of exclusion must be operative on the salt marshes within the zone covered by the tides, from low to high water marks. It is impossible to enter into details here, but the facts of plant distribution in the marshes are substantially as follows: A single seed plant, the eelgrass, *Zostera marina* L., grows commonly in the salt water, entirely submerged, and may rarely reach a level a few inches above mean low water. The other species growing submerged in salt water are of too infrequent occurrence to be mentioned here. From low water to about mean sea level, no seed plants grow, and from the half tide level, to nearly mean high tide, only a single species occurs, the salt thatch mentioned above. This species grows down to the edges of the bare "flats" and apparently rarely endures submergence for fully half the time, that is, grows down below mean tide level, and then only under unusual soil conditions. It also grows in stunted forms, on the parts of the surfaces of marshes where water stands most of the time, because of slight depressions, or very poor drainage.

The prevailing plants that cover the surfaces of most New England salt marshes are two small grasses, called commonly salt marsh grass, without distinction (scientifically, *Spartina patens*—Ait.—Muhl., and *Distichlis spicata*—L.—Beauv.). Of these, *Spartina patens* is probably more common than its associate, but the essential thing to be noted regarding the association is that it is found only on those parts of the marshes just reached, or slightly overflowed by the average high tides, and which are not exposed to flooding by sea water for more than about an hour by each tidal wave, or for about two hours in the day. The areas not reached by the average high tides are generally occupied by other plants in associations that become more complicated, as the salt water decreases, to the exclusion of the *Spartina patens* association. Those flooded for a longer time than that mentioned, are covered by the salt thatch. The turf formed by the *Spartina patens* is entirely distinct from that developed by any other plant or group of plants known to the writer, and in no way resembles that formed by either fresh or brackish water plants or by the salt thatch. The vertical range of the *Spartina patens* association is estimated at approximately two feet, or somewhat less; it grows only at the high tide level and best at the level of the mean high tide. Above this plane its place is taken often by the so-called "black grass," *Juncus Gerardi,* Lois, and below by salt thatch. The associations therefore may be more definitely located as a horizon, with respect to the mean high water level of a given portion of the sea, than any other which has yet been found. It is much more definite than any association of fresh water plants, because although these can not grow within reach of the tides and below their level, they may grow at any distance above it, and aquatic types of fresh water vegetation, in certain cases, may grow below sea level, if protected from the inflow of salt water. It is scarcely necessary here to point out the fact that basins extending below the mean sea level in the coastal region of New England would be filled with water, hence would support only aquatic plant associations.

In view of the facts that *Spartina patens* has such a definite and limited range, and forms such characteristic and unmistakable turf, the presence of this turf, in place, must be accepted as evidence that at the time of its formation, the tides did not rise above its surface for a longer time than two hours in the day, if there is any foundation for the assumption that identical species have always grown under the same conditions, as those at present necessary for their existence.

Correlating these facts, and the last assumption with the general occurrence of perfectly homogeneous beds of *Spartina patens* peat in the salt marshes of New England, ranging from two to twelve, fourteen and even to more than eighteen feet in thickness, in which carefully made sections from top to bottom show absolutely no variation in the structure and in the character of the plant remains, and if one has any background of knowledge of the extreme sensitiveness of the biological balance, the conclusion is inevitable that the bottom of the deposit was formed at the mean high tide level and that each succeeding inch was formed at the same plane.

The Formation of Turf.—Considering now the question of the formation of the thick strata of *Spartina Patens* turf, but one hypothesis seems to fit the facts of the limited vertical distribution of the living plants and the development of deposits in which their well preserved remains extend to even three feet below mean high tide, not to mention those which extend unbroken by even silt beds to a depth of two to three feet below mean low tide or even to nine feet below; that is, that the plane of the marsh surface has practically always coincided with the plane of the mean high tide.

In order to have these two planes coinciding, we must assume (a) stationary marsh surface and stationary plane of tide, but in that case there would be no thickness, or at most two feet, of the peculiar peaty accumulation, and the facts are unaccounted for; (b) stationary marsh surface and steadily rising plane of tides, for unsteady tidal elevation would not permit uniform building of the marsh deposit; the objection to this theory is that we have no other evidence that the tidal plane has steadily risen for a sufficient length of time to permit the accumulation of the mass of material to be accounted for; (c) subsiding marsh surface, and stationary, or nearly so, tidal plane. The last mentioned is more in accordance with other well known geologic facts than the others and it requires less mental readjustment to think of subsiding bottom than rising sea level. It is only necessary to assume a slow, steady subsidence at a rate equal to that of the upbuilding of the marsh deposits, to reconstruct the marsh and tidal planes with always the right relationship, so that the biological balance is undisturbed, and if climate and soil are constant, the material resulting from the growth of the plants of the kinds mentioned will form to any depth.

