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THE ORIGIN AND NATURE OF SOILS

BY

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PREFATORY NOTE.

The object of this report is to set before the general reader a somewhat popular account of the origin and nature of soils; to show the importance of their relations not only to the well being of men but their influence on the course of the physical and organic events which have determined the geologic history of the planet. It is also intended to show that this slight superficial and inconstant covering of the earth should receive a measure of care which is rarely devoted to it; that even more than the deeper mineral resources it is a precious inheritance which should be guarded by every possible means against the insidious degradation to which the processes of tillage ordinarily lead.

The peculiar order of the relations of civilized men to the soil are now the subject of serious discussion. More clearly than ever before it is perceived that the roots of our society, like those of a tree, strike deep into the fertile earth and draw thence the nurture which maintains all its springs of life. The way in which the soil may best be made to support the state, the laws by which it can most effectively secure this need, the measure of governmental interference with the ownership of the fields and forests, are now all matters of serious debate. In the consideration of these problems it it desirable that the nature of the matter under discussion should be well understood. We should as far as possible obtain a clear notion as to the way in which the varied soils stand related to the needs of our people. It is of importance, for instance, to know how much tillable land still remains in the unused reserves of the inundated and arid districts of this country and how far these may provide for the necessities of the generations to come. It is equally desirable for us to know the extent to which the fertility of this superficial coating of the earth needs the peculiar care which men give to their personal property, but which they rarely if ever devote to goods which are not endeared to them by absolute possession. The discussion of these and many other correlated questions demands a certain amount of knowledge which in order to meet the need must be separated from the special learning or at least the special phases of the several sciences of geology, physics, chemistry, and botany, which are applied to the inquiries relating to the constitution and economy of the soil.

It is a somewhat remarkable fact that while the scientific treatises on soils are very numerous constituting, indeed, a tolerably rich literature, the general essays on the subject are few in number and are, moreover, almost without exception, devoted either to the conditions of some particular region or to a particular class of questions which demand in the reader who is to obtain profit from their pages a considerable amount of training in chemical science. So far as I have learned there is no work in our own or in any other language which will give the reader who has not had special technical training in the subject any connected story concerning soil problems, which will in familiar phrase tell him the leading and most important facts concerning the chemistry, physics, and geologic history of these deposits. The farmer who imperatively needs to know something as to the part of the earth with which he is dealing is, in the main, compelled to rely upon personal or traditional experience as the guide of his conduct. This body of inherited learning is doubtless of great value; it is indeed in the best sense scientific as well as practical, for it rests, as all true science does, on a series of experiments; yet it is necessarily limited, for the reason that it is derived from contact with the conditions of a small field. For its best use it needs the enlargement of view which comes from an understanding of the general aspect of the subject and a knowledge of the experience of other men in other regions who are dealing with the same class of problems.

Where the people who till a particular soil have dwelt for centuries upon the same ground, the mass of learning concerning it which is gathered in tradition is usually very great, and in most cases provides better guidance for the husbandman than any more recondite science can afford him. The folk who have summered and wintered with their fields for many generations know in most cases the effects of diverse means of tillage in a very complete way. The effect of this ancestral experience in such immemorially cultivated land is commonly shown in the preservation of the original fertility of the earth or even in the enhancement of its returns by the skillful treatment which it has received. The people have in these cases learned how to husband and augment the soil resources, and a sound public opinion commands a large measure of care in agriculture. In these countries the owner has himself struck root in the soil; he has come to love it as the source of his own life and to look forward to the time when it will nurture his descendants. He may appear to the eye as a stupid peasant, but he is in most cases learned in all that relates to his acres from his own experience and the body of information which has come down to him from the past.

It is otherwise in this new world of America. Save here and there in the parts of the country longest settled, the traditions concerning the soil of any district are comparatively meager. It is indeed rare to find a farm which has been tilled for as much as a century by the members of one family. The larger part of the land, particularly that of the Northern States, has been occupied but a few years by the people who now possess it. A great portion of our agriculturists have but recently come upon the fields which they cultivate. Thus among the farmers of the continent there is no extended experience in the conditions of the soil they till. Left to such lessons, it will require generations to gain that information which the history of other fields might readily and immediately supply. It is in this way that science can best help in practical affairs such as agriculture and mining, viz, by presenting the results which have been gathered over a wide area of ground for the guidance of laborers in a particular field.

One of the greatest improvements in modern agriculture consists in the use of various mineral manures which within the lifetime of many active men have been made elements of commerce. Although the profit of these resources is in most cases to be quickly and cheaply determined by actual trial, it is, nevertheless, important that those who are interested in farming should know something concerning the nature and origin of these geologic fertilizers in order that they may be prepared to discover them in their own districts. There can be no question that at a great number of as yet undiscovered localities in this country there are deposits which will serve well as sources of materials for the refreshment of the soils. As far as seems practicable within the limited scope of this essay, care is taken to point out the conditions in which such materials may be expected to occur.

Although it is hoped that the practical needs of many persons may be served by this essay, the main intent of it is to afford a clear, simple and connected idea of the place of the soil in the economy of nature. So far as this can be done it will tend to ennoble the conception of all those relations with the earth on which the daily life of mankind depends, and on which the whole future of our civilization must rest. To obtain this end it will be necessary to devote the larger part of the essay to a study of the origin and nature of soils, showing how they originate, and the steps by which they are continually reformed. Only by a careful discussion of these points can the true nature and importance of this covering be made plain.

NATURE AND ORIGIN OF SOILS.

Many of the most noteworthy features of this world are, by their ever present nature, in a way concealed from us. The starry depths of the heavens afford a spectacle which would overwhelm the minds of men if they were revealed to us but once in a generation, but from the familiarity of the vision they nightly pass unregarded. In a like manner the soil beneath our feet, because we have been accustomed to its phenomena for all our lives, appears to us commonplace and uninteresting; it seems a mere matter of course that it should everywhere exist and that from it should spring the manifold forms of life; that into it the dust of all things should return to await the revival of the impulse which lifted them into the living realm. Now and then a poetic spirit, anticipating with the imagination the revelations of science, has spoken of the earth as the mother of all; but the greater part of mankind, those who are well instructed as well as the ignorant, look upon the soil as something essentially unclean, or at least as a mere disorder of fragmentary things from which seeds manage in some occult way to draw the sustenance necessary for their growth. Any chance contact with this material fills them with disgust, and they regard their repugnance as a sign of culture.

It is one of the moral functions of science to change this attitude of men to the soil which has borne them; to bring men to a clear recognition of the marvel and beauty of the mechanism on which the existence of all the living beings of the earth intimately depends. This end it attains through the clear views which it opens into the structure and history of the earth by removing the dull conception of mere chance which we almost instinctively apply to the phenomena of nature, and in its place giving an understanding of those processes which lead to the order and harmony of the universe. In no part of this great work of ordering and ennobling nature in our understanding is modern learning doing a better or more profitable work than in removing the veil of the commonplace with which long and ignorant familiarity has wrapped this earth, hiding its dignified meaning from the understandings of men. Though this task is but begun, enough has been accomplished to insure in those who have an appetite for such truths a nobler conception of this sphere, a new and imposing sense of the relations which they themselves and all their living fellows bear to the earth which has nurtured them.

This view of the moral relations of men to the earth is attained by the method of science in a simple way; following step by step the history of the earth's features and noting the processes by which they have taken form, there gradually develops in the mind a sense of the activities and the relations between the forces which have shaped its growth. No sooner is this inquiry begun than the mind ceases to look upon this sphere as a dull matter-of-course. Every event in the history is seen to have been determined by well adjusted modes of action. Each of these events blends its influence with every other so that the whole sphere moves forward in the process of its evolution, a vast array of forces perfectly ordered in their ongoing, steadfastly winning successes in organization and bringing all of its activities to a higher plane of existence.

It is beyond the compass of the human mind at once to conceive the course of the many different fields of this earth's progressive activities.

We have to limit our inquiries to some particular part of the vast realm in order that the number of the considerations may fall within the compass of our understanding. The student of the earth may select any one of the dominions of its mechanism and from the study win an exalted conception of the wisdom and beauty of its processes. On many accounts the soil covering is the best field for the beginner of such inquiries. The facts with which he has to deal are in general of a simpler and more evident nature than those which are afforded by the concealed portions of the globe. They are everywhere presented and are to a great extent open to the light of day, while the student of the earth's successive periods or of its mineral deposits is compelled to seek beneath the surface and in many different lands for the phenomena he deals with. The observer of the soils everywhere finds the part of nature with which he is concerned close about him and accessible to his inquiry, as are no other parts of the geologic field. All that is needed is an interest in the problem and an easily acquired training in certain simple methods of observation to fit any one for the study of the more evident phenomena of soils.

As the greater part of the soils of the earth in their natural condition are forest clad, we shall begin our inquiry with the portions of the earth which are covered with woods. The reader should, however, bear in mind the fact that a large portion of the lands are destitute of timber, and are either covered by a luxuriant growth of lowly plants, as in the case of the prairies, or in arid districts may present a very scanty growth of vegetation. In certain very rare cases the surface bears a true soil which does not support any vegetation whatever; but in such instances we may be sure that a recent climatal change has led to the destruction of a vegetable coating which originally existed in the district.

In beginning a study of the soil covering it is well to gain an idea as to the nature of this substance of which it is ordinarily composed. In this first step it will be useful to select a handful of ordinary soil from any convenient place, taking care that it is from within an inch or two of the surface and from a place where it has not been disturbed for a century. It is best it should be virgin soil; that is, unaffected by the processes of tillage. The naked eye commonly shows us that the mass is composed of two distinct kinds of materials. In part it is made up of decayed vegetable matter, portions of which so far retain their living shape that we can easily see that they are derived from leaves or twigs. From these discernible bits, by progressive decay, the vegetable matter shades down to less and less distinguishable form until it appears as an unorganized blackish mold. Mingled with this dark waste of rotted vegetation there are more or less distinct fragments of a stony nature in the form of sand or pebbly matter. If the sample has been taken from an old forest bed these bits of rock may be so rare as to escape observation; taken from a lower part of the soil they will always be evident, if not to the eye, at least under a simple microscope, or, if that is not convenient, they may be felt between the teeth as gritty particles. Observing them closely we find that, however small, they are more or less angular fragments of rock, generally a good deal decayed on the surface, often so much changed that they fall into dust at a touch. The magnifying glass shows that the process of decay is fracturing all these fragments along their structural planes, joints, or cleavages, and this indicates that some action is at work which serves to break up the stony matter of the soil into an ever finer state of division. That this action is in a way peculiar to the soil is shown by the fact that if we take a sample of finely divided rock, as for instance from any soft sandstone or other like deposit lying at a considerable depth below the soil, we find that its grains do not exhibit this progressive decay. We shall hereafter note how this breaking up of the stony matter is brought about.

In order to see in a clear manner that the soil is not a mere mixture of decayed organic matter and of broken-up rock it will be well for the observer to make two small experiments which will throw much light upon this problem. In one experiment, a sufficient quantity of the rock lying below the original soil at such depth as to preserve it from the chemical influence of the superficial materials should be taken and reduced to a state of division like that of the stony matter of the soil. In this seeds of some grain-bearing plant, such as wheat, should be sprouted and kept duly moistened with distilled or rain water. It will be observed that while the seeds readily germinate and enter on the process of growth the plants soon become stunted and fail to produce their fruit. If we then take decayed woody matter, such as forms the other component of the soil, carefully excluding all mineral materials from the mass and, as before, sow it with grain, we find that there also the plants grow for a time sustained by the nutriment contained in the seed and the trifle of sustenance they find in the materials about their roots, but they likewise fail to come to full maturity. It is not indeed necessary, to perform these experiments artificially. We may often observe them in the fields. On the storm-blown places where the natural soil has been removed by the wind and bare sand exposed we may observe that the seeds of the tough wild grasses, which lodge upon this material, sprout as in the suggested experiment with powdered rock, but die before they blossom. In other places we may see where some deep mossy bog has been recently drained and an effort made to reduce it to cultivation. Hardly any flowering plants will ripen their seeds upon it, the pure vegetable mold evidently being unfit for this nurture. It is necessary to remove this swamp deposit by burning or by allowing it to decay until it is so thin that the plow can mingle the humus with the rocky matter which lies beneath the layer before any green crops can flourish upon it.

Although it is in general true that decayed organic matter is necessary to fit a soil for the uses of vegetation, it should be remarked that in certain instances the earth may yield its mineral stores to vegetation even where there is no trace of decayed organisms in the mass. This condition occurs most commonly in arid lands which by irrigation have been made fit for tillage. Such soils, even where destitute of organic matter in a state of decay, often have a relatively large proportion of their mineral ingredients in a state in which they may be assimilated by the roots. The reason for this exceptional condition is perhaps as follows, viz: Even in the desert districts there is a small amount of rainfall, enough to provide the soil at certain times of the year with a share of water. This water effects the decomposition of the mineral matter in a slow way, but as the substances made ready for solution are not removed by plants, nor to any extent carried away by underground movements of water, they remain stored in the earth and are ready for the use of vegetation when the field is provided with water.

In some parts of the Southern States, notably in Florida, soils which contain scarcely a trace of organic waste at the depth of say an inch below the surface will nourish vegetation. In this case the solution of the mineral substances is probably in good part effected through the action of the water which, in its course through the thin layer of decayed vegetation, takes up the acids which facilitate, though they are not absolutely necessary to, the decay of the rocky matter.

These artificial or natural instances appear to show us that true fertilized soils are not usually made of either stony matter or vegetable materials alone; that what is needed is a mixture of the two substances. Similar experiments, or, in their place, observation in the field, will indicate that some time must elapse after the mineral and vegetable materials are mingled together before the soil becomes adapted to the growth of plants which produce fruits important to man; it in general requires a year or more for the results of the mixture to be evident. The general meaning of this evidence is plain; it is clearly to the effect that true fertilized soils, at least those from the point of view of human interests and needs, are the result of some reaction between the decayed organic matter and the broken-up bits of the solid earth with which it is commingled in varying proportions according to the circumstances of its development. Before we proceed to consider the natural history of soils, in which task we shall endeavor to show the way in which this commingling of their organic and inorganic components has been brought about and the chemical influences arising therefrom, it will be best for us to examine in a brief way into the effects of this mixture of these decayed materials derived from the remains of forms which were once living and from the lifeless rocks. In this way we shall see something, at least, of the importance of the questions with which we are to deal, and shall at the same time have a chance to note the problems which in our further inquiries we should seek to solve.

One of the most noteworthy features of soils is their wide extension over the surface of the lands. It is only in a very small portion of the land area that they are absent. The nature and origin of these fragmentary and on the whole insignificant soilless areas should be noted, for the facts are very instructive. We observe in the first place that soils are wanting on those surfaces of the bed rocks which are swept by moving water in such manner that the detrital materials can not remain in their natural position. The shores of the existing sea and of some ancient sea margins within the section beaten by the waves, the rocky beds of rivers and torrents, the steep parts of mountains where the rain urged downward by gravity clears everything before it until it flows on the bed-rock, are instances of this action (see Pl. II). Also, where rocks are steeply inclined, the effect of frequent earthquake shocks is to urge all loose materials in a sliding motion to the base of the declivity. Again, in regions from which glacial ice has recently disappeared it happens that occasional patches of bed-rock are left without any of the detrital coating which is usually deposited on such surfaces (see Pl. III). In regions overflowed by lavas derived from recent volcanic eruptions we now and then find that the once fluid but now solid rock has not yet become soil covered (see Pl. XXI). Lastly, in certain places where the soil at times when the wind blows violently is very dry and maintains at best but a scanty vegetation, the moving air may sweep it away. Notwithstanding this considerable list of conditions which may lead to a soilless earth, at least nineteen-twentieths of the land areas are occupied by a coating of commingled rocky and organic matter of sufficient thickness and fertility to afford sustenance to a varied vegetation and in a greater or less measure, if carefully tilled, to contribute to the necessities of mankind.

However these soils may differ in their character we shall find that they all have the common feature above noted of containing an admixture of materials derived from the decay of the firm-set underlying earth and similarly decayed fragments of plants and animals; the animal remains are less evident and important, but they are present in all soils and in many of them are a considerable element in their composition. On the adjustment in the proportions of these diversely originating materials depends to a great extent the fitness of the earth in the particular region to bear an abundant vegetation, whether planted by nature or by art. The variations in this regard largely depend on the operation of the natural agents which serve to bring about and maintain this association of the two elements, the organic and the inorganic, which compose the soil.

The extension of the soil coating of the earth is not more widespread or more evident than its importance to the organic life of the land. Nearly the whole of the plants other than those of the sea and the lichens and mosses require as the first condition of their existence that there shall be a soil beneath them from which they may derive the mineral or ashy parts of their bodies and the water of their sap. On the arid soilless lands of the desert or on lava rocks we may find a variety of the

VIEW ON THE EASTERN SHORE OF CAPE ANN, MASSACHUSETTS, SHOWING SHORE LINE STRIPPED OF SOIL MATERIALS BY WAVE ACTION.

rootless non-flowering plants such as the "tripe de roche," a species of lichen, or the "poverty grass," another similar plant of the sandier fields of New England, but unless there be a distinct though it may be thin soil, none of the higher plants, especially those of importance to man, will grow there. So, too, on the bogs where the vegetable mold is deep and the plants can not strike their roots through it to the under earth and where the deposit is so placed that mineral matter can not be washed in from the land or blown on by the winds, we find the vegetation to consist of species which, like the water-loving mosses, have but a small amount of mineral matter in their composition. This mineral matter they give, when they decay, to the swamp water, whence it is returned to the growing forms. No plants having nutritious seeds or fruits, none yielding strong fibers or endowed with other qualities making them immediately valuable to man or useful to him because they serve the needs of food for his domesticated animals, will flourish in these swamps, where the depth and purity of the vegetable mold excludes the roots from the advantages of a true soil. It is by such observations made plain that were it not for the peculiar conditions which are afforded by this admixture of the débris of the underearth and of organic bodies, the higher plants which afford sustenance to man and to all the higher animals as well would have no place on this sphere.

A little consideration of the relations of the higher animals to plants makes it clear that all the advance of the earth's life above its simpler forms depends upon the existence of moderately fertile soils such as produce food fit for the nurture of the higher forms. They could not have developed if the world had afforded no better provision for them than the lichens of the rocks or the mosses of the peat swamps. We thus see that the soil is really the immediate source not only of the superior kind of plants which feed in the soil, but also of the animals which depend upon them. If the plants, such as those which produce fruits, grains, or nutritious herbage, had not had this field for their development there would have been no chance for the evolution of the series of animals which have led life up to the estate of man to find a place upon the earth. Important as the effects of the soil are to more advanced beings, they have been almost as important to many of the lower orders of life. Of the vast array of insects existing on the earth, the species of which are to be numbered by the hundred thousand, the greater part likewise depend for their nutrition either on the food they obtain from the soil nurtured on higher plants or on other animals which themselves feed on such vegetation; only a few lowly forms can subsist on plants which do not require true roots for their support. The bees and ants, nearly all the butterflies and moths, in fact all but a trifling remnant of the insect world, need the conditions which the soils bring about quite as much as does man or his kindred among the mammals.

It is not alone on the relations of the soil to the life of the land, however, that we must look for its action in the economy of the world; those relations, though most important and apparent, are not the most far-reaching of the consequences which arise from the mingling of decayed organisms with the stony matter of the earth. To perceive these we must look in succession at the conditions of the seas and of the rocks which lie in the depths of the earth. We shall find that on these apparently remote realms the influence of the soils is felt in many and interesting ways.

On the floors of the seas there is no soil coating; there is on these surfaces a quantity of detritus worn from the land, cast into the seas by volcanoes or laid upon their bottoms by the decay of organic bodies, the whole forming a layer which in many ways resembles the soil covering of the lands, but it serves no purpose in nourishing vegetation. The true algæ or seaweeds have no roots; they absorb through the surface of their bodies the materials which ordinary plants procure by these processes. As the waters of the sea, and in a less considerable way the fresh waters in our lakes and streams, contain a considerable amount of mineral matter which they readily yield to these aquatic plants, this lowly vegetation has not been compelled to invent the special underground structures which take the ashy material necessary for their growth from the soil waters. When plants originating in water forms were by the course of their development transferred to the land, they found in the rain which fell upon their leaves no mineral materials to serve their needs, and therefore the parts of their surfaces above ground abandoned the function of absorbing mineral matter and only the under earth parts retained those absorbing functions which were common to the whole of the seaweed, and these roots performed the office for the whole plant. As we shall see hereafter, it is in a considerable degree to the penetration of the roots that we owe the characteristic features of the soil; therefore, while the materials accumulated on the sea floor resemble in their fragmentary and unorganized form those of the land surface, they really differ from them in a distinct and important way.

There are other differences in the constitution of the sea-floor deposits which separate them from the true soils; thus on the ocean bottom there is no current of water through the detritus; none of that alternate wetting and drying which is of very great importance in the economy of soils. Only a few of the root-bearing plants have accustomed themselves to draw nourishment from the débris deposited on the sea floor, and these, like the mangrove tree, can do so only in the marine mud next the shore, which is in large measure composed of waste washed in from the neighboring land. Furthermore, though there is generally a soft layer of a muddy or sandy nature lying on the floor of the water areas, this matter is always passing from the incoherent to the compact state, while on the surface of the lands the process is exactly reversed, the change being from the solid condition of the rocks to the loose state of

GLACIATED ROCK SURFACE FROM WHICH THE THIN SOIL HAS BEEN SWEPT AWAY, EASTERN MASSACHUSETTS.

the soil materials. In a word, the marine conditions are those in which the rocks are being integrated or built up, while on the land the state is that of disintegration. It happens that these two contrasted processes alike for a time afford materials of a somewhat similar appearance, though in fact the state of the respective deposits are essentially dissimilar.

In the processes which go on beneath the surface of the soil of the land and below the pseudo-soil or growing bed of the sea floor, we find widely contrasted phenomena. Thus below the soil and thence indefinitely downward we find that the rain-water finds its way through the innumerable crevices of the earth, carrying agents of change along with it. In this manner it produces the ordinary caverns of our limestone rocks and has a large share in the formation of mineral veins and other alterations in the original character of the rocks. In many cases these soil effects are propagated downward for hundreds if not thousands of feet; in many parts of the world, in all portions of the land, indeed, where the surface has not recently arisen from the sea or been in late ages scraped away by the glaciers, this downward-going influence of the soil is clearly marked to a great depth, producing in general a profound decay of the rocks, which often become so much softened that beds originally hard granite or tough mica schist may easily be cut into with a miner's pick. No such effects arise from the presence of the detritus of the sea floor, for the reason that here is no opportunity for the waters to penetrate downward from that level in the manner which occurs beneath the land.

This contrast between the conditions of the sea floor and those of the land in all that pertains to the effects of the detrital layer, if we consider it well, points to the obvious and important general conclusion which will be enforced by all that we shall have hereafter to consider, viz, that the life of the land in a singular way depends upon the destructive processes acting on the portions of the air-bathed parts of the earth's crust. It is to the ceaseless wearing down of the land that we owe the formation and preservation of the wonderful mixture of decayed rock and organic matter which forms our soil. This is one of the most beautiful and significant facts of nature; it shows us that the processes, which from a short-sighted view we term destructive and associate with death, are in fact but steps in the system of advance which lead matter from the lower mineral state to the higher condition of organic forms.

The foregoing inadequate sketch as to the general place of soils in nature will serve to show, at least in outline, the importance of the problem which they present, and also to indicate the path which our inquiry should pursue. We shall now undertake to trace the genesis of soils in the different conditions in which they come into existence, beginning with instances in which the observer may verify the statements in almost any part of the world, and then passing to those cases in which the process is not so easily seen but has in a measure to be inferred from geological study.

PROCESSES OF SOIL FORMATION.

From what we have already considered it is evident that soils are not original features of the land areas, but have been in some way produced after they were elevated above the sea.

Nearly all the areas of the continents and islands are known by geologists to have been formed beneath the sea and then uplifted above the level of the water. The process of their soil-making necessarily began when the rocks of which they are composed were clad with land vegetation and subjected to the manifold influences of the atmosphere. From time to time, the soils, after they were formed, were swept away by various chances, as when glaciers removing the soft materials left the rock bare, where earthquake-shocks have caused the soil to slip from steep places into the valleys, when lava floods or volcanic ashes have buried portions of the surface beneath layers of rock, or in a far less important but for us significant way, when man for some purpose has stripped away the soil from the surface of a part of the earth. To the observer these instances of the artificial baring and subsequent covering of the bed-rock again with soil are particularly interesting for the reason that they can be more easily understood than the larger work done over cultivated areas; the effects are also more computible in these partly artificial cases than those of the purely natural sort. We shall therefore begin our studies with this small class of soils which we may observe to be forming in old quarries or other places where the detrital coating has been for many years stripped away and the surface left to the processes of nature. (See Pls. III, IV, XVIII, XX, XXI.)

In all the older parts of this and other countries, where the rocks below the soil are of a nature to make it worth while to quarry them, abandoned pits can be found, and the length of time which has elapsed since the area of the bare rock was left untouched may usually be determined with tolerable accuracy.

Visiting any such old excavations where the rocks have not been stripped away for, say, ten years, we observe that on the surface of the stone there is a discoloration which gives it a hue differing clearly from that exhibited in the neighboring quarries where the faces have been recently disclosed in quarrying. Examining the rock closely with a glass the mineralogist can detect the beginnings of the decay arising from the exposure of the materials to the sun's heat and to frost and rain. The feldspar shows signs of the change which reduces it to the state of kaolin, a very soft material, and the hornblende exhibits marks of rusting due to the combination of the iron which it contains with the oxygen of the air. These changes are least on the vertical faces and steep slopes of the quarry; on the level surfaces they are much more advanced; we can indeed find spots where the water stands in shallow pools, where the decay has advanced to a point that a little sand and mud gathers as a film on the stone, the coarse grained fragments being

EFFECT OF GLACIAL ACTION ON A SURFACE WHICH HAS NOT YET BEEN RE-COVERED BY SOIL.

the half-shaped crystals of quartz and the finer matter the decayed feldspar.

All over the surface of a quarry which has been abandoned for as much as ten years we find that tiny lichens have attached themselves to the stone and from it drawn the small amount of mineral matter which they require for their bodies; this they can not do except for the decay which has served to render the material soluble. Even where the unaided eye fails to observe this vegetable growth an ordinary magnifying glass will generally reveal it. At the foot of the slope of rock we may notice a small talus of débris which has washed from the rocks above; examining the mass we find it to be composed in part of stony material, the crystals of which have become detached by decay, and partly of the remains of the lichens which are constantly dying and contributing their waste to the deposit. That the accumulation thus formed is a true bit of soil is clearly shown by the fact that when it is kept moist it affords a foothold for many small flowering plants. The crevices of the rock formed by the joint planes and other fissures are often filled with the débris which has been washed into them by the rains and blown there by the winds and thus affords points of vantage for many flowering plants, which in the moist springtime are sufficiently nourished to flower and ripen their seeds, though in the dry and heated season of summer they wither away.

The share taken by the winds in bringing about the accumulation of dust in ancient quarries is often considerable, but in a verdure clad region like New England the detrital material is usually derived from the artificial cliffs of the quarry.

In the older quarries, the stone of which has been exposed to the elements for 50 years or more, we find the same process of decay much more advanced; the heap of débris begins to creep up the slope and sustain larger and more luxuriant plants; the rifts in the rock are here and there occupied by species of trees which tolerate occasional droughts and their roots are wedging the fractured stones apart so that some fragments have fallen to the base of the slopes. In this work the frost plays also an important part, thrusting the masses asunder as it expands in freezing as effectually as the process is accomplished by the quarryman's wedges and hammers, though more slowly. We note also the fact that the lichens are larger, and evidently better nourished, than in the case of the first quarry examined, and they are therefore yielding more vegetable matter to the increasing talus. In the moist places the mosses are spreading upward from the base of the cliffs; with their spongy mass they hold water even in tolerably dry times, so that the rock is gradually being enveloped in a mantle of their growth. On the surface of this mass the débris worked from the rocks is constantly gathering, so that the coating affords sufficient soil material for the support of many plants, such as our huckleberries and other forms of flowering vegetation. These by their annual contribution of leaves and stems add still more to the increasing coating of commingled rock waste and decayed organisms.

From the aspect of old quarries to that of natural rock surfaces left bare of soil at the end of the last glacial period is an easy transition for the observer to make. On the fields of glacially bared rock, from which the ice has scraped and rubbed away the débris which once covered them, we may find every stage of the healing process which takes place when the solid parts of the earth have been stripped of their soil covering. The variety of conditions depends on the resistance which the rocks present to the agents which tend to break them up and in an important way on the nutritive value which the broken-up stone has for plants. Thus it is when the rocks are composed of quartz or other forms of pure siliceous material which is little affected by the atmosphere, especially where, as in compact quartzites and sandstones, the stone seems at times to bid defiance to the elements. As in the case of the rocks of this nature near Sugar Hill, New Hampshire, known as the "Thrashing floor," and the innumerable other instances in the region of crystalline formations in northern North America, the surface is so little decayed that it still bears the finer marks of the glacial scratchings, though, in the thousands of years which have elapsed since the glacial period, it has had no other protection against the weather than a thin sheet of moss and lichens which was in the course of time formed on the surface, (See Pls. III, IV, and XXXI.) A little decay was required in order to support this thin growth, but the rotting has not been at all sufficient to remove a twentieth of an inch in depth from the stone. There are in the aggregate in the northern part of this continent many thousand square miles of rock of this exceedingly resisting nature, which, though affording very little mineral matter for the formation of soil, still has furnished enough to maintain a scanty vegetation. The fact is that where there is but a small amount of material yielded by the soil to supply the ashy matter for plants the precious store is effectively retained by the vegetation, each plant deriving its supply of ashy matter mainly from the decayed bodies of its predecessors.

CLIFF TALUS SOILS.

From this condition in which the least possible soil making has been effected in the vast time which has elapsed since the glacial period, we may in a region underlaid by rocks of varied hardness, such as the glaciated region of New England affords, find every gradation in the measure in which the rocks have been brought into the condition of soil. Generally the decay of rocks has been great enough to furnish soil sufficient to maintain a tolerably luxuriant vegetation. But it happens in some instances that, while the rock breaks up rapidly, the size of the fragments is on the average too large to permit them to be used in soil making. This condition occurs where the rock is rifted by many joints or other divisional planes so that it breaks into a multitude

PRECIPICES WITH TALUS OF ROCK FRAGMENTS PASSING DOWNWARD INTO RUDE ALLUVIAL TERRACES.
This picture is taken from within a cavern arch.

of fragments of considerable bulk. These bits of stone accumulate at the bottom of the cliffs, forming a steep rocky talus into the interstices of which the finer matter yielded by decay penetrates below the level of daylight, so that the plants can not convert it into soil. We may observe that each of these masses of stone is attacked by lichens which are doing their fit work; but before they have time to accomplish the task the surface is covered with new falls from the overhanging cliffs. Usually we find that near the lower margin of this talus the plants have managed to stretch the mantle of vegetation over its surface, and though from time to time rock avalanches invade a portion of the field thus won to the uses of life, the growth gradually creeps up the slope. With each downfall of material from the precipice the talus rises nearer to the top of the cliff, until in the end the face of the escarpment is buried in its own rubbish. (See Pls. V, VI, VII, IX, XI, XII, and XIII.)

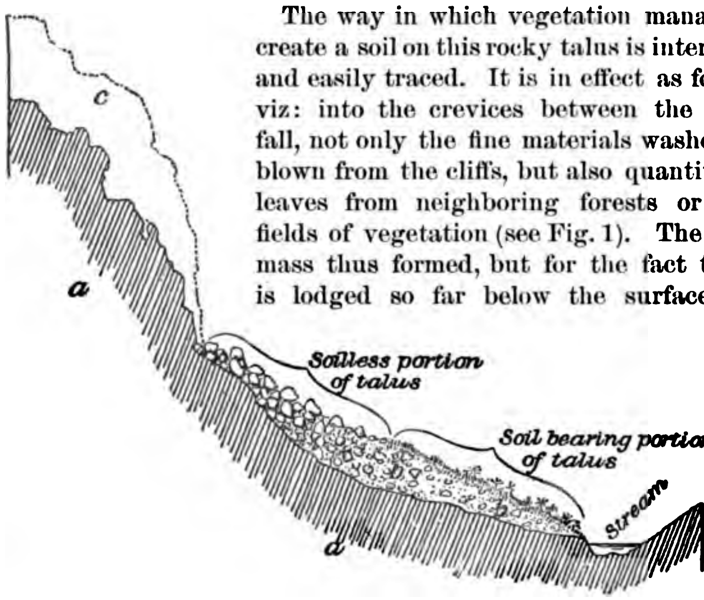


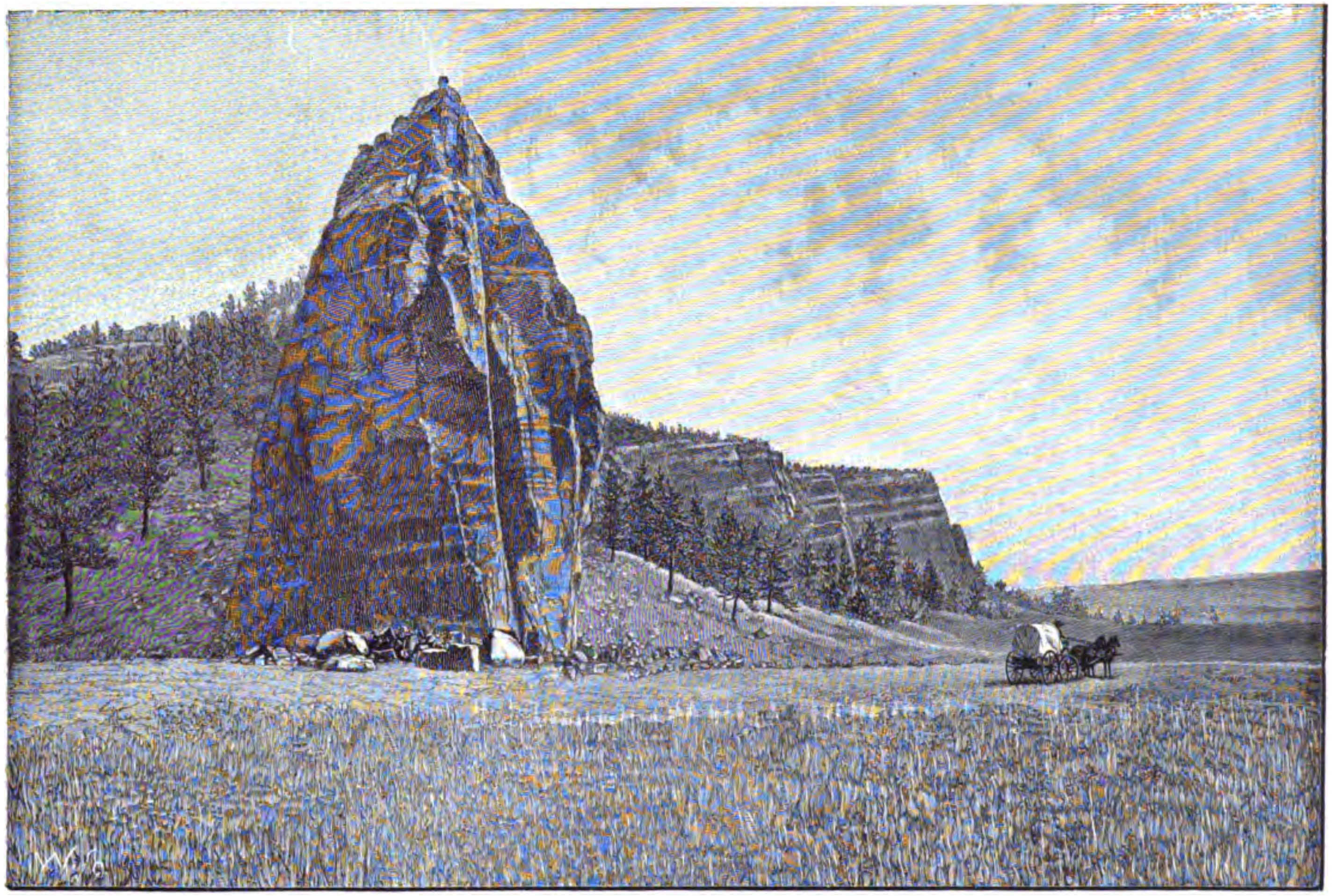
FIG. 1.—Diagram showing the history of a talus. *a*, bed rock; *b b*, talus; *c*, destroyed portion of cliff; material now in talus.

The way in which vegetation manages to create a soil on this rocky talus is interesting and easily traced. It is in effect as follows, viz: into the crevices between the stones fall, not only the fine materials washed and blown from the cliffs, but also quantities of leaves from neighboring forests or other fields of vegetation (see Fig. 1). The whole mass thus formed, but for the fact that it is lodged so far below the surface that the roots can not seize upon it, is excellently fitted for the sustenance of plants. Seeds which germinate in the depths of the rubble die before their shoots can escape above the darkness. Gradually, however, as the talus climbs up the side of the cliff and the annual contributions of fragments grow less considerable, the lichens seize on the surfaces of the stone and add their contribution to that obtained from other sources, and all the while fragments of rock are decaying and adding to the accumulation. Finally the fine débris rises to the level of the daylight, the seeds of the plants of most vigorous growth take root and flourish in what is really the very rich soil. Not long after the vegetation secures a good foothold, the mass of ruin becomes the seat of a heavy growth of large trees. Such talus slopes, indeed, are often covered by very luxuriant forests.