Wallace W. Atwood.

A Geographic Study of the Mesa Verde.—Printed in full herewith.

Ralph S. Tarr.

An Excursion to Spitzbergen.

A brief description of some of the physiographic features observed in Ice Fiord, Spitzbergen, on an excursion of the International Geological Congress in 1910. It was pointed out that there had been previous great expansion of glaciers as a result of which much erosion was accomplished, causing hanging valleys and steepened slopes, in many places in horizontal strata which, sculptured in this climate of light rainfall, assume forms closely imitating those of an arid country. The several tidal glaciers were briefly described and reference made to the conditions of supply and the fluctuation of the glacier fronts. Spitzbergen is a "No Man's Land," but the recent development of extensive coal beds gives to it a new importance.

Cyrus C. Adams.

Foundations of Economic Progress in Tropical Africa.—Read in Abstract.

Richard E. Dodge.

Geography and Agriculture.

Geographical conditions affect the details of agriculture as definitely as they do the larger problems of crop distribution. The paper presented certain detailed relationships between slope, exposure, drainage, groundwater, weather, climate, and plant and animal production.

R. H. Whitbeck.

Contrasts Between the Glaciated and the Driftless Parts of Wisconsin.

About nine thousand square miles of Wisconsin escaped glaciation. This area is not, as might be expected, an elevated region: on the contrary it includes a part of the main valley of the State and a section of the Mississippi Valley.

Why, in every glacial advance, this particular region escaped, is not entirely clear, but the cause seems to be connected with two facts: (1) that the driftless area lay approximately between the western margin of the Labrador ice sheet and the eastern border of the Kewatin sheet, and (2) that north of the driftless area is a highland which diverted the ice right and left.

The contrasts between the glaciated and the driftless portions of Wisconsin may not impress the casual traveler, but when examined they prove to be striking. There are contrasts in the contour of the land, contrasts in drainage, contrasts in soil and resulting agriculture, contrasts in the original forests and contrasts in opportunities for the development of water power and related manufacturing. These differences have produced notable differences in the distribution of people and in their occupations and economic progress.

Robert Marshall Brown.

A Review of Recent Publications on the Mississippi River.

This review covers the Report of the Inland Waterways Commission, 1908; the Report of the Commissioner of Corporations on Transportation by Water, three volumes, 1909; the Report of a Special Board of Engineers on the Survey of the Mississippi River, 1909; the Report of the Mississippi River Commission, 1909; Special Report of the Census Office—Transportation by Water, 1908; and the Report of the National Conservation Commission, three volumes, 1909.

In order to systematize the review of such weighty volumes, the results are arranged in an argumentative form having for a thesis the decline in commerce on the Mississippi River and its tributaries. The following headings furnish a brief of the paper:

The decline results—

1. From the river itself.
    a. The unreliability of depth of water.
2. From the nature of the carrier.
    b. The river boats have not improved in fifty years.
    c. The terminals and the systems of loading and unloading have not improved.
3. From the nature of the commerce.
    d. Restricted to movements of freight between river points.
    e. The necessity of transshipment.
4. From competition.
    f. Competing lines of railroads and their methods.
    g. Burdens of insurance, wharfage charges, etc.

Frank Carney.

The Geographic Provinces of Ohio.

The boundaries of geographic provinces change as trade routes temper the influence of barriers. The following stages are noted in the working out of this principle in a single state:

1. Early settlement.
2. Expansion of local industries.
3. Influences of the state's geographic environment.
4. Intra-State Adjustments following from No. 3.
5. Reactions due to the bridging of major provinces outside the state.

During the settlement stage, drainage basins form the provinces. These provinces are frequently enlarged by the activities of local industries. Geographic environment determines the traffic-highways (stage and freight pikes, and truck railways) passing through the state; industries already established are affected by these new transportation lines, and new industries are started. But the strongest influences in blending the early geographic provinces of the state arise from the bridging of major provinces outside the state.

George D. Hubbard.

The Effects of Gold and Silver Mining on the Character of Men, Individually and Socially.

The most obvious effects constitute the mania known as the gold fever, whose chief manifestation is the "rush." In this a bunch of men abandon profitable mining to seek a new gold field on the unsubstantiated report of wealth elsewhere.