The soils formed on talus slopes are generally well suited to natural vegetation, though for a time they are not at all adapted to the uses of the plow. The large fragments of rock inclosed in the somewhat dispersed earth gradually decay; whenever a crevice forms, the roots of the stronger growing plants send their fibriles into the opening and these, expanding with great energy as they grow, rupture the mass and so extend the surface exposed to decay. To conceive of the importance of this action we should bear in mind the fact that in such a soil there are usually within the limits of an acre millions of these root processes searching for every cranny in which they may find nourishment for the plants to which they belong; no chance escapes them; no sooner is the slenderest crevice opened than they invade it, and if they find sustenance there they burst the mass as with a wedge. So effective is this process of external decay combined with the riving action of the root that unless the fragments of which they are composed are very unyielding these talus deposits are rapidly converted into deep and fertile soils. They are rarely well suited for ordinary tillage for the reason that as long as they are stony they turn the plow or spade, but they are excellent nurseries of timber and admirably suited for the culture of the grape; some of the best vineyards of the world are situated on slopes of this description.

It often happens that deposits formed of detrital materials are shaken down the slopes on which they rest by violent earthquakes. It is characteristic of regions which are much affected by such shocks that the detritus at the foot of cliffs is reduced much nearer to a horizontal attitude than it ordinarily assumes. It is naturally impossible to give any graphic representation of this action in the case of débris lying on steep slopes, but an adequate idea as to the efficiency of these disturbances in moving débris may judged from the fissured character of the field shown in Pl. VIII where the earth has recently been broken by an earthquake.

The above description as to the method in which cliffs gradually become covered by talus slopes is mainly applicable to the escarpments which are developed in countries which have been subjected to the action of glacial ice, and to those which have been formed along the banks of rivers which after a time have worked away from the bases of the steeps which they carved. There is another class of cliffs, such as are abundantly found in regions south of the glaciated fields, where the precipices are due to the fact that the materials of which their faces are formed are rapidly passing into solution and are borne away to the streams. In such cases the cliff usually exhibits hardly a trace of true talus, for the reason that the fragments in their divided state decay even more rapidly than the firm-set rock whence they are derived. Such cliffs retreat across the country, leaving at most a thin



VIEW SHOWING VARIED RATE OF DECAY OF TALUS FORMATION IN TRIASSIC SANDSTONE SCHIST NEAR FORT WINGATE, NEW MEXICO.

layer of very hard materials as a sheet upon its surface. Very often nothing whatever is left to denote the ancient positions of the escarpment talus (see Pl. XIV).

The study of the formation of soils on rock taluses leads us naturally to another condition in which soils are developed in confused masses of rocky matter, i. e., where they form on the waste left at the close of the glacial period in the regions over which the ice has moved, or in which, though the field may have been in front of the glacier, the débris it produced has been spread. Clearly to understand the work done under the peculiar conditions of the glacial epoch, it will be well for the observer to know something of the living ice streams, as they are exhibited in Greenland, Norway, or Alaska. From the abundant studies of their action in these and other countries, it has been made plain that the first effect arising from the presence of these singular masses of solid water on the surface of any district is to strip away the soil and other incoherent deposits of its surface, the waste being sent forth beyond the limits of the field by the streams of fluid water which flow from beneath the icy sheet, or they are pushed forward as by a scraper, or conveyed in the mass of the glacier to its front and there dropped on the ground as the mass melts away. When one of these glaciers of to-day has maintained its front a considerable time in one position, we find there a heap of stones and coarse sand which has been shoved forward by the movement of the slow-going streams or carried in its mass and dropped at the ice front. The greater part of these stones are smoothed by the ice carriage, and all the matter in the moraine is entirely without vegetable growth and usually deprived of finely divided rock, such as sand of small-sized grain or mud, this much divided material having been washed away by the streams of water which flow from beneath the glacier or over its surface, these streams carrying away all but the coarser fragments of the rock (see Pls. IV, XII).

In Switzerland, and most other countries where glaciers exist, they are now slowly retreating up the valleys they occupy, with occasional interruptions in which they readvance for a short distance, so that these frontal moraines are being constantly left to the action of the soil-making agents. No sooner is the mass of stones deserted by the ice than the great army of plants invade it. First comes the skirmish line of the lichens, which, springing from light spores easily wafted through the air, seize upon the rough places along the stone. When, as is so frequently the case, these fragments have too little fine material between them to fill the interspaces, the process of soil-making is slow; it goes on as in the formation of the rocky talus before described, by the falling in of decayed bits of lichen, the blowing in of leaves, and the slow decay of the bowlders which form the mass. As the bowlders are composed of hard rocks, that by endurance have been able to withstand the violent disrupting action to which they were exposed in their journey in the ice, they break up much more slowly than the fragments formed in an ordinary talus. So gradual, indeed, is the process of decay that in the case of many of these moraines left in New England and other parts of the United States by the ice of the last glacial period, the bowlder heaps have not yet had their interspaces filled by material to the level where the plants can make use of the débris and convert it into soil. It is sometimes possible to creep down into the cavern-like recesses of these moraines and see the accumulation which is gradually filling the crevices and slowly rising to the surface of the mass. We may in such places observe that the fragments are yielding a more or less considerable amount of débris to the soil which is accumulating in the crevices. A large part of the morainal matter left by the glaciers of the ice age has in this way been brought into a state in which trees can find root between the fragments; other portions, where the erratics are large and enduring, still retain the aspect noted in Pl. xv, but in all of these the process of crevice filling is going on, and in time all such bowldery places will be forest clad.

GLACIATED SOILS.

Where, as is usually the case, the ground left bare by the retreat of the ice is occupied by occasional large stones which are extensively mingled with gravel, clay, and sand, all left compactly huddled together as they fell from the melting ice, the rocky material is very quickly converted into soil. At first, owing to the lack of vegetable matter, it will not support flowering plants, as we may see by examining the earth left bare wherever in an artificial way considerable areas of these bowldery clays are exposed, as, for instance, in pits whence materials have been taken for road repairs or in the heaps thrown out from beneath the surface beside railway cuts. Here again the lichens and mosses, because of their tiny, easily wafted seeds or spores and their small need of nutriment drawn from the earth, find foothold and prepare the way for the higher groups of plants, so that in a few years species with strong roots occupy the area and rapidly mingle organic matter with the mineral substances and produce a fertile soil. Such glacial till or bowlder clay soils commonly have a remarkable endurance to cropping, for the reason that, being largely composed of rocky fragments, the process of decay which goes on upon these bits constantly yields to plants the ashy materials they need, the very substances, indeed, which the process of cropping tends to take away from the soil. The main difficulty with soils found on the till or bowlder clay is that the material is generally rather impervious to water, and the roots of the plants are not able to penetrate the dense mass. Moreover, they are commonly filled with large bowlders, which impede the plow and are often so numerous and of such great size that it is not profitable to remove them. Yet the greater part of the tilled land of New England, Canada, northern Britain, and much of that of the northern parts of Europe has been

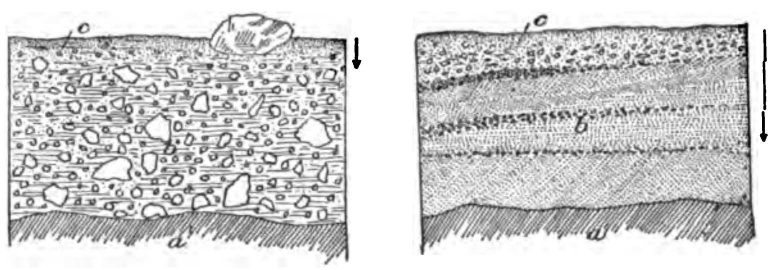
PROCESS OF DECAY OF SOFT ROCKS WHICH ARE EASILY WORN BY FLOWING WATER.

won from these bowlder-covered fields. The farmers heap the stone in great walls or upon the surface of the bare rocks; or where the erratics are too large to be readily moved they excavate a pit beside each one and so provide it with a place of burial so deep that the plow will not touch its top. In New England it is probable that more labor has been expended in this tedious task of clearing the bowlders away from the tilled ground than has been given to the construction of all the roads and farm buildings of the country (see Fig. 2 and Pl. XV).

The way in which the pebbles of a glacial soil afford nutriment to plants through their decomposition may often be clearly seen in the stubborn fields where these large erratics abound. Around the base of these bowlders, which the farmers, on account of their great size, have been compelled to leave untouched, we may often find a narrow strip of very fertile earth on which many plants requiring rich feeding flourish luxuriantly. If the bowlder, as is generally the case, is of some granitic rock, it slowly decays in the air, and every season sends down to its base a certain amount of material derived from the crystals of feldspar and mica, rich in lime, potash, soda, and other important soil ingredients; this share of fertile substances which may be shed from a stone many feet in diameter nourishes the plants which feed in the strip of earth next the stone. Each pebble in the soil is in a smaller way, but in proportion to its size and rate of decay, doing the same useful work for plants. On account of their solidity, due to the fact that only the very enduring stones survived the rough handling of the ice, they are rarely riven by the roots; some of these stones are so dense that they still carry on their surfaces the fine scratchings due to their journey in the glacier, thus showing that they have not decayed to the depth of one-fifteenth of an inch in all the time they have been exposed to the solvent action of the soil. In most districts, however, the greater part of these ice-carved fragments are so far decayed that a portion of their substance has already become food for plants, and in time they will be entirely converted to this service.

Where there is clay enough in the glacial waste to retain a share of the water which comes to the fields, and too much is not retained, the progress of soil-making is rapid. Where, however, the water either passes swiftly through the débris or can not find a passage at all the formation of a fertile layer is much more difficult and in some cases becomes impossible. In the district formerly occupied by glaciers are many fields having one or the other of these hindrances to soil-making. The washed gravels and sands deposited by the flowing waters during or just at the close of the glacial occupation of a country are often so permeable to water that they dry out immediately after a fall of rain. In this case the roots, except those of strong growing trees, can not get the humidity they need. Moreover, in the long periods of drought the vegetable matter which may have become mingled with the earth is so far exposed to atmospheric action that it can not be preserved from complete decay. Furthermore, the finely divided matter, which alone can enter into solution in the water, is constantly being borne down into the depths of the earth beyond the reach of the roots, either dissolved in the rapidly percolating water or carried along in the form of mud in the downward-setting subterranean movement. By these actions the formation of a soil is hindered, and many of these sandy areas within the old glacial region are essentially worthless for tillage. (See Fig. 2.)

Excellent instances of such soils, which are made unprofitable to agri culture by the extreme ease with which the rain water passes through



Till or bowlder clay. *Stratified drift.*

FIG. 2.—Sections showing the two common varieties of glacial detritus; *a*, bed rock; *b*, glacial detritus; *c c*, fine sand and clay brought up by ants and earthworms. The arrows show the relative permeability of the materials to water.

them, exist in many parts of North America and in Europe in the regions which lie to the south of the southern line of the glacial sheet, or which lie within the ice-occupied district in positions where sands were accumulated during the retreat of the great glacier. Thus on the islands of Marthas Vineyard and Nantucket, Massachusetts, south of the most southern line to which the glacial mass appears to have extended, there are great areas of sand plains composed of débris brought out from beneath the ice by the subglacial streams of fluid water. The great plain of Marthas Vineyard occupies an area of about 30,000 acres. The whole of this district lies in a position where it is near the great markets. It is free from bowlders, and is thus easily reduced to tillage, but it has remained since the settlement of the country essentially useless to man, and has so little value that it is not deemed worthy of taxation. The material of which this soil is composed is chemically not unsuited to the nurture of certain valuable crops, but the mass, owing to the partial lack of the finely divided materials essential to soils, is so porous, that all the rain water at once and within a few minutes after the rain has ceased to fall passes below the level occupied by the roots.

Other instances of the same nature occur in Plymouth and Bristol Counties, Massachusetts, and in the southern part of Long Island, New York, in New Jersey, as well as elsewhere, wherever the rocks worn by the glaciers have afforded large quantities of siliceous débris. Where the material yielded to the wearing action is of a limy or clayey nature these plains formed in front of the ice are often of a more compact structure, and therefore better suited to the needs of vegetation.

EARTHQUAKE FISSURE IN ARIZONA, SHOWING THE MANNER IN WHICH THESE SHOCKS MAY RUPTURE THE SURFACE.

Quite opposite conditions, those in which the water cannot penetrate the soil because of the amount of clay it contains and its exceeding compactness, lead also to an arrest in the process of soil-making. In this class of cases the roots of the plants find difficulty in penetrating the tough foundation, and so the area is generally given over to the mosses, which, owing to the spongy nature of their growth, retain yet more water, and so the area, unless steeply inclined, is reduced to the state of a swamp. Now and then some water-loving plant of the higher orders of vegetation may be able to strike its strong roots through the peaty swamp material and derive some nutriment from the surface of the clay beneath. Generally, however, they content themselves with the little mineral matter which the bog earth contains and which has been brought to it by streams which flow into the morass from the neighboring dry land.

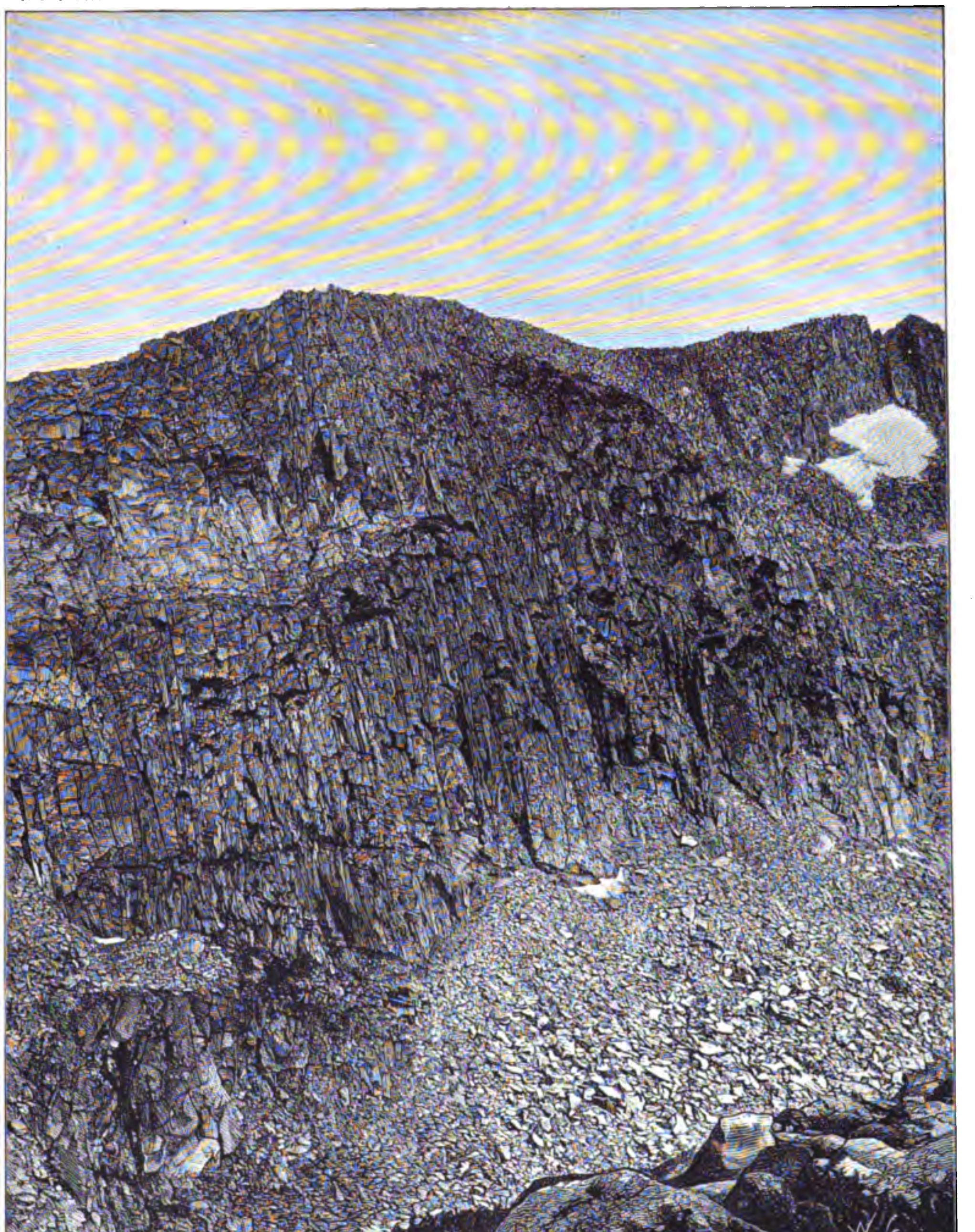
Although the conditions of soil-making in glaciated countries are difficult, the great invading armies of plants which hurried into those regions as the ice went away have in a wonderful manner subdued the stubborn fields and covered them with a coating of vegetation which is on the whole very well fitted for the uses of man. The soils of these regions have been the nurseries of our race. The Aryan folk, according to the opinion of those who have most attentively studied their unwritten history, appear to have attained their character in the glaciated districts in and about the peninsula of Norway and Sweden. Their name signifies plowman, and they were probably the first people who used this instrument on the stubborn bowlder-set fields of that part of Europe; perhaps, indeed, the first to nurture the earth with the aid of the plow. Their descendants in Scotland, northern and central England, and by far the larger part of North America which lies north of the Potomac, the Ohio, and the Missouri, have dwelt on débris of glacial origin. The soils of these once ice-ridden fields are rarely of great natural fertility, but with labor and care they generally afford a tolerably certain return to the husbandman and endure very well the tax he puts upon them.

VOLCANIC SOILS.

We now turn to the conditions which control the production of soils on rocks which have been formed on the surface of the land by volcanic action. These fields, though occupying a smaller area than those which have been deprived of their vegetable coating by glaciers, are much more widely disseminated over the earth. While the glaciated districts are confined to high latitudes and to certain elevated regions near the equator, volcanic outflows may occur in all parts of the continents, though they are usually limited to the districts which are or were at the time of the igneous activity near the sea. Although these fields covered with rock which was once molten are widely scattered and are usually of small area, some of them occupy regions of thousands of square miles in extent. In the aggregate they probably amount to near the thirtieth part of all the dry lands and include some of the most sterile as well as some of the most fruitful parts of the earth. The region about Naples and that of the volcanic district of central France and parts of the Sandwich Islands afford types of excellent soils formed on these volcanic materials; while in each of these districts, as well as in the extensive lava fields of the cordilleras of North America, other plains overlaid by lava beds are examples of the infertility which may come from volcanic action (see Pl. XXI).

The solid matter which a volcano throws out upon the surface of the earth may be in either of two states. It may assume the form of fluid lava, which flows over the surface in the manner of streams, filling and clogging the original river or torrent valleys, or, in rarer cases, covering the whole surface of the area in which the outbreak occurs with a vast sheet of molten rock; or the molten matter may be blown to fragments termed ashes by the energy of the dilating steam escaping during the eruption; these comminuted bits of lava, which solidify as they fall through the air, often cover the earth with a deep coating like fine gravel or sand. In most cases the flow of lava from a volcano is limited to a few streams which rarely in any one eruption exceed half a dozen square miles in extent; but it sometimes happens that the escape of lava is not from the tube-like orifice of an ordinary crater, but the mass of fluid will pour forth from a long rent in the earth. In this case the volume of the ejection may be vastly greater and the tide of molten matter may spread over an area of many thousand square miles. Thus in Oregon and Washington there is a district containing not less than 100,000 square miles of territory mainly covered by vast sheets of lava, the product of successive eruptions which appear to have broken forth from extended fissures. In eastern Europe, in southern India, and elsewhere there are similar districts of vast extent. In the region of the Deccan, in southern Hindostan, these sheets of lava have an aggregate depth of many thousand feet and form the elevated table land of that name (see Fig. 3 and Pl. XVII).

The comminuted lava which is blown to fragments by the explosion of the steam it contains is scattered farther than the lava flows and often covers the surface of the earth to a depth sufficient to place the original soil beyond the reach of plant roots. So widely is this ashy matter distributed and so vast is it in amount that as a means of destroying the vegetation of the earth it must be regarded as more devastating than lava flows. In the great eruptions of the volcanoes of the Malayan Archipelago which have occurred within the last 120 years the total amount of this pulverized lava which has been hurled into the air and fallen upon the land or sea may safely be estimated at not less than 100 cubic miles, or enough to cover the area of a district the size of the State of Massachusetts with a layer over 6 feet deep. It is not improbable that the total amount of this earthy matter poured forth from the



PROCESS OF DECAY IN TALUS FORMATION IN MUCH-JOINTED GRANITIC ROCK, MOUNT LYELL, SIERRA NEVADA, CALIFORNIA.

Javanese volcanoes during that time has been as much as 200 cubic miles. On the surface of the earth it is perhaps safe to say that in the average each year sees the soil destroyed or deeply buried over a region of some thousands of square miles in area by the action of these volcanic products.

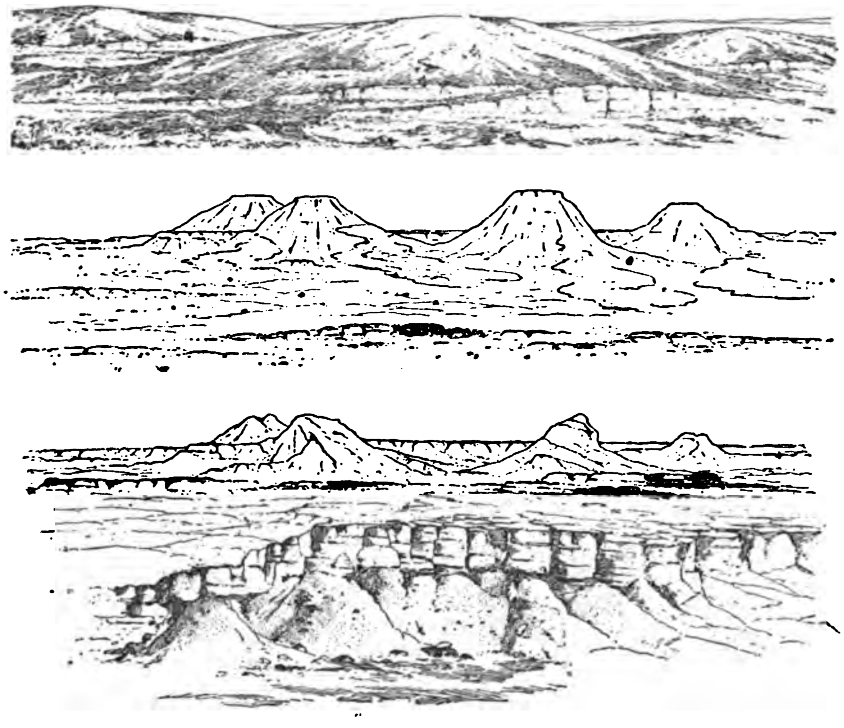


FIG. 3.—Successive states of a district where volcanoes are for a time active. The upper figure shows the supposed original state of the surface: the middle the state when the volcanoes have been long active; the lower the condition after their fires have been long extinct.

The steps by which the vegetation regains its possession of the surface covered by volcanic ejections and proceeds to remake the soil are essentially like those by which it regains its place in districts from which it was expelled by glaciation, but the details of the process vary in some interesting features. When the covering is of volcanic ashes the effect upon the vegetation depends upon the thickness of the sheet. In all parts of the field, except upon the flanks of the volcanic cone itself, this comminuted rock comes to the earth in a cooled state, having dispersed its heat in the lengthened journey through the atmosphere. In many cases the fragments are driven upward to the height of from 7 to 10 miles, and it is some hours before they find their way to the earth. Near the cone and upon its sides there are often heavy rains of heated water which effectually destroy the plants and seeds of vegetation, so that the country is completely sterilized. A little farther away these torrential rains are not so hot as to destroy life, and there we often find the old soil buried beneath the ash shower, but in other features essentially unchanged (see Pl. XIX).

It is characteristic of volcanic ash that it is generally a very light substance and the particles do not cohere with one another, at least until they are considerably changed by the agents of decay. They are like the sands which lie on seashores or in dunes. Their lightness is due to the fact that the bits enclose blebs of air, which are often so numerous that the fragments will float in water. Under the influence of rain water the ash easily slips down the steeper slopes on which it lies and much of it goes away through the rivers to the sea. That which remains, provided the average thickness be not more than 3 feet, washes down into the valleys, leaving here and there exposed patches of the original soil, with the plants, or at least their seeds, essentially unharmed. These remnants of vegetation serve as colonies, whence the organic life spreads over the sterilized fields. The process of this extension takes place at rates varying with the nature of the ash bed. Where the material is of a coarse nature, the fragments of the average size of a pea, the deposit may long resist the advance of vegetation, for rain goes through it as through a sieve and plants which depend upon their roots for sustenance find it too dry for their needs; the result is that for a time the lichens alone can maintain a place upon the ground. In most cases, however, the fragments of which these ash beds are formed are easily decomposed. Cooling rapidly from the state of fluid rock, they are often as frail as Prince Rupert drops and are broken to bits by the weight of the superincumbent materials or by the changes of temperature in the seasonal variations of heat. Moreover, their chemical nature favors decay. At first sight the material of which they are composed appears to be a dark-colored glass, but though glassy in its general character it usually contains a good deal of lime, potash, soda, and iron, substances which greatly promote the action of the agents of decay. The result is that within a score of years this ashy matter has become compact enough to retain a share of the rain water, and its materials are sufficiently decayed to fit the field it covers for the growth of a tolerably luxuriant vegetation. When the ash is more finely divided, with its particles of the size of ordinary sand, the water is sufficiently retained and in a few years the plants may do their usual work of renewing the soil-coating.

So speedy is the decay of this volcanic ash in all countries where there is a fairly abundant rainfall that the material usually cements together by the partial decay of its fragments, forming the variety of soft rock known as tuff. This consolidation goes on most rapidly where the divided matter falls into a basin containing water, as a lake or the sea, but it occurs in these cases when the material becomes sufficiently close of texture to hold rain water in a permanent manner. In any case, when the mineral matter next to the surface has been mingled with

VIEW SHOWING PROCESS OF ROCK DECAY WHERE THE MATERIAL CONTAINS SOLID PORTIONS WHICH ARE NOT READILY CORRODED.

plant mold, as always happens in rainy districts, these ash beds make good soils and some of them are of admirable fertility. The variation in their fitness for the use of plants depends on the proportion of the various substances which the lava contains. The range in this regard is very great. Some lavas are mainly composed of mineral species like silica and iron, which are relatively of little use to plants; others abound in the elements which most promote the growth of vegetation. Even from the same volcano there may be ejections which at one time afford lavas and ashes well suited for soil-making and at others produce ejections which are not well adapted for this end. In general, however, the most fertile soils of volcanic districts, and indeed some of the most productive in the world, are in these ash-covered fields. In the region about Naples, where the ashes of Vesuvius and other volcanoes of the district which at various times in the last 2,000 years have been in eruption have covered the surface to a great depth, the earth richly repays the husbandman for his labor.

In the great outbreak of Vesuvius in the year 79 of our era, a sheet of ashes covered the country over a radius of 20 miles from the crater to an average depth of probably from nine to ten feet, yet the tillage of the country seems not to have been seriously interrupted. In fact, when the ash is of a tolerably fine grain and composed of easily decomposed rock rich in mineral materials, such as are required by plants, the effect of the downfall during an eruption may be to fertilize the field upon which it comes. Looking upon the surface of a cultivated district which has just received such a shower from a neighboring volcano the appearance is that of utter ruin and desolation. The earth is smothered beneath the blackish mass of powdered rock which often levels over the walls and fences and mantles the roofs like the snow after a great winter's storm. The material seems the very image of sterility, and if it were an unprecedented visitation the people might abandon their fields in despair, but experience has taught them that a little time will return them a fruitful earth. The ashes, at first very open textured, settle down into a compact mass or are swept away by the rain, and when the sheet has settled so that it is not over a foot or so deep the farmer can by plowing or spading often begin to crop it again in the very year in which it falls. In a short time the mass may be better soil than that which was buried, for the older layer has ordinarily been somewhat exhausted by tillage. Owing to the frequent and usually thin falls of volcanic ash the region about Naples has had the fertility of its soils maintained better and at less cost to the tillers than those of most regions which are exempt from such visitations. The same is the case with the volcanic districts of the Javanese Archipelego, where these ash falls have been greater in amount than in any other known district of the world. Very few areas are thought to have been permanently made desolate by these showers of comminuted lava; even where the immediate result has been calamitous, the final result is usually not evil.

The process of soil restoration on the lava which flows from the volcanic vent over the surface of the earth is usually much slower and more ineffective than in the case of the areas covered by the layer of ashes. When the lava stream or sheet has any considerable thickness it retains a share of its heat for many years after the mass has ceased to flow; while it is cooling the plants have no chance to obtain a foothold on its surface. Long after the outer part has acquired the temperature of the air, the inner portions of the lava retain a great deal of heat; this causes every deep fissure to send forth an acid steam which is very deadly to vegetation. If the lava flow is a hundred feet in depth, as is not infrequently the case, it may be centuries before the temperature permits the sprouting of seeds upon it. The conditions of the lava surface when the mass has cooled to the point where plants can begin their work of soil-making differs greatly according to the mineralogical and chemical nature of the rock of which it is composed. In many cases, notably in the Vesuvian district, the rock is easily broken up by atmospheric action and soon becomes covered by a layer of débris. Generally the contraction of the rock, which shrinks much on cooling, leads to the formation of very numerous crevices, extending downward some distance from the surface; into these crevices and also into the irregularities of the lava plain produced by the "roping" of the lava while it flowed, the rock detritus gathers (see Pls. XX and XXI). The first plants to take a hold upon the rock are usually the lichens. Their waste, mingled with the decaying lava, soon affords the beginning of a soil in the crevices and depressions. In these vantage places the higher flowering plants find root and extend the field fitted for their needs in substantially the same manner that we have noted when they operate on a country from which the ice of a glacial period has just passed away.

The rate at which soils are formed on the surface of lava is, as above remarked, dependent on the mineral nature of the deposit, and this varies greatly in different volcanic regions, and even in the case of the same volcano in flows which occur at different times. Thus on the island of Ischia the vast flow of lava from one of the several craters which spread such wide destruction that the Syracusan colony was abandoned in the fourth century B. C., the rock has remained for more than 2,000 years but little affected by decay. Only here and there have the laborious islanders succeeded in gathering enough soil together to maintain their plantations of vines. This soil, though very scanty in amount, is of surprising fertility. Many native plants attain to such a luxuriance of growth that at first sight they often defy recognition. While these Ischian volcanoes have produced very enduring lavas which have been little changed in twenty centuries, several of the effusions from Vesuvius of comparatively recent date have decomposed with relative rapidity,

VIEW OF A MOUNTAIN VALLEY SHOWING COALESCED TALUS SLOPES THROUGH WHICH THE RIVER FINDS ITS WAY BELOW THE SURFACE.
Showing also patches of vegetation beginning to form on the face of the detritus.

forming tolerably deep soils. The rate of decay which permits the formation of soils on lavas is to a great extent determined by the rainfall of the country in which they lie. Thus, in the arid lands of the Cordilleras, the lavas of volcanoes long extinct are generally soilless, while those of the relatively well watered country of the upper Missouri, though not more ancient, have in many places produced an abundant soil.

SOILS OF NEWLY ELEVATED OCEAN BOTTOMS.

The foregoing account of the processes of soil formation on the land areas, where the accidents of frost and fire or those arising from land slides or avalanches have deprived the surface of its natural covering, shows us how swift and effective are the means whereby organic life wins its way back to the regions from which it has been rudely dispossessed. We have next to consider the rather different conditions attending the formation of soils on lands which have newly emerged from beneath the sea. The instances in which this process can be observed are rare and have never been adequately recorded. So gradual in most instances is the speed of uprising that the land gains on the sea at the rate of only a foot or two in a century and the soil gradually extends so as to cover the emerged surface. It is, however, tolerably certain that in many of these changes of level the upward movement takes place rather swiftly, so that in a few years a large area of land is left dry and thus subjected to the actions which make soils. Thus, at the close of the last glacial period a large part of the northern and eastern region of this continent, and probably the neighboring portions of Europe, were below the level of the sea, from which they emerged in an upward movement, evidently of a rapid nature. There is reason to believe that the uprising in the region along the New England coast was at the rate of as much as a hundred feet of altitude in a year,[1] the result necessarily being that a large extent of country newly won from the sea was open to the incursions of plants. To conceive the way in which they won a foothold on this surface and reduced it to the state of soil it is necessary to consider the conditions of the sea floor in the shallows next the shores of the continents, for it is mainly from such ocean bottoms that the new lands are won by the process of continental upgrowth.

The bottom of the sea next the continental shores is usually, to a great extent and to a great depth, composed of matter which has been removed from the land by rivers and waves and distributed over the bottom by the action of the tides. Along the Atlantic coast of Europe and North America this deposit forms a broad fringe of shallows the surface of which slopes gradually from the shores, generally at the rate of 5 or 10 feet of descent to the mile, until it attains a depth of about 500 feet. Then it descends rather suddenly into deep water. Along with the material swept from the land, sand and mud derived from ancient

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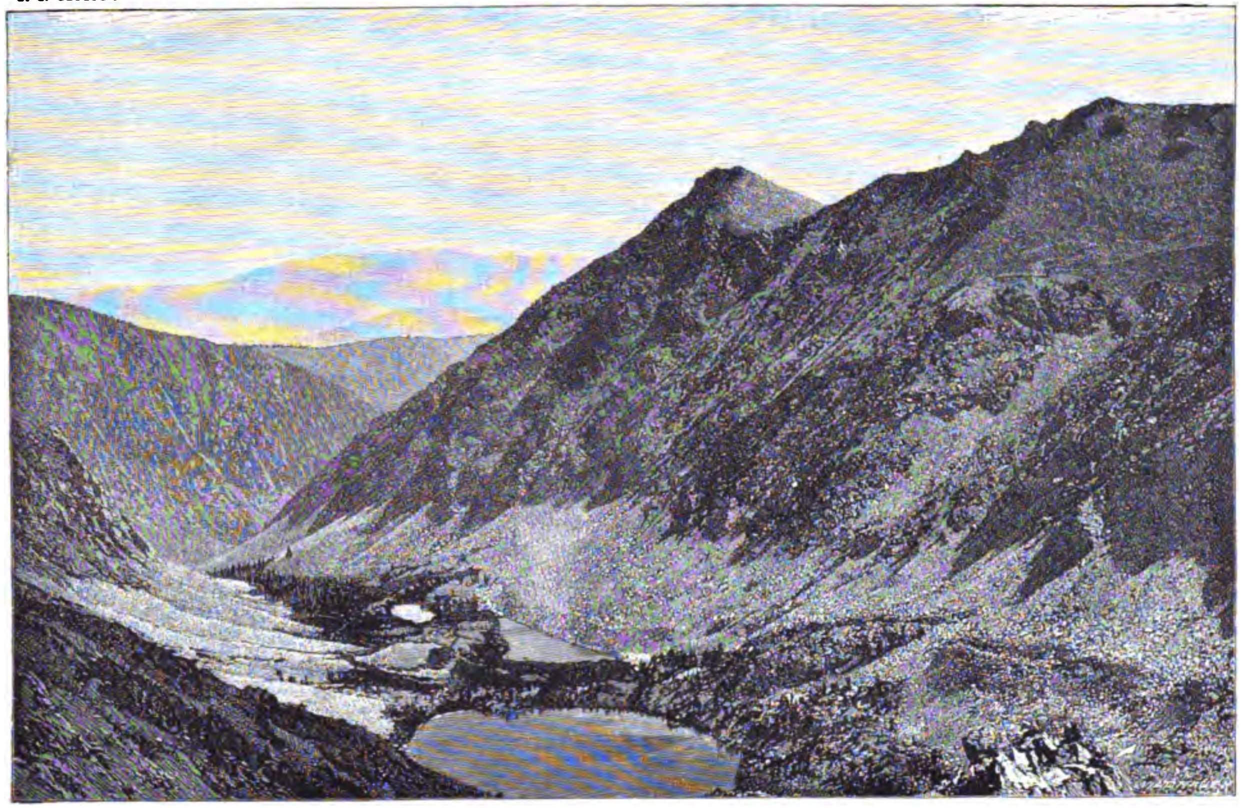
[1] See Eighth Ann. Rep. of Director of U. S. Geol. Survey, 1886-'87, p. 987 et seq.

soil which the streams have carried out from the interior of lands or waves have removed from the coast line, there is mingled a large amount of organic matter derived from the decay of animals and plants which dwell on the sea and, dying there, give their remains to the bottom. Wherever this detritus is very rich in lime, as is the case in the portions of the sea floor on which shell-fish or corals abound, the deposits are apt to consolidate as they are formed, making loose-textured limestones, generally with more or less admixture of sandy matter. Where mud prevails the resulting beds are of a clayey nature and do not commonly become more compact than ordinary brick clays. Where, as is commonly the case, the materials on the floor are mainly sandy, the strata which they build remain in an incoherent state, for it is not until they have undergone considerable changes that pure sands will firmly cohere.

In most cases all materials laid down on the sea floor have in them a mixture of ingredients well suited to the formation of tolerably fertile soils. These they derive in the main, or in most instances, altogether from the organic materials which they contain. Wherever by some chance we have had lifted into the air a portion of the ocean floor which was covered with siliceous sand, it remains for a long time sterile. Such instances of arenaceous sea bottoms are fortunately rare, and when the continental fringe or shelf rises into the atmosphere there usually is enough fertile material in the mass to support plant life, and generally the mineral matter is suited for the maintenance of a good soil. Moreover, the substances not being much consolidated, there are no such hindrances to their appropriation by plants as exists in the older and more consolidated rocks that underlie the whole earth and appear at or near the surface over the greater part of its area. Except when composed of limestone the newly emerged sea floors generally have a composition which offers no resistance to the penetration of plant roots.