In addition, many personal characteristics are called forth, nourished or developed. Among them are self-reliance, friendship, cordiality and a jovial fellowship. Gambling, drunkenness and improvidence are the greatest vices. Speculation and betting find a fertile soil in the spirit of camp life.

Not all persons are identically affected because they have brought different qualities with them which react diversely under the same external stimulus.

Some are happy and hopeful, others imperious and hasty; some are resourceful, ingenious, others brave, loyal or orderly. The conditions seem also to call forth qualities in the man heretofore latent.

Socially, the commingling of races, nationalities and social classes, has the result of giving to the West the most cosmopolitan spirit, and the most democratic society of all American communities.

F. V. Emerson (Introduced by A. P. Brigham).

Life Along the Graded Missouri.

Two well marked ontographic effects of the Missouri River in Missouri are considered. The Missouri as a part of the Ohio-Mississippi-Missouri highway directed early traffic and immigration into the region. The local effects of the River and its flood plain are characteristic.

Lawrence Martin.

The Progressive Development of Resources in the Lake Superior Region.[3]

A discussion of the Lake Superior Region, showing how its physiographic features and its geographical relationships have influenced a

[3] Published in Bull. Amer. Geogr. Soc., Vol. XLIII, 1911; pp. 561-572, 659-669.

progressive development of resources. The fur trade came first, lumbering and the iron and copper mining soon followed, and are still of prime importance, though fishing, agriculture, and the summer resort business are growing. The routes of trade for ships and railways have always been of great importance. The influence of glaciation, of harbors, of canals, of low railway grades, etc., are discussed and five types of towns described: (1) trading posts, (2) missions, later becoming forts, (3) sawmill towns, (4) mining towns, and (5) lake ports.

Mark Jefferson.
The Culture of the Nations.

From independent statistical studies for each of the countries of the world it appears that contiguous land-groups in Europe fall into three culture classes, most of Asia and Africa into another, while the rest of the non-European world for the most part falls into the classes of its mother countries.

The highest, or Teutonic culture, characterizes the lands about the North Sea and West Baltic, as also English speaking America and Australia. Mediterranean culture characterizes Spain, Greece, Roumania, Bulgaria, and also includes the Argentine Republic and Uruguay. Levantine culture is of Russia, Turkey, Portugal, Algeria, Egypt, as also Chile, Ecuador, Mexico, Central America, Paraguay and Venezuela. Asia except Japan, much of Africa together with Colombia, Brazil, Peru and Bolivia, fall into the lowest or Oriental class.

F. V. Emerson.
Population in Missouri as Related to Physiographic Provinces.

The general distribution of population in different physiographic sections since the time of permanent settlement to the present, was considered.

Wallace W. Atwood.
Areal Physiographic Mapping.—Read by Title.

In pursuing detailed physiographic studies in the western mountains and attempting to discriminate the features of each stage in the development of the present topography, an attempt was made to work out a plan for an areal physiographic map. A trial map and several diagrams to illustrate the plan were presented.

W. M. Davis.
A Swiss School Atlas.

A school atlas of exceptional merit, lately prepared by an educational committee of the Canton of Zurich, was exhibited and described.

O. D. von Engeln (Introduced by Ralph S. Tarr).

A Method for Combining the Topical, Regional and Cultural Phases of Physiography Study in the Laboratory.

Indoor laboratory study in physiography should satisfy three sets of ideals. There should be interest on the part of the pupil, it should have an educational value by affording training in observation and deduction, and it should lead to an understanding of the subject-matter.

The greatest difficulty in meeting these ideals has been met with in the study of the physiography of the lands. The problem is to teach the origin of land forms, their occurrence, distribution and significance in human affairs by the laboratory method; and at the same time afford systematic training in map reading: all in a single course. By laboratory method is meant that the results obtained shall be dependent on the student's own observations and deductions.

In general, the solution proposed is to bring the various land forms into intimate association with a regional geography background and to lead the student to an appreciation of human response to physiographic environment by map study.

This has been done by providing the student with an outline map of the physiographic provinces of the United States. An 18 x 28 foot contour map of the United States forms the basis of the general study of these physiographic units, and for detail work one or more United States Geological Survey contour maps typical of each area are furnished. The student first plots from the outline map on the larger topographic map the physiographic province to be studied. A set of suggestive questions (only such are proposed as can be answered from the data which the map gives), leads to a general study of the area, its size, location, larger topographic features, and the distribution and density of settlement. The position of the topographic sheets within the area is then determined and their areas outlined on the larger map. As in the case of the general features on the larger map, a detailed study of the topographic sheets is then undertaken. Here individual land forms and cultural relations are emphasized.