We may obtain some imperfect idea of the process by which land newly risen from the sea becomes occupied by vegetation by examining the areas where the tides have been diked out from a territory which they have been accustomed to overflow, and the area of sand or mud flats thus opened to land vegetation. We note that the surface is at once seized upon by the various spore-bearing cryptogamous plants, such as the lichens and mosses, which make a whitish or yellowish crust on the surface. After a short time, when these lowly forms have made a layer of intermingled mineral and organic matter perhaps a third of an inch thick, higher species of slender and lowly habit find a lodgment, and by sending their roots a little further into the earth deepen the nascent soil. In their turn come the sturdier plants which demand more nutriment, and in the course of a few years the earth is fit for the occupancy of forest trees.

In the great plain land of the Southern States of this Union, includ-



TALUS DEPOSITS IN A MOUNTAIN GORGE WHERE THE STREAM HAS SLIGHT CUTTING POWER; LAKE CANYON, CALIFORNIA.

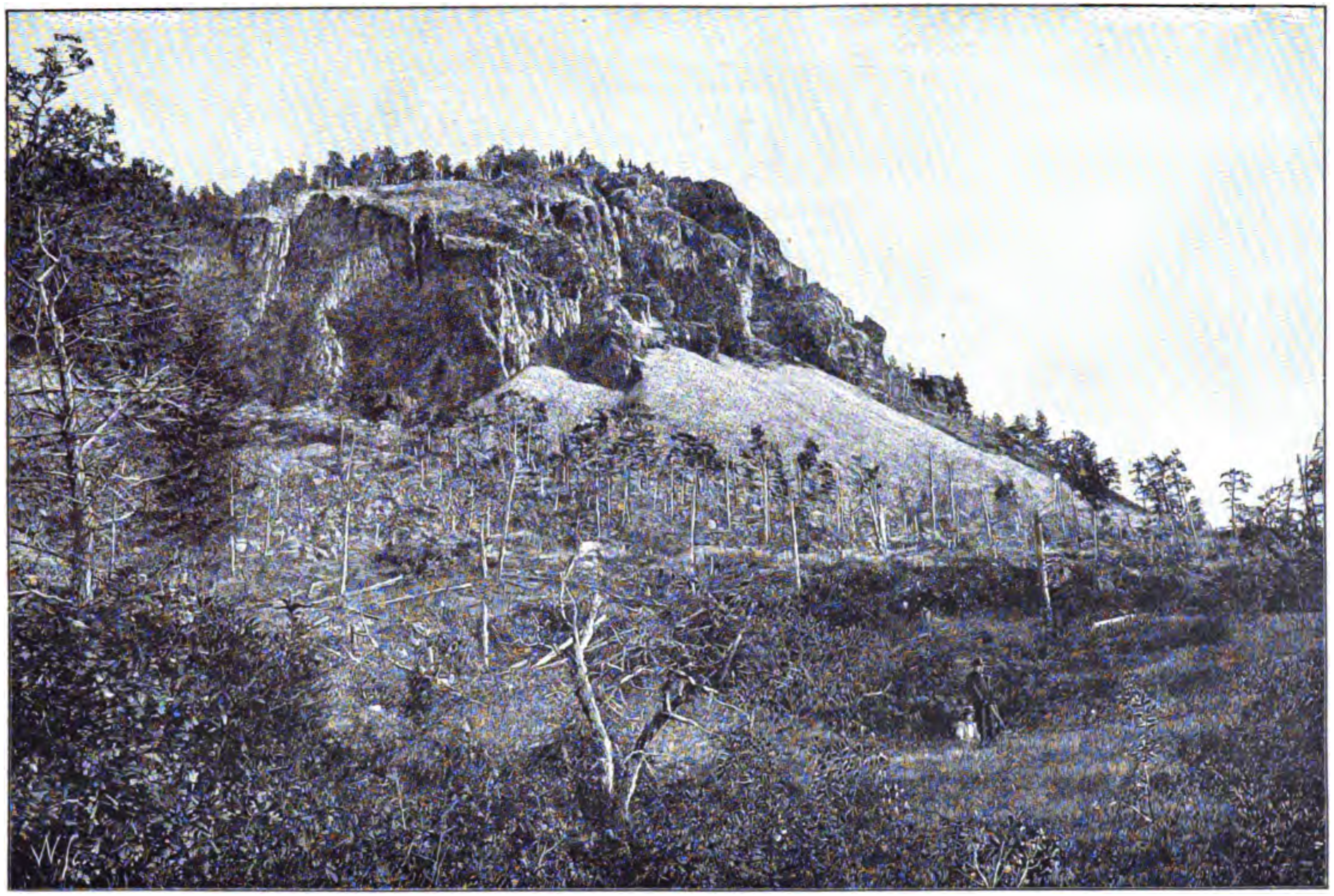
ing the eastern parts of Virginia, the Carolinas, Georgia, the whole of Florida, and the fringe of lowlands bordering the Gulf of Mexico and the Lower Mississippi, in general all the surface of the region below the level of 500 feet in altitude, we have a district in which the land has recently arisen from the waters of the ocean and become soil covered. In all the lower lying parts of this vast area, say the ground within 300 feet of the sea level, the emergence is so recent that we can still perceive that the surface usually has the peculiar gently undulating shape which is characteristic of the sea-floor. In this part of the country it is interesting to observe the process of soil-making on the different classes of materials—clays, sands, limestones, or various admixtures of these substances. We note in the first place that the soil on this district is generally thin, a fact which goes to show that unlike the deep rich earths of other and higher lying regions, it has not been a long time in the process of construction. Then we may trace the varying degree of retardation which the soil-making process has met and from the inquiry learn among other things how slight differences in the conditions of the rock may produce very important variations in the results.

One of the best places to study these southern soils is in Florida, for in that State the surface varies but little in height or in climate, and the condition of the rainfall to which it is exposed and the profound differences in soil are due mainly to variations in the nature of the underlying rock. In the region of the Keys we have that rare form of coast deposits consisting of coralline limestone; the islands being in fact ancient reefs which have been elevated to the height of 20 to 40 feet above their original position. The material of which they are made is nearly pure limestone, derived from the remains of corals and mollusks and other lime-secreting organisms which lived on the reef while it was below the level of the sea. There is in the mass a little volcanic ash brought to the region by ocean currents from remote volcanoes and a small admixture of various other substances, such as phosphorus from skeletons of fishes and crustaceans, a little potash, soda, iron, and other mineral matters taken from the sea by marine animals and plants and built as fossils into the deposits of the sea floor. The material is a very good source for a supply of the mineral elements necessary to insure fertility in a soil. The rainfall is great and the temperature is tropical, so that the vegetation, when it finds a foothold, is very luxuriant. But a large part of the surface of these reefs remains singularly destitute of soil; here and there only do we find a patch of detritus which is deep enough for ordinary tillage, and this only where the slope of the ground has preserved in a small area the accumulation of débris which has been produced over a much larger neighboring surface.

The cause of this paucity of soil in a region where we should expect to find an abundant deposit is interesting, and it leads us to discern a certain feature of the earth's history which has generally escaped attention. There can be no doubt that soil-making material of fertile quality is produced on these reefs with great rapidity. The little there is of it in the crannies and low places of the rocks bears a luxuriant foliage. What, then, is the reason for the small amount of the accumulation? The explanation is to be found in the remarkable purity and solubility of the lime rock which forms the Keys. It is evident that this rock is rapidly wearing away; it is everywhere channeled by sink-holes and caverns, and the water which flows from them is heavily charged with limy matter. The fact is, that as fast as the rock decomposes and the bits are appropriated to the soil they dissolve in the water and are returned to the sea in a state of solution. The result is, that it is impossible to keep the mineral elements in sufficient proportion in the mixture with decayed vegetable matter to form a continuous soil coating. It is only where the decomposed rock is washed from a considerable area of the surface into some cavity that a soil of ordinary thickness can be formed. If there were 10 or 20 per cent of ordinary sand in the limestone there would be a solid basis for the soil which would serve to inclose the vegetable matter, or if the region were in a moist, cool climate the slower decay of the limestone bits would still enable them to remain to nourish the plants. In such a climate in the winter season there would be no process of solution going on, and the rain water being less heated the solvent action would be much less considerable than in the summer season, but in this frostless land, where the rainfall amounts to as much as 90 inches per annum, all the bits of stone which should go to form a soil are taken into the water and borne away. We shall hereafter have occasion to note that in other limestone districts the excessive solubility of the mineral matter, as well as its occasional insolubility, may alike interfere with the formation of soils.

In the everglade country of Florida we have another type of soils which, though in part coming under the head of swamp deposits, deserve mention here, though they must be again referred to in a later section of this report. In the everglades the water on the eastern side and in the central portions of that remarkable region rises in the late summer and autumn until it forms a vast lake covering almost the whole area. When in this extended form this water absorbs a great deal of lime from the rocks which it covers. When these waters dry away in the winter and spring they leave a thin coating of limy mud intermingled with leaves on the surface of the bared earth. This, accumulating from year to year, forms a peculiarly black dense soil, rich in lime and other elements needed by plants, and therefore of remarkable fertility. Unfortunately, only a small part of this excellent soil-making material is retained on the land; the greater part escapes to the sea through the streams which drain the everglade country.

In the central and northern parts of Florida, there are extensive areas occupied by sands which have evidently been subjected to the action of strong marine currents, and in this manner have had the finer



PROCESS OF EROSION OF RATHER SOFT ROCK, THE TALUS FROM WHICH IS INVADING FOREST.

materials, such as clay, removed from them. Here the soils are very thin because the plants find little mineral nutriment. The siliceous element is, it is true, essential to plants, but they can not support themselves on that alone. In such places we find scrubby pine trees rising from an earth which bears little other vegetation. The roots of these trees strike deep into the earth and thus, occupying a large space, gather the little they need for their scanty growth; but the ordinary annual and herbaceous plants can not endure the sterile conditions. Moreover, the soil is not only lean, but the rain which falls upon it quickly percolates, carrying with it to a considerable depth nearly all the soluble material which might be useful to plants and leaving in the rainless season no water near the surface. The conditions of this region as far as its soil is concerned remind us of those which we have noted as occurring in the washed sands of the glaciated part of the world. In both we have the surface covered by porous sands which, by permitting the speedy and complete passage of the water, hinder the work of making the earth a fit place for plants.

In a large part of the southern lowlands the evils arising from the sandy nature and excessive poverty of the soil are considerable. In most districts, however, there is a sufficient admixture of clay to make it possible for the forests and lower growths to convert the mineral matter into fairly good soils. It is probable that the whole region was covered by a growth of flowering plants almost at once after its last uplifting above the sea; as yet, however, the work of soil-making is much less advanced than it is in the higher country, where the surface of the earth has been above the ocean many times as long as the southern coastal plain.

We have now considered the processes of soil formation where the surface of the earth is newly exposed to the conditions which create this covering. We shall now have to undertake a more detailed study of a typical soil with a view to acquiring a general idea of what we may term its physiology; that is, the way in which it is maintained in its essential functions and the manner in which the various processes of a geologic nature which go on within it are accomplished. In this task we shall consider little of the chemical work which is done in this stratum, for the reason that such problems for their understanding demand a good deal of technical knowledge and come rather more in the special domain of chemical than within the limits of geological science.

For the purpose of our further inquiry the reader should keep in mind the general aspect of at least two classes of soils which are familiar to most persons or may readily be seen in all parts of this country save those which have been extremely affected by glaciation, viz, those derived from the decay of the rocks which are immediately below the soil and those which have been brought into the region by rivers and deposited in alluvial plains. It is well also to know something of the aspect of the glacial and volcanic ash soils, but a sufficient idea of these may, perhaps, be gained from the figures which accompany this text.

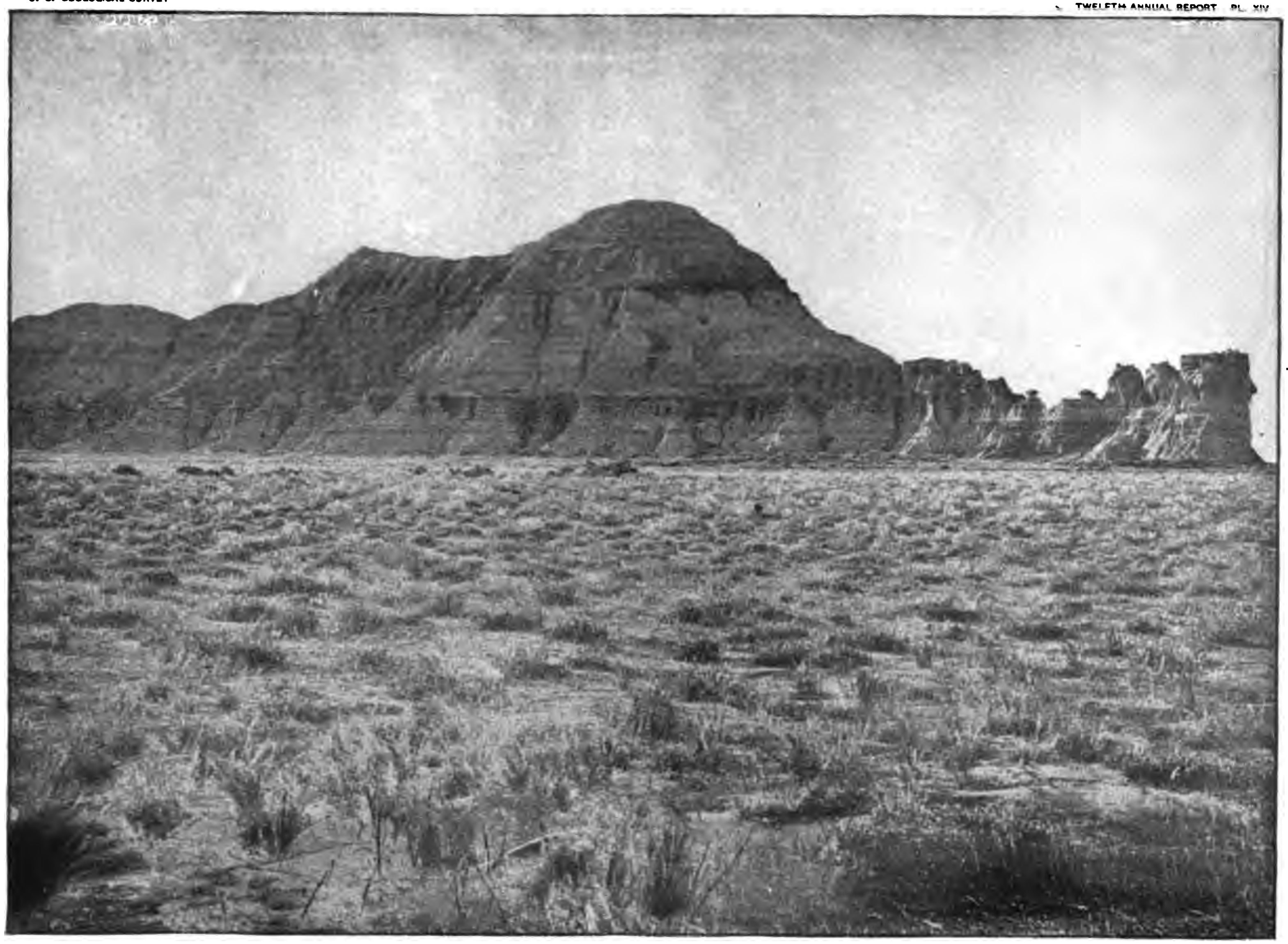
PHYSIOLOGY OF SOILS.

So far we have been considering those very general features concerning the origin and distribution of soils which we may term their physiography. We shall now proceed to examine into the details of certain processes by which soils come to serve the needs of plants, the ways in which their fertility is maintained, and in general their relations to geological actions. These inquiries should be begun upon that type of soils which occurs on the older part of the land surfaces, on those portions of the continents which for many geological periods have been above the level of the sea, for there alone can we trace in a satisfactory way the successive steps in the history of a soil. After learning the history of such a typical area we may then compare the deposit with the less normal forms, some of which we have sketched in the preceding pages.

This detailed study of the physiology of soils may best be approached through a consideration of the forces which operate in the production of such deposits. It is easily seen that all soils represent the application of a certain amount of energy, which diversely applied constitutes in the aggregate a vast sum. Soils are composed in part of rocky matter which has been broken into bits and mingled with organic matter. The stony material has been much affected by chemical agents which have produced an evident decay, and this also indicates the application of energy. The vegetable and animal waste, which is as necessary in a soil as is the mineral matter it contains, owes its existence to the special application of energy which brought the elements of the plants from the soil and the air into the combinations of life which contribute so much to the soil. We shall now inquire as to the source and methods of application of these diverse modes of action.

It does not require much observation to show us that the greater part of the forces which operate on the soil are derived from the sun. It is clearly solar heat which causes all the movements of animal and vegetable life; and all the growth of roots, stems, and leaves is evidently due to the warmth of the growing season. In our latitudes, when the sun moves away to the south, the share of its radiation to our land is so far diminished that the growth of plants is arrested and the ground is commonly frozen, so that all the operations which lead to soil-making are for the time suspended. When the great source of power rises higher in the springtime, all the machinery of organic life and chemical change in the superficial parts of the earth renews its activity. Thus the dependence of the soil upon the solar heat for all the actions connected with seasonal temperature is absolute.

Slightly more extended considerations show us that the rainfall which comes to any country is also due to the heat of the sun. The waters of



CLIFFS OF SOFT ROCK WITHOUT DISTINCT TALUS.

the sea, warmed by the rays from the solar center, ascend as vapor. Their upward movement is due to the energy which is thus applied. When these vapors attain the higher regions of the atmosphere, they are drifted by the winds, which owe their motion also to the same source of heat, and pass from the oceanic areas to the land, where, if not before precipitated, the store of moisture descends in the form of rain or snow. Falling upon the earth, this water imported from the sea becomes a part of the chain of causation which is in various ways related to the formation or destruction of soils. The rôle of actions is extended and varied, but it is easily to be understood, and it constitutes one of the most charming series of phenomena which the earth exhibits to the inquirer.

When the water which falls from the clouds comes down in the form of snow it descends gently upon the earth and accumulates in the familiar covering which winter lays upon lands outside of the torrid zone. At first and for the duration of a single season the effect of the snowfall is advantageous to the soil, for it prevents the deeper freezing which is likely to take place when the earth lacks this snow blanket. The frost which has seized upon the ground before the snow falls is melted by the heat ascending from the deeper earth. Often the warmth thus induced in the soil is sufficient to start the lesser plants into life and even to stimulate into a certain activity the roots of trees whose trunks and branches are in the cold upper air. It has often been observed that in frigid countries, where the snowfall is so deep that it does not melt away until the summer warmth is well affirmed, the small flowering plants will blossom beneath the frozen sheet. Released by the action of the snow covering from the bondage of frost, the soil is free to undergo the manifold chemical changes which are necessary to bring the mineral part of its constituents into the state in which they can serve for plant food. Thus the season of preparation of the soil for the demand which the roots make upon it is, through the action of the snow covering, very much prolonged, and the preparation of nutritious matter takes place at a time when there is little or no drain made upon it. The advantage of this condition, brought about by the snow blanket, is recognized in the adage, "Snow is the poor man's manure." In this phrase farmers have embodied their sound observation as to the effect on the open soil which the winter's mantle insures.

If the snow vanishes, as it usually does during the summer season, the effect of the accumulation is altogether beneficial. If, however, the covering is so thick that it outlasts the time of warmth, so that the layer thickens from year to year, the mass soon begins to move downward toward the sea. Even in a single winter snow which is deposited on a steep slope takes on a glacial movement and creeps toward the base of the inclination, carrying with it the loose materials which lie upon the surface. Where this action is continued and intensified the effect is, as we have already noted, the inevitable destruction of the soil. This glacial movement acts upon the earth's surface as a rasp, gradually wearing away at first the incoherent materials which lie upon the more solid ground and afterwards the firmer rocks, which it may erode to a great depth. When the ice sheet disappears it leaves the land bestrewn with débris of various kinds. The old valleys by which the rain waters were discharged are greatly changed in form, so that, as in the boreal parts of North America, the originally well drained surface is to a great extent occupied by lakes and swamps or by sandy and rocky fields, on which the soil-making processes find it difficult to accomplish their work in a way to serve the interests of higher life. The sharp contrasts between the conditions which are brought about, on the one hand by a temporary covering of snow and ice and on the other hand by the more continuous coating of a glacial sheet, affords us one of the many instances in which slight differences in the mode of natural action produce on the soil as elsewhere the widest variation in effect (see Pls. IV and XVI).

There are only a few places within the limits of the United States where glacial work on a considerable scale can now be observed, and these are all situated in the western portion of the Cordilleran region. It may therefore be worth while to note certain familiar examples of the rubbing action which even an ordinary winter's snow sheet has upon steeply inclined portions of the earth, where it lies as a thick covering. If we visit a hillside of moderate steepness at a time when a thick coating of winter's snow has just been cleared away we may note in the attitude of sticks and other dead bits of wood that the surface has been subjected to a certain amount of rubbing which has urged the fragments down the hill. Thus we not uncommonly find where a branch, fallen from a tree, has in its downward movement encountered some obstacle, such as the trunk of a tree, around which the bough has bent in the manner of a bow, the two ends being dragged some distance down the hill. Occasionally we can note where stones, sometimes as large as a man's head, have been pushed down the hill, leaving a slight groove to mark the energy with which they have been urged forward in their movement. Sometimes, though rarely, this downward movement of the winter's snow is sufficient to disrupt small stone columns which have been constructed upon steep hillsides. Thus, in the cemetery in Augusta, Maine, where the monuments have been placed on a steep hillside where the snow deeply accumulates, it has more than once happened that the slow, creeping glacial movement has broken off stout tombstones and iron fences which surround graves. This action has taken place, not in the manner of an avalanche, but with a slow motion which carried the disrupted objects only a few feet from their original position. In this way we see how, even in regions where true permanent glaciers are unknown, the snows of winter give us a very clear semblance of their action.

On the greater part of the earth the rainfall comes in the form of flood water or ordinary rain, and as such journeys downward to the sea. To understand the function of this fluid the observer should trace

MORAINAL FRONT IN EASTERN MASSACHUSETTS, SHOWING THE WAY IN WHICH VEGETATION OCCUPIES A BOWLDER-STREWN SURFACE.

its action from the place where it fell upon the earth to that where it reentered the ocean. This, at least in a general way, I shall now endeavor to do. When the drops of water strike the surface we observe that they fall with a certain amount of force; this energy is immediately due to gravitation, but it is remotely owing to the sun's heat, which uplifted the water to the clouds whence it falls. This blow of the raindrop may seem of slight importance, but it is really of great moment. If we watch any newly plowed field where it is èxposed to a heavy rain we notice that the drops cut the clods to pieces in a rapid manner. After a single shower following the work of the plow we may here and there find where a flat pebble or a potsherd has protected the earth from the assault of the descending water. Each of these sheltering bits rests upon the top of a little column of soil, which may be an inch in height. In many countries, as for instance in Colorado, where there are extensive areas of soft rock, with occasional hard patches of material contained in their beds, we find that this phenomenon is shown on a large scale, the columns often being 20 feet or more in height, each capped by the protecting stone which has preserved its pedestal from the stroke of the raindrop.

It is to the disrupting effect of this reiterated dropping of the rain that we must in the main attribute the rapid washing away of soils which are by tillage much exposed to the direct attack of storm water. If there were no natural protection against this the soils would be in a geologically brief time entirely swept away; they would indeed not now exist as a general coating, but would be limited to certain places of a swamp-like character into which the detritus from higher lying rocks would be swept by the floods. From all surfaces of evident slope the materials would be worn away. Fortunately for the economy of the earth, a nearly perfect natural protection is afforded by the coating formed by the stems, branches, and leaves of plants, which along with the débris from their bodies lying confusedly heaped upon the ground, serves to protect the earth from the direct action of the falling rain and yields the water gradually to the under earth.

As soon as the rain drops strike the surface they flow together and form a thin sheet of water; where the earth is bare of vegetation a part of the fluid quickly gathers into rills and flows away, rill joining to rill until considerable streams are formed. On plowed ground this surface water bears with it a heavy burden of the soil which it conveys away to the lower lying district and often transports to the greater rivers and thence to the sea. A large part of this loss of the soil is due to the admixture of its substance with the water under the action of the falling raindrop. In a time of heavy rain a field, if it be much inclined in its surface, will often lose on the average half an inch in depth of its soil covering by this action. On the other hand, in a forest-clad country the rain even where it descends in heavy showers forms no sheet of water upon the surface; it is all absorbed in the forest bed and thus no small rivulets result. The water sinks into the spongy coating, and in that tangle of decaying vegetation it slowly creeps down the declivities until it is gradually yielded to larger streams, trickling out along their margins from the mantle of leaves, twigs, and roots which covers the earth perhaps to the depth of 2 or 3 feet. While on a bared field there may be two or three rivulets formed in a time of heavy rain on each square yard of the surface, so that the area is quickly seamed by a labyrinth of little valleys, in a neighboring district having the same character of soil and a like inclination of surface, but covered by a virgin forest growth, we may not find an average of one stream to the square mile. This feature is illustrated in the accompanying diagrams, which are intended to indicate the contrast. While each of these water ways in the forest is occupied by a perennial brook fed from the spongy soil, stream beds on the tilled land are all dry save when the rain is actually falling (see Fig. 4).

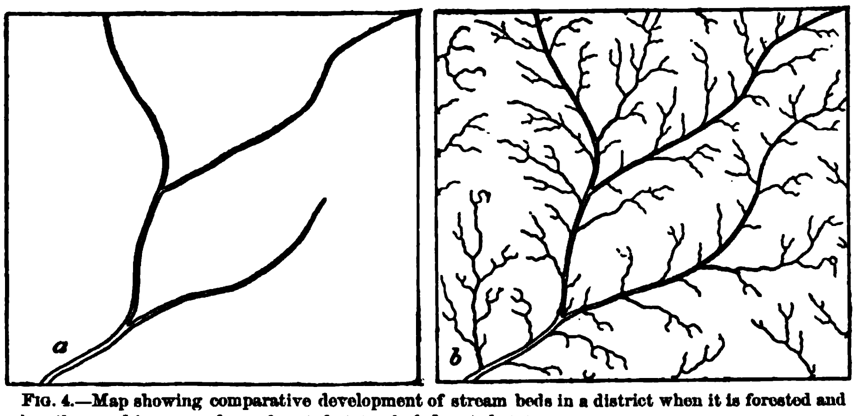


FIG. 4.—Map showing comparative development of stream beds in a district when it is forested and when the wood is removed. *a*, forested state; *b*, deforested state.

It is very evident that the difference in the amount of energy applied by the rain to the surface of the earth in these two contrasted conditions of forest-clad and bare earth is very great Creeping through the interstices of the vegetable coating, rain water may descend the mountain side through a vertical distance of thousands of feet, moving all the while so slowly that it does not apply any sensible energy to the soil covering, while if that surface be deprived of vegetation it may on account of its swift motion apply an intense erosive force to the incoherent soil.

All that part of the rainfall which flows away over the surface tends to destroy the soil coating, and, as we have seen, it effectively accomplishes this end wherever the earth is not protected by its action. This surface water, however, represents only a portion of the rainfall; the remainder enters the earth near where it falls and is thenceforth, until it is again gathered into the surface waters through the springs, mainly an agent of soil construction. The proportion of the under and surface water, or that which sinks into the ground and that which flows

DRUMLINS OR LENTICULAR HILLS IN EASTERN MASSACHUSETTS, SHOWING THE ARCHED OUTLINES OF THESE DEPOSITS.

away upon it, differs very much according to the physical characteristics of the district in which it falls. In general, the ground water is proportionately much greater in amount in those cases where the surface is forest clad than where it is tilled, for in the woods the earth never becomes baked or compact, and, held in the forest sponge, the water has ample time to penetrate the soil before it escapes to the streams, while on the bare ground it slips away rapidly toward the sea. It is a familiar observation that the soil of a tilled field, especially if it be of a clayey nature, remains quite dry in its under parts even when its surface has been seamed by a torrential rain. Where the earth is very open textured, as is the case with the washed sands of the glacial districts or of the similarly sandy and nearly soilless areas of Florida, the water, however heavy the rainfall, may all immediately penetrate the ground without flowing over its surface. Thus in the glacial sand plains of southeastern Massachusetts there are often no traces of stream beds over districts of many square miles in area. It is evident that no water has flowed over them since they were formed in the closing stages of the last ice-time, save perhaps during winter when the soil was firmly frozen. Where the soil is a dense clay, even though it be covered by primitive forests, the proportion of the water which enters the earth may not exceed one-third of the rainfall. On tilled ground the relative amounts of the under and over water varies exceedingly, in a measure determined by the character of the rainfall, whether rapid and brief or long continued and slight. When the surface is of bare rock the amount of penetrating water is always relatively small in quantity (see Fig. 2).

When the winter's snow remains on the ground throughout the frigid season and the under earth consequently passes from the frozen state which it acquired before the snow came down, the melting snows commonly yield their water to the under soil in a larger measure than is the case with other forms of rainfall. The snow when it gradually disappears commonly melts most rapidly upon its contact with the earth, so that the water retained beneath the remainder of the coating has abundant time to filter into the soil. The reader may have noticed that in the time of snow-melting the layer generally lies upon extremely wet earth, and if the soil be of a clayey nature there may be an almost continuous sheet of water upon its surface. Thus regions where the snowfall is abundant and persists into the spring-time are apt to get a thorough soaking of the earth at the time of year when abundant watering is extremely advantageous to natural as well as to tilled vegetation.

That part of the water which has entered the ground is the efficient instrument of soil-making. All other processes contributing to this end depend upon its action in an immediate and complete manner. We shall therefore have to scan the history of ground water in a somewhat careful way. When the heat of the sun takes the water of the sea into clouds in the form of vapor the fluid rises in the distilled form; it has left behind all the mineral substances which were dissolved in it and is in a nearly chemically pure state. There probably remains some trace of certain dissolved substances, but the quantity of admixture is so small as to have a scientific interest only and no economic consequence whatsoever. When the vapor is converted into rain, and possibly while it is still in the diffused form of clouds, the water is in a condition to absorb into its mass various gases for which it has a physical affinity. The measure of this capacity for taking in gases varies greatly and does not immediately concern our inquiry. It is, however, as we shall see hereafter, of the utmost consequence that among the gases which this liquid readily and in large quantities absorbs, is that combination of oxygen and carbon commonly known as carbonic acid gas (CO_2) now termed by chemists carbonic dioxide. This substance exists in all parts of the air in proportion to its weight in nearly equal parts. Thus in the atmosphere through which it passes, the rain has a chance to absorb a considerable amount of CO_2 before it touches the earth. Snowwater, because of its frozen state, probably takes in less of this gas and may enter the earth with comparatively little of the material dissolved in its mass.

When the water from the clouds, coming either in rain or snow, enters the earth, it commonly passes through a more or less extensive layer of organic material in the state of decomposition. From this layer it takes up a yet larger charge of this gas as well as of other materials which are of importance in its subsequent work. It probably gains from this layer an additional amount of ammonia and other nitrogenous substances which it had begun to acquire in its journey through the air, but it notably increases its store of carbonic dioxide. The quantity of this gas which water may contain when it finally enters the true soil is indeed surprising; it may amount to several times the bulk of the fluid.

Now on the presence of this dissolved carbonic acid gas depend some remarkable effects which water produces on the soil. The most notable influence of the CO_2 contained in the soil-water arises from the singular increase in the capacity of the fluid for taking substances into solution, which is afforded by the presence of this gas. Ordinary distilled or rainwater at the temperatures which prevail on the earth's surface has very little capacity for taking such mineral matters as abound in ordinary soils into solution; it will take up only a trace of lime carbonate or lime phosphate or of the ordinary salts of magnesia, iron and a number of other substances which must be brought into solution before they can be of use to plants. The charge of CO_2 which water may absorb before it enters the deeper part of the soil increases by some fifty-fold its capacity for dissolving lime carbonate and manifolds its absorbing power in the case of many other substances.

In passing through the layer of vegetable mold and the upper part of the true soil, in which there is much decaying organic matter as well as many living roots, the water encounters a set of conditions which are exactly fitted to provide it with this charge of carbonic dioxide. In the decay of carbonaceous matter CO_2 is generally formed in larger

ASPECT OF A SURFACE ON WHICH LIE EXTINCT VOLCANOES; ALSO SHOWING DETAILS OF TALUS STRUCTURE.

amounts than any other gas. The reader is probably familiar with the fact that wells and other pits which have been sunk through rich soil are likely to become filled with this gas, or what is commonly called fixed or irrespirable air. The presence of this gas frequently leads to the death of those who venture into such excavations without the simple precaution of testing the nature of the air by means of a lighted candle lowered into the pit. Among the many nice adjustments of the conditions of the earth to the needs of life we must reckon this arrangement by which the soil water absorbs a large part of its charge to the gas which renders it most efficient in its work through the decay of kindred forms.

It is a characteristic feature of water that its capacity for absorbing and retaining gases rapidly increases with an augmentation of the pressure upon it. This may be seen by observing the action of CO_2 in a common glass siphon charged with what is commonly called soda water. This fluid consists of ordinary water into which the above-named gas has been introduced by pressure. We note that while the fluid remains tightly inclosed, the gas is not visible; but on opening the stop-cock the gas may be seen rapidly to separate from the mass of fluid and form bubbles which rise at once to the surface. If the

FIG. 5.—Diagram showing action of soil water in excavating caverns. *a a*, layers of limestone, easily dissolved in soil water; *b b*, sink holes by which the soil water enters the cave; *c c*, vertical shafts or domes; *d d*, horizontal galleries. The arch in the middle entrance is a natural bridge or remnant of a large cave.

passage is widened the uprush of the gas will be so rapid and plentiful that a portion of water will be driven out with it. If the escape is made gradual the gas will be seen to separate bubble after bubble until the eye readily recognizes the fact that a quantity of the CO_2, amounting in bulk to several times that of the water, has escaped from the vesse without sensibly diminishing the quantity of the fluid. By this experiment it is easy to perceive how great an amount of carbonic dioxide water, under slight pressure, may contain.

When it enters the under earth and passes thence into the subjacent rock the soil water, provided it courses through limestone, excavates caverns which are so well known in many parts of this country. The soil water gathering on the surface finds its way downward through the joints of the rocks which it gradually enlarges, forming a vertical shaft or dome; thence it creeps through galleries to its place of discharge into the open-air rivers of the region in which the cave lies. At the upper entrance of the cave a funnel-like depression is formed, at the bottom of which there is a shaft which permits the downflow of the water into the chambers below. (See Fig. 5.) These pits are often very numerous and sometimes seriously interfere with the work of the farmer. If he leaves them open the beasts of his fields are often killed by falling into the caverns. If he artifically closes the shafts, water gathers in the basin, frequently overflowing considerable areas of tilled land. The general aspect of these sink holes is shown in Plate XXII.

When the ground water enters the depths of the earth it passes into a realm where, with each step of its descent below the surface, it becomes liable, especially where the soil is wet, to be more and more subjected to heat and pressure; owing to this action it is constantly enabled to increase its charge of the gases, which aid it in dissolving substances of a mineral nature. Thus when it penetrates the underlying rock, as it often does to a considerable depth, the pressure to which it is subjected, due to the column of water above it, materially increases its capacity for dissolving limestone and other rocky matter. When it flows back toward the surface the pressure is reduced—it loses a portion of the CO_2; and as it held the mineral matter by virtue of this gas and in proportion to the quantity which it contained, the dissolved substances are in part laid down near the surface of the soil. The importance of this action in bringing upward to the true soil materials of value, which plants could not obtain by means of their roots, is doubtless very great (See Fig. 6.)

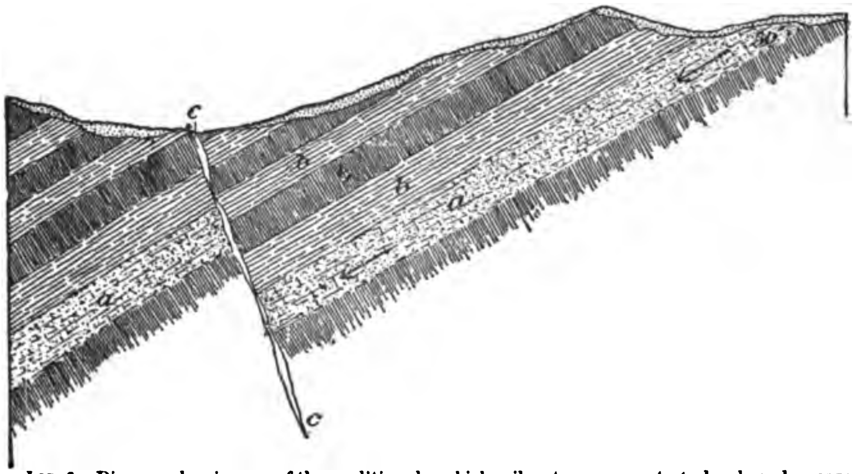


FIG. 6.—Diagram showing one of the conditions by which soil water may penetrate deeply and emerge as a hot spring. *a a*, porous bed of rock; *b b*, impervious layers; *c c*, fault.

It is to the ceaseless movements of water through the detrital coating of the earth, and the consequent solution and carriage of materials which are brought for the needs of plants into positions where the roots can feed upon them, that we owe much of the fertility of the earth. It is therefore desirable to consider another action which, combined with that just described, still further favors the process of uplifting the nutrient matter of the earth into the levels where the roots do their appropriate tasks. This uplifting effect on the ground water is brought about by the process of evaporation. When a soil is filled with water as it is after a time of heavy rain or melting snow, all the crevices of the mass

VIEW SHOWING RAPID DECAY OF LAVA.