The order of study provides a correlation of similar regions, and develops the notion of development from young to mature and old stages in land forms; and the effects of climatic differences. As an illustration of such a series, the following may be cited for plains and plateaus:

The Mississippi Flood Plain and Delta.
The Glacial Lake Plains.

The Atlantic Coastal Plain.
The Appalachian Plateau.
The Great Plains.

Accurate interpretation of topographic maps, a definite conception of the location, characteristics and extent of the physiographic regions of the United States, knowledge of the occurrence and features of such forms as mesas, volcanoes, moraines, etc., and reasons for their occurrence, are some of the results of such a study. As care is taken in the preparation of the questions so that they may all be answered directly by map study, distinct observational and deductional training is afforded. The student's interest does not flag because of the consecutive nature of the studies.

Archer C. Bowen (Introduced by Lawrence Martin).

Child Development and the Teaching of Elementary Geography. —Read by Title.

1. What does child development seem to demand as basal in geography teaching?
2. Child teaching versus subject-matter teaching.
3. Point of contact in all geography teaching.
4. Stages in child development as a background for geography teaching.
   a. Experimental—Projects to be taught—Contact—Methods—Sources.
   b. Informational—Projects to be taught—Contact—Methods—Sources.
   c. Rational—Projects to be taught—Contact—Method—Sources.

Collier Cobb.

The Sands and Dunes of Gascony.

Philip S. Smith.

The Consumption of Electricity in a Sub-Arctic Region.

The consumption of electricity for illuminating purposes affords an insight into many of the characteristic habits of the people of a region. This is particularly true in high latitudes where the length of daylight changes materially during different seasons. An illustration of this fact is afforded by the records of one of the electric light and power companies at Nome, Alaska. A diagram of the production of electricity by the plant for the first four days of each month from November, 1909, to June, 1910, inclusive, brings out clearly many of the habits of the people that are based upon seasonal and diurnal controls.

Explanation of Plate I

a The sloping highland above the head of Fourmile Creek, looking southwest, from same point of view as that of Plate I*b*. Subdued mountains south of South Boulder Creek in the distance. See page 41.

b Bald Mountain (12,000 feet?)—see Plate I*a*—looking west from near Gold Hill station of the narrow gauge line to Ward, which is seen on the graded slope of the mid-distance ridge. Mt. Audubon in distance on right.

PLATE I

a

b

Explanation of Plate II

a Granite crags north of the South Platte Valley, near Buffalo. See page 50.

b Looking down the normal early-mature valley of Fourmile Creek, over Sunset, from nearly the same view-point as that of Fig. D 1. See page 51.

a

b

Explanation of Plate III

a Eldorado Springs, at the mouth of the gorge of South Boulder Creek, cut in the resistant basal sandstones of the mountain border, which a little farther north form the Flatirons of Plate V*b*. See page 53.

b Nearly complete dome, with small cirque on its eastern side, next north of Hegermann Pass, in northern part of the Sawatch Range. See page 56.

PLATE III

a

b

Explanation of Plate IV

a Half consumed dome, with large cirque on its eastern side, next south of Hegermann Pass, in northern part of the Sawatch Range. Vegetation in the pass alligned by wind action. See page 56.

b Cirque of one of the head branches of South Boulder Creek in the foreground, looking south-southwest. The dome-remnant of James Peak, with deep cirque of Mammoth Gulch on left, and greater cirque of Jim Creek on right. In part, same as that of Fig. E 2. See page 61.

a

b

Explanation of Plate V

a Mature and spurless trough at head of Frying-Pan Creek, looking south along the west side of the Sawatch Range. Mt. Massive in left foreground. See page 62.

b The Flatirons, near Boulder, looking southwest. The basal members of the covering strata are here unusually resistant, and hence rise in bold forms along the mountain border, the weaker overlying strata having been worn away. See page 75.

PLATE V

a

b

Explanation of Plate VI

a Navajo Canyon and a portion of the upland Surface of the Mesa.

b An unused alcove at the head of one of the smaller canyons in the Mesa.

a

b

Explanation of Plate VII

a Balcony House.

b A portion of Spruce Tree House, showing a few ceremonial rooms and the outer walls of the Homes.

a

b

Explanation of Plate VIII

a Cliff Palace from the rim of the Canyon wall.

b Near view of a portion of the Cliff Palace showing several circular Kivas or ceremonial rooms, the circular watch tower, four-story rectangular tower in the distance, and a few of the three hundred or more rooms in the dwelling.

PLATE VIII

a

b

INDEX