The dead trunks in the foreground were overturned by the stream. The smooth surfaces are occupied by volcanic dust.

and the spaces between the bits of organic and mineral detritus are occupied by the solvent fluid which takes into itself a large share of the soluble matter which the neighboring earth affords. Such a time of thorough watering is apt to be followed by a season of drought in which evaporation goes on in a rapid and effective manner; the superficial portion of the soil water then passes into the state of vapor and disappears in the atmosphere. As the evaporation takes place altogether at the surface of the earth, the upper layer of soil becoming partly dry, the spaces between the grains of the material suck up the water from lower levels of the earth; this in turn evaporates and as it goes off as vapor it leaves all the mineral matter held in solution as a deposit in that part of the earth, sometimes sufficient in amount to form a crust.

It may not at first seem clear that the process of vaporizing the surface water should cause the lower lying fluid to rise to the upper level of the soil, but the action may be made perfectly clear by remembering the kindred phenomena exhibited by the wick of a lamp, which draws up the oil as rapidly as the flame consumes that part of the fluid in the upper portion of the capillary tubes formed by fibers of which the wick itself is composed. Or we may in any tree find a partial illustration of the same principle; the sap rises because the evaporation from the surface of the buds and leaves calls upon the fluid which is lower in the plant to supply the place of that which goes away as vapor, so that the whole structure becomes like a great wick in which the water is gradually drawn upward perhaps hundreds of feet above the reservoir of the soil. This analogy is satisfactory only in part, for the reason that at the extremities of the branches where growth is going on a certain movement of the sap is due to a peculiar action of cells which can not be here described, but in the body of the trunk the motion is probably caused by capillary attraction.

The energy of the attraction which the adjacent surfaces of the soil exercise upon the water may perhaps be more clearly conceived if we note the fact that if wedges of dry wood be driven into a crevice of a rock and then be wet, the water will be drawn into the interstices of the wedge with such energy that a disruptive effect will be produced so powerful that it may rive the tough stone asunder. It is in good part to this capillary process set in action by the demand which the roots make upon the soil as well as by the evaporation from its surface, that we owe the ceaseless to and fro wandering of the earth waters. These movements enable the fluid to gather into itself a great variety of substances. In its journeyings it offers the matters it has dissolved to the rootlets of plants so that they may select the materials necessary for the sustenance of the individuals to which they belong.

To this capillarity we also owe, in large part at least, the efficiency with which the soil water attacks rocks, whether those which form the massive substructure of the soil or bits which are mingled with the detrital layer. By this attraction of fine interstices of the stone water is sucked into its inner parts, taking with it the charge of CO_2 which promotes the process of decay. In this manner the soil water operates continually to break up solid parts of the earth and by the process of rotting brings them into the dissolved state from which they may pass into the realm of plant life. Thus the ground water not only acts as the intermediary between the mineral and the vegetable kingdom, but it is continually winning new materials to the state where they will serve the needs of vital processes.

It may well be noted that recent researches on the mode by which plants take in mineral matters through their roots point to the conclusion that the process of appropriation is assisted by the excretion from the underground parts of the plant of some chemical substance, the exact nature of which has not yet been determined. The true value of this assistance which the plants give in the process of taking mineral materials into solution has not yet been ascertained in a definite manner. It seems, however, safe to say that whatever be the result of further inquiry in this direction we shall still, in the main, have to attribute the fitness of the mineral material for the uses of plants to the solvent action of the carbonic dioxide contained in the water.

There is yet another physical property of water which has a great influence on its action within the realm of the under earth. This is the quality by which the materials dissolved in water are evenly distributed through the fluid. It is easy to observe that when we place any portion of a soluble substance in a vessel containing water the material distributes itself uniformly through the mass; thus, if we drop a little carmine ink into a glass of the fluid, we note that without any stirring it rapidly mingles with the mass until every part is alike colored with the dye. This diffusive action operates in the case of all substances which are really dissolved, be they fluids or gases; it acts, as we may note, through the rapid diffusion of odors more quickly in the air than it does in fluids, and more rapidly in water than in the case of other liquids.

The result of this process is that whenever ground water obtains in one part of its mass a particular material, this substance in the state of solution is gradually diffused through the adjacent earth. The process of diffusion goes on more slowly in the confined interspaces of the soil than in a mass of unobstructed water, but it nevertheless proceeds in an effective manner. In this way a small portion of the ground water which may be adjacent to mineral matter that affords the solution a substance of a nature to be useful to plants does not retain this matter in a small compass, but yields it to the neighboring fluid, and so greatly extends the chance of its coming to the roots of plants. The effect of this action is also in another way beneficial. When in contact with a particular mineral substance the ground water, but for this principle of diffusion, would take up a relatively large amount of certain chemical materials and so become poisonous to the sensitive root. If there were no influences of an equalizing kind at work the soil water would be

PROCESS OF DECAY OF OBSIDIAN OR GLASSY LAVAS NEAR MONO LAKE, CALIFORNIA.

locally so diverse in its mineral contents that the plants would not be able to obtain uniform nutrition. By the operation of the diffusive process the roots have a much better chance of doing their peculiar duty than would otherwise be afforded them.

The variations in the level of ground water have another important influence on the soil, for the reason that they bring about a constant movement of the air through the interstices of the earth. When, during a heavy rain, the openings of the débris are filled with water, the greater part of the air they contain when dry is expelled; as the fluid drains away and the water level is lowered the atmosphere is urged again into the spaces by the considerable pressure (about 14 pounds to the square inch) which it applies to the surface. Thus when the earth becomes dry the soil generally contains air to the amount of from one-tenth to one-twentieth of its mass. The next heavy rain which falls repeats the process of expelling the air, and so in succession in moist climates, many times each year, the wetting and drying of the earth pumps the atmosphere in and out of the soil coating. In this way more than the entire bulk of the earthy detritus is each season drawn into and driven out of the soil.

The effects of this action are manifold. Some of them we may profitably note. The air drawn into the soil serves to aid the roots in their process of assimilating plant food. Most vegetables can not tolerate conditions in which their roots are permanently bathed in water during the growing season. This is the case with nearly all our forest trees. A few species, like the bald cypress (*Taxodium distichum* Rich.) and the tupelo (*Nyssa uniflora*), have managed to accommodate themselves to a permanently wet earth by means of processes from their roots which give sap in those parts of their bodies a chance to obtain contact with air. These singular devices serve to show how important it is for the soil to secure the repeated visitation of the atmosphere.

Another effect of the air on the soil is to promote the process of decay in the mineral and organic matter of which it is composed. A certain amount of this change will, it is true, take place beneath the water, but in general these alterations are far less effective than when carried on in the air. Thus while vegetable matter, after life is extinguished, undergoes on the surface of the ordinary humid ground a complete decay which returns all of its matter to the state of dust or gas, the same material when buried under water only in part rots, the remainder continuing for an undetermined time in the condition of peat, lignite, or coal. The complete decay of this vegetable matter is necessary in order that the ashy material may return to the soluble state from which it can again be taken into the plants, and also in order that the carbon may combine with oxygen and form CO_2, which, dissolved in water, gives to that fluid the peculiar power of taking up mineral substances on which the utility of the soil for plants immediately depends. Moreover, were it not for this return of the carbon to the state of gas the atmosphere would soon be deprived of the material and the leaves would be unable to obtain the carbon with which they build the woody matter. Whenever the entrance or exit of the rain is so hindered that the earth does not undergo those successive wettings and dryings which characterize ordinary soils, the effect is to diminish the measure of fertility which would otherwise characterize the deposit. If the limit put upon the successive uprisings and downsinkings of the ground water be such as to keep the soil either excessively wet or dry, sterility will characterize the district thus affected, though it might be otherwise well suited for the nurture of plants.

There is possibly a third way in which the penetration of the air brought about by the alternate wetting and drying of the soil is helpful to vegetation; that is, the action of certain microscopic forms of vegetation akin to yeast plants. It is now deemed probable that some of these lowly forms separate the nitrogen from the air and combine it with potash or soda, thus forming the nitrates of those substances, of which saltpeter is a familiar example. These materials are of great value to plants as affording them nitrogen required in certain of their functions. Although this element abounds in the atmosphere, vegetation can not directly appropriate it, but can do so only through means of ammonia or combinations into which nitrogen has entered. Unless the air freely enters into the soil and is frequently changed by an enforced movement such as the variations in wetness, it seems doubtful if this process of nitrification can go on. There are possibly other ways in which these underground movements of the air affect the processes of plant life, but these which have been given are sufficient examples of its action. They may serve, moreover, to show how the methods of tillage, all of which rest upon the plan of stirring the soil, effect certain of their beneficial results. Plowing, spading, and other modes of overturning the soil are, as unlimited experience shows, essential to the growth of crops. Although these processes doubtless serve a diversity of purposes, such as destroying wild vegetation and burying organic matter which lies upon the surface, the most important effect probably consists in opening the ground in such a manner that it is penetrable by the air. The same influence is exerted in the successive tilling with plows or other tools commonly given to ground occupied by crops whose habit of growth makes such care possible.

Besides the extensive and varied work which water, in its free state, accomplishes in the soil there is a large class of effects of other sorts due to frost action, that is, to expansion by the freezing of the moisture in the soil. In all the regions where cold is great enough to congeal the ground the effects of freezing are important. At least half of the land area of the earth is more or less exposed to this action in the winter. The measure of the effect is, according to the intensity of the cold, extremely various. We find that in certain cases the earth is submitted to a freezing which may, as in the border land of the tropics,

MARGIN OF A LAVA STREAM OVERFLOWING A SOIL OCCUPIED BY VEGETATION.

amount to no more than the occasional and brief congelation of the soil to the depth of a few inches. Again it may in the frigid district about the poles cause the earth to remain permanently locked in frost to the depth of hundreds of feet below the surface, only the superficial soil thawing during the summer season. As an instance of this permanent and profound descent of the frost into the earth we may note the case of the soil at the town of Irkutsk, near lake Baikal, in northern Asia, where the freezing process has extended to the depth of over 700 feet. Not only is the depth to which the frost penetrates exceedingly diverse, but the nature of its action on soils of varied quality is likewise extremely different. It will therefore be necessary in a somewhat careful way to inspect the range of these actions which depend upon the congelation of the ground water.

When the soil water is at any temperature above the freezing point it is ceaselessly moving at rates of speed dependent mainly on the size of the interspaces in which it is contained, the successions of rains and droughts, and the steepness of the declivity on which it lies. Everywhere it is dissolving and distributing materials and yielding them to the demand of the roots. As soon as it is seized with frost all of these numerous functions at once cease to be active, the water changes all its qualities and becomes a mass as rigid as stone, perfectly inert, not only itself dead, but locking all the life of the plants in a deathlike embrace. Thus the frozen conditions mean to the soil the complete suspension of all that vast range of mechanical, chemical, and vital operations which constitute its physiology. A few of these actions we have already endeavored to trace, but the number of the operations which depend on the fluid condition of water, and which cease when it becomes solid, is vastly greater than it is possible to indicate in this sketch.

Although the effect of the soil water while frozen is to reduce the whole of the detritus to the depth to which it penetrates to an altogether inert state, the process of freezing and thawing when often repeated has a noteworthy influence on the conditions of the ground. The ways in which these effects are brought about are somewhat complicated. The process of solidification in the case of water, as in that of many other substances, is attended by the formation of crystals. Save in snowflakes these crystalline forms are not ordinarily visible in ice, but often they may be detected by pouring a thin, colored fluid upon the surface of a block of ice when it is near the melting point. The liquid will then be seen to penetrate along the planes of the crystals, thus indicating their presence, which, because of the transparency of the mass, might not otherwise be evident. The old ice of our northern rivers may in the springtime often be seen in a shattered form where it has been swept against a bank at the time when the streams break up. In such masses we may often observe the massive separate fragments, each constituting a dagger-like bit some inches in length.

Instructive examples of another effect of frost on the ground water may be seen where a sharp frost in spring or autumn comes upon wet clayey ground. The ice is often at that time developed as a thick-set mass of slender columns, which constitute a bristling coating in and on the upper part of the soil. Each of the slender bits may have a length of several inches and a diameter of a quarter of an inch or more. It often happens that we find a layer of earth and small stones which originally lay on the surface of the soil uplifted by these crowded columns to a height of several inches above their original level. With a little care the process of growth can be tolerably well observed; we perceive that separate pieces of ice begin to form between the bits of débris which cover the ground; they grow by additions to their bases due to the successive freezing of the water which the soaked earth affords as they form; they shear the earthy matter apart and rise perhaps to the height of half a foot before the morning sun arrests the process of augmentation. Owing to the open spaces between the slender shafts the ice does not hinder the cooling of the water from which they are formed as it would if the frozen mass were united in the form of a sheet.

It is a noticeable fact that the peculiar species of ice forms above described is commonly produced only in the autumn, when the ground is warm and the air cold; it occasionally though more rarely occurs in the spring, when a cold period follows one of sufficient warmth to bring up the temperature to the thawing point. The reason for this probably is that unless the soil water is moderately warm the frost penetrates the ground with such rapidity as to form a continuous ice sheet, thus arresting the growth of the uprising columns. It is interesting to note the sharp contrast between the condition of growth of this columnar soil ice and what is known as hoar frost. Hoar frost branches grow by accretions to their upper extremities from water congealed from the atmosphere; soil-column ice by additions to the lower end derived from the earth water. It is also interesting to note that this last form of ice exercises a considerable overturning effect on the superficial portions of the soil; although the action is most visible on tilled ground, it often occurs below the leaf-clad surfaces of woodlands.

The formation of ice similar to that above described but occurring in a less perfect way takes place in the interspaces of the soil as far down as frost penetrates. By this action particles of soil are slowly but violently thrust apart and ground against each other so that they are affected somewhat like grain in a mill. This process extends the commingling of mineral and organic matter and serves to make the soil material more soluble. The effect of these frost movements on the soil are not readily discernible for the reason that they go on in an invisible realm, but we can easily note a number of facts which show us something of their nature and effects. All persons who dwell in regions where the earth freezes deeply have noticed the "heaving" effect of frost upon various objects which are planted in the soil. Fence posts if their bases are not placed so deep as to be some distance below the

SUMMIT OF MOUNT VESUVIUS, SHOWING CONE OF COARSE VOLCANIC ASH LYING UPON LAVA WHICH OCCUPIES THE FOREGROUND.

zone of freezing will gradually be uplifted by the successive movements of the soil until they fall over upon the ground. They are dragged upward by adhering earth each time freezing occurs and the soil is forced to expand; when the melting time comes the thawing process, beginning at the base of the frozen section as well as at the top of the ground, releases a certain amount of débris from the frozen state and allows it to slip under the base of the post, so that when the ice is entirely melted away the timber can not return to its original position. The same action takes place in the case of stones which by natural processes may have come into the soil. The tendency of freezing is to lift them above their beds and finally to leave them on the surface of the ground. As we shall see hereafter this action of the frost is directly the reverse of that brought about by the work of plant roots and burrowing animals, which tend to remove the soil from beneath stones and to accumulate material on the surface in such fashion as to bury the masses. Where plants possess long and tapering tap-roots, such as those of red clover and many cultivated vegetables, the effect of this heaving action is often such as to throw the plant quite out of the ground. This rarely occurs to the wild species for the reason that they have adapted the shape of their roots to meet the dangers which the heaving of the soil imposes.

The expansive movement of the soil under the action of frost is in good part due to the fact that water, unlike almost all other substances, has the eminent peculiarity of expanding on becoming solid, the increase in bulk amounting to about one-tenth of the mass. On level soil the thrust which this expansion brings about causes an upward movement in the frozen mass; if the soil is frozen to the depth of 2 feet the rise of the surface may amount to half an inch or more. When the ice melts the particles of earth fall back into the place whence they had been driven. When, however, the surface has a distinct slope, as is the case with the greater part of land areas, the influence of gravity may lead to a slight movement of the expanded coating of detritus at the time of melting in the direction in which the surface inclines. When the frost passes away the fragments of which the soil is composed have been pushed apart by the ice crystals so that they are not in perfect contact with each other.

The reader has doubtless observed the peculiar softness of the ground after the frost leaves it. This open nature of the detritus is due to the fact that bits of earth after freezing do not cling to each other as they did before they were separated by the freezing action. Now, when on a slope even of moderate steepness, a soil thus made incoherent again settles into a firm mass, there results a slight movement of the débris down the slope, which, repeated often during the winter and year after year, causes the soil in frosted countries where the declivities are tolerably steep gradually to move downward toward the stream. From observations made in northern Kentucky I have determined that on a slope of 6 degrees inclination a deep clay-loam soil moved downward at the rate of about 1 foot in from 10 to 20 years. In some cases the creeping movement is probably yet more rapid, but in general it is doubtless, save on slopes of great declivity, considerably slower.

An important effect arising from this downward movement of soil is due to frost action. The amount of freezing is greatest in the upper part of the soil and diminishes as we descend. The result is that particles of detrital matter are shoved over each other in such a manner as to disrupt them. Something of the same action is brought about by the growth of roots. These processes of plants are largest and most numerous in the upper part of the soil. By their action the débris is pushed apart; when they die and decay, openings are left into which the soil again falls. Naturally this movement is most considerable in the direction of the declivity. At the foot of soil-covered hillsides we often find a brook the banks of which are formed of soil presenting newly cut faces. The freshness of these little escarpments makes it evident that the débris must be constantly pushing against the stream; were this not so, the steep faces would speedily break down and become covered with vegetation. Wherever frost operates it is a most effective agent in supplying to the streams the detritus which they convey to the alluvial plains and to the sea. To this action we may in part, at least, attribute the fact that in high latitudes the débris arising from the decay of the under rocks generally forms a thinner coating than in the regions nearer the equator.

Although the effect of frost in hastening the movement of detritus down the slope toward the streams doubtless in part accounts for the relative thinness of the soils in high latitudes, something of this feature must be attributed to the comparative slowness with which rocks decay in cold climates. In such regions the effect of vegetation on the mineral materials is limited to a relatively brief season, and for a considerably part of the year all rock decay is arrested by the frozen condition of the earth.

Not only does the action of freezing water profoundly affect the conditions of the soil in the ways above mentioned, it is also of consequence in the economy of the earth in several more remote ways of action, only one of which is of sufficient importance to demand our attention. This particular influence is brought about by the disrupting effect which freezing water exercises on the rocks into which it penetrates. An excellent example of this action may be seen in any slate quarry where the workmen set the seemingly solid blocks of stone in a position where the edges of the cleavage planes face the sky; water entering into the invisible crevices between the sheets of slate and there expanding, in the process of freezing, will usually in a single winter open the cleavage planes so that the flakes may be readily separated. On any cliff, or even on the rocky summits of mountains, the effect of this frost action may be seen in the great number of blocks of stone which the winter's frost has riven from the firm-set mass. In the upper portion of Mount

VIEW NEAR CAVES OF LURAY, VIRGINIA, SHOWING THE CHARACTER OF SURFACE IN A COUNTRY UNDERLAID BY CAVERNS.
The depression delineated in the foreground is a sink-hole or place of entrance of the cavern-making waters.

Washington, New Hampshire, where the rocks are scantily soil-covered and are thus exposed to freezing, the surface is so thickly strewn with these frost-detached masses that it is hardly possible on certain fields to obtain a sight of the unshaken bed rock.

The work of frost on masses of stone is by no means limited to that first stage of their disintegration which consists in riving them from their matrix. As fast as decay of any kind opens the structures of the masses the water penetrates into the pieces and in freezing them serves to break them into small bits. This process is not arrested until the fragments become so small that they are less in size than the finest grains of sand. Even where the rock has no distinct joints or cleavage planes into which the water can penetrate the fluid is likely to soak into the substance of the stone, and if its elements be not very firmly bound together the freezing will scale a layer of the material from the outer part and this thin sheet will readily fall to powder in subsequent processes of decay. This scaling process takes place most commonly in the case of rocks which have a rather open texture, such as is found in some forms of granite and in most sandstones; it is so powerful an agent of decay that many stones which in the tropics endure very well crumble to pieces in high latitudes. An instance of this frost effect is afforded by the so-called Cleopatra's needle, an obelisk which of recent years has been brought from the frostless land of Egypt to the climate of New York. Exposed to the open air in its new position the process of decay is going on so rapidly that before the end of the century the stone will probably be more effectively disintegrated than it had been in 2,000 years in its original location.

In several ways the disruption of rocks greatly aids the action of chemical agents of decay, which serve to bring rocky matter into the soluble state in which plants may make use of it. In general chemical forces act only upon the outside of rocky matter. As the particles of rock grow smaller the proportion of superficial area to the mass is increased, and this in a rapid ratio. Thus a cube a yard in size exposes 54 square square feet of surface; if divided into cubes of 1 foot each, the aggregate surface exposed to corrosive action is increased to 162 square feet. If it is broken into cubes of 1-inch mass, the material then presents a total surface of nearly 2,000 square feet; still further reduced to bits of one-twelfth of an inch in diameter, the exposed faces of the rock are increased until their surface is equivalent to about 20,000 square feet, or nearly half an acre in area. In the finer bits of earth, such as compose the principal part of the mineral matter contained in the more fertile soils, the total area of a cubic yard of rock which in the original massive form exposed an area of only 54 square feet to the chemical action which prepares such substances for solution in soil water, and thus for the use of plants, may be increased until it amounts to something like ten thousand times the original area. So far as frost action aids in comminuting the rock it is a beneficent agent of very great importance. The effect of freezing is naturally most conspicuous in the regions where the ancient soils have been removed by glacial action. In all the fields where the ice of the last glacial epoch has done its singular work of abrasion and has stripped away the ancient soils the expansive action of freezing water does much to help the restoration of the earth to the state where the higher plants can be fed. In the tropical and other districts beyond the action of the frost the process of soil-making lacks this aid, but there the generally increased rainfall and the absence of long-continued frozen condition of the earth which commonly attends frost action serves in part as a compensation for the absence of this rock-disrupting force (see Pl. x).

Before leaving this interesting portion of our inquiry, we should note the fact that the heaving or interstitial movement of the soil produced by freezing has an important influence on the ease with which water enters its mass. The action of gravity in the soil itself, combined with the weight of the winter's snows and that of the forest trees which generally cover fertile soils, tends to give to the earth a measure of compactness which is undesirable. By these actions the soil is often made so dense that the water does not easily penetrate it; when the frost leaves the ground, we find, as before noted, that the earthy matter is so open that it may contain a large amount of water which has found a place in the crevices formed by the heaving of the mass due to the expanding ice crystals. In this manner, in regions where the frost penetrates to a considerable depth, the soil is secured against the evils of excessive solidification. When the frost departs the ground is left in a state analogous to that which is given to it by the work of the spade or plow; the slender and weak rootlets which plants in the growing season put forth find their passage through the earth made easy, and the food-bearing water can easily range through the open-textured mass.

EFFECT OF ANIMALS AND PLANTS ON SOILS.

This division of our task concerns that part of the preparation and maintenance of soils which is effected by the plants and animals that by their habits are intimately related to the detrital coating of the earth. This group of results due to the action of organic life is to be classed as hardly second in importance to those brought about by the action of water. The influence of organic life on the soil is effected in a variety of ways, only the most important of which can be here considered. For convenience, these effects may be classed in the following groups:

First. The influence of organic species on the rocks from which the soil derives its mineral constituents.

Second. The modification of the soil through peculiarities in the life habits of animals and plants which occupy it.

Third. The contribution made to the soil by remains of the organic forms which have occupied it.

(1) The first of the above-named classes of action may for the present

be briefly dealt with for the reason that it will have to be again considered in some detail in the section of this paper concerning the relations of the soils to the underlying rocks whence in good part they are derived. Briefly, the facts are as follows, viz: The greater part of our rocks owe the measure of their fitness for producing good soils to the store of nutritive materials placed in them when they were formed on the sea floor by the creatures which inhabited its waters when they were constructed. The sediment of which these rocks are composed contain, in varying proportions, lime, phosphorus, potash, soda, and a host of combinations of these and other substances which to a great extent owe their deposition in the strata to the work of organic species which aided in accumulating the sediments.

(2) The immediate influence of living beings on the soil is exhibited in manifold ways; of these we shall first examine those due to the plants. When, as in the case of the lower forms of vegetable life, such as lichens, the individuals have no true roots, the effect of their growth upon the soil is purely secondary, i. e., it is due to the contribution they make by their death to the earth in which they grew and to the reaction brought about by the CO_2 which they contribute to the soil water. When, as is the case with the greater part of the plants which grow upon ordinary soils, roots exist which search downward into the detrital layer for their appropriate food, vegetation exercises a great mechanical effect upon the soil coating. Each root is, at the time of its beginning, a slender thread-like object, which extends itself through the interstices, between the bits of débris which compose the earth in which it grows. At first it has a very slight power of displacing the soil; when, however, it effects a lodgment in the crevices of the under earth and finds sufficient food to warrant its further growth, it rapidly increases in size and vigor of development. From a slender fiber, having a diameter of perhaps one three-hundredth of an inch, it may increase to be a foot or more in diameter, as in the case of our larger forest trees. In the process of growth the root, after it has gained a considerable thickness, energetically pushes outward; when it is even as much as half an inch in diameter it may exercise a powerful wedging action. By the larger roots of our forest trees the soil is often, in the course of a generation of growth, in a surprising manner moved to and fro. The effect of this movement is to grind the particles of soil against each other and thus to advance the work of diminishing their size and of making them more ready to pass into the state of solution (see Fig. 7).

When a growing root penetrates into a crevice in the rocks and expands in its further growth, the effect of its action in disrupting the mass may be very great. We may often find fragments of any kind of stone which affords plant food, especially those varieties of limestones of the richer sort, quite interlaced and shot through by the fibers. Where one of them finds a fissure and enters the mass it is almost certain to disrupt it in the course of growth. As fast as decay softens the stone and opens little spaces in the planes between the grains of which it is composed or along its joint planes, the small roots penetrate these fissures and break up the decayed portion of the mass, in this manner opening the inner portion to the access of chemical agents which promote decay. When the roots find their way down to the level of the bed rocks which underlie the soil, provided these strata are much divided by joints or bedding planes, divisions of extremely common occurrence in most rocks, the roots often find access to these incipient fractures in which the penetrating waters have already produced a certain amount of corrosion. Expanding in the crevice the roots which come first break

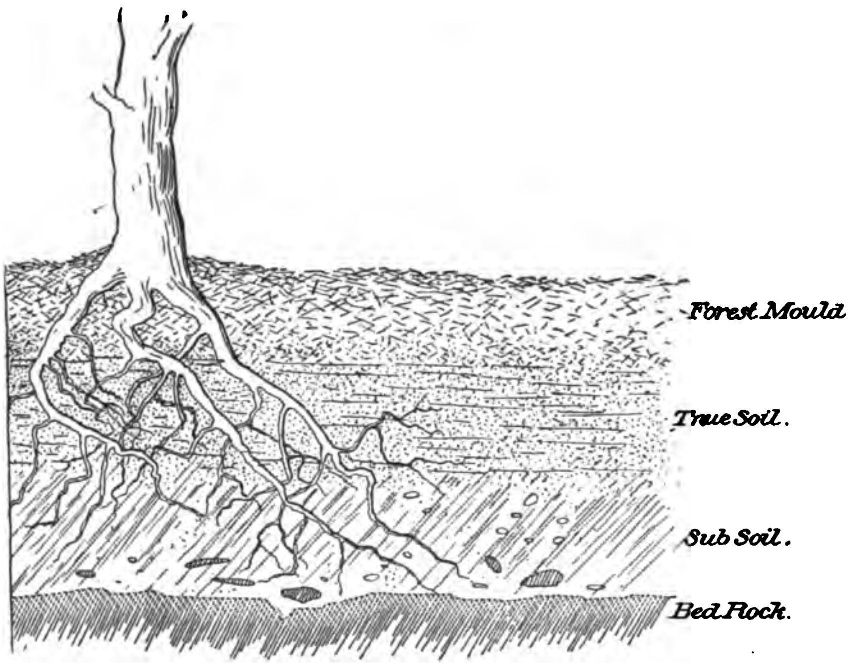


FIG. 7.—Effect of roots of trees on the formation of soil.

up the rock and open its structure so that the next which penetrate may have freer access and extend the demolition. This deep root work is mainly performed by certain forest trees, such as our walnuts, which have the habit of sending down a strong tap root which often penetrates 10 feet or more below the surface of the earth. These tap-root trees have a certain advantage in the struggle for existence, arising from the fact that they feed in depths whereunto the roots of other species do not attain, and they thus secure a field where they do not have to contend for food with a host of competitors. Where these tap-root trees grow in abundance the soil is generally deep, partly for the reason that such species flourish best on soils of this description, but in the main because they are by their habits the most potent agents which tend to disrupt the solid under rocks and give their fragments to the uses of the soil. As long as the bed rocks lie in a firm-set mass the agents which serve to rot them have little chance to do their appropriate work, for, as we have seen, the incidence of decay increases in a rapid ratio with the division of the stony matter. Serving as the roots do, incidentally, to break up the underlying rocks, they are agents operating to deepen and enrich the undersoil. They act substantially like subsoil plows.

When a district is occupied altogether by forest trees or other plants having roots which penetrate to no great depth the tendency is to divide the soil into two distinct layers, the true or upper soil and the false or under soil. The upper layer or the zone occupied by the roots exhibits that combination of decayed mineral and organic matter which we have found to be the essential elements in the construction of soil. In the lower-lying layer we have the mineral matter alone, which, while it exhibits the effects of the chemical action of the ground water, is much less easily penetrated by decay than that which is found in the true soil. The origin of this under soil is plain: its formation is due to the action of the agents of decay below the level to which the roots have penetrated; in certain common classes of rock, particularly in limestones, the chemical decay often advances downward at a much more rapid rate than the roots penetrate into the earth. We may thus have, as is the case in many parts of the country lying south of the glaciated region, very deep false or under soils, while the truly fertile layer, owing to the fact that the roots have not penetrated deeply into it, remains compact and unsuited to the uses of plants until it is artificially mingled with the vegetable waste as by subsoil plowing.

If the reader will examine any cubic foot of ordinary forest soil he will find that every part of it is occupied by the roots of trees; generally there is not a cubic inch of the mass but contains one or more of the fibers or terminal twigs of the underground branches of the tree, and often there is a branchlet of the roots in every cubic line of the mass. Many of these roots are in a way experimental; they are sent out by the plant in a reconnoitering manner to see if a particular part of the ground affords nutriment; if the search is successful they enlarge; if they fail to derive sufficient support then they die, and their organic waste is by decay added to the deposit. It is easy to observe that the open-air branches of the tree are continually dying and returning to the earth, though the plant itself may be in a flourishing condition. A similar pruning occurs in the underground branches of the roots. As these lop off, a portion of their substance decays and is absorbed by the water and yielded to other roots. It is indeed to a considerable extent to the decay of roots that the deeper part of the soil is supplied with the carbonaceous matter taken by leaves from the atmosphere in sufficient quantities to maintain the nutritive quality of the detritus. The decaying roots, when they are of considerable dimensions, serve also another curious function: as they rot away they leave open channels through the soil which sometimes extend for a distance of 30 feet or more, and occasionally, when they belong to the tap-root species, in a vertical direction for 10 or 15 feet. The compaction of the soil which is effected by the outward pushing of the root in its process of growth, especially where the earth has not been influenced by freezing, often causes these old root channels to remain open for a long time after the woody matter has dissolved away. Through these tubes the water finds a path down to the under soil, and by these means the excess of the fluid is to a certain extent removed as if by a drain pipe. In an old forest these water ways often serve the purpose of drainage in a singularly perfect manner, the water finding its way deviously but effectively from the path of one dead root to another until it escapes into an open stream.

While the roots are constantly contributing to the vegetable matter in the soil through their partial decay, the upper branches of the tree are sending down even a larger share of vegetable matter to decay in the bed of the forest mold, and at the death of the plant the whole of its substance returns to the earth. The amount of woody matter which a single forest tree of moderate size during its lifetime contributes to the earth is surprisingly great; it commonly amounts to many times the weight of the living tree at the date of its full maturity. This contribution of vegetable matter arises from the annual fall of leaves and the occasional and generally frequent dropping off of branches, and also from the exfoliated bark, which is considerable in quantity. It is safe to estimate that in the more luxuriant primitive forests, such as flourished in the Appalachian district of this country, the amount of this vegetable matter which falls to the ground each year is sufficient to make a layer of compact forest mold at least an inch thick over the area occupied by the wood. Although this process of accumulation has been going on for millions of years in the region south of the glacial belt, the sheet of decayed vegetable matter usually does not exceed a foot in depth, and even in rather moist woods, where the material is best preserved, it is rarely found more than 2 feet thick. This fact shows us that there is some process at work by which the layer of vegetable matter continually passes away from the surface of the earth.

The removal of the forest mold is accomplished by a simple chemical process. Woody matter is composed in large part of carbon, which the plants have taken from the atmosphere, where it exists in the form of CO_2. To obtain this carbon the plant breaks the gas into its elements, allowing the oxygen to go back into the air, while the carbon is built into the tissues of the plant. The lesser part of the woody matter consists of various substances, such as lime, potash, soda, iron, silex, etc., which the plant has won by its roots from the soil. The process of decay operates through a simple reversal of the chemical changes which took place in the formation of the wood. The carbon recombines with oxygen, forming once again CO_2, and the mineral substances dissolved in the rain water return to the soil and are ready to renew their work if taken up by the roots of plants. If we examine a section through the forest mold we may see every stage of this beautiful reversionary process. On the surface lie the newly fallen leaves and branches scarcely affected by decay; an inch or two lower down we find the débris which was accumulated a year ago partly rotted and breaking to pieces from decay; a little farther down we can no longer trace the original shape of the vegetable matter, and at the base of the section we observe that there is a mass of confused earthy and vegetable matter which shades downward into the true soil, where the roots do their work. It probably requires on the average not more than a score of years for the leaves and twigs entirely to pass back either into the soil or the air, so that the available matter which they contain is not long kept from the uses of life.

FIG. 8.—First effect of overturned trees in introducing vegetable matter in soils. *a*, leaf mold accumulated in pit. (See also Fig. 3.)

The intermixture of the leaf mold and the mineral matter is in part accomplished by the action of roots in the manner before described and in part by the operation of various agents which serve to bring considerable amounts of the surface accumulation into the soil. This process of inhuming organic matter is in a measure brought about through certain accidents which occur to the trees and in part by the action of various kinds of animals. When a forest tree dies by old age or disease its greater roots decay, leaving large openings extending from the surface to a considerable depth. While these cavities remain open the rains and winds bear fallen leaves and small twigs into them, and thus a certain amount of vegetable matter formed in the air enters deeply into the under earth. When a forest is overturned by a strong wind the trees, unless they be tap-root species, are commonly torn from the ground or uprooted, and thus it occurs that the soil about the base of the bole is rended away so that it lies at right angles to its original position. This mass of uprent roots is often as much as 10 feet in diameter, and contains a cubic yard or more of soil. The pit from which it has been torn is often 2 or 3 feet in depth. This cavity quickly becomes filled with vegetable waste, and as the roots decay the earth which they interlock gradually falls back upon the surface whence it came, burying, it may be, a thick layer of leaf mold to the depth of a foot or two below the surface. (See Figs. 8 and 9.) In certain parts of the country where hurricanes are of frequent occurrence the amount of vegetable waste thus buried is considerable.

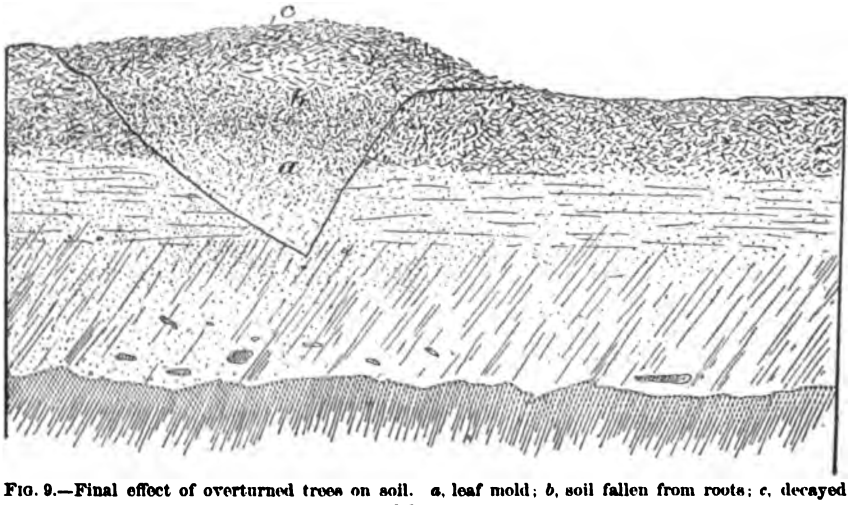


FIG. 9.—Final effect of overturned trees on soil. a, leaf mold; b, soil fallen from roots; c, decayed wood from roots.

By far the greater part of the work of mingling the waste from the aerial parts of the plant with the soil, at least on the upland districts of the earth, is accomplished by the action of animal life, particularly by that arising from the numerous species which burrow in the earth. So wide is the range of these actions that it would require a lengthy treatise to consider them in a detailed way. We can only note the influence which certain forms exert, and it will be convenient at the same time to consider some other effects accomplished by these burrowing species as well as their influence in introducing the vegetable matter into the under earth. We shall begin this study with the earthworms, a group which Charles Darwin has admirably shown is exceedingly effective in determining the conditions of the soil.

In common with many of their kindred which dwell on the sea floors these vermiform animals which inhabit the soil are accustomed to excavate burrows extending from the surface of the earth downward to a depth of 2 or 3 feet below the light of day. In their up-and-down journeying the creatures in part thrust the earth aside, but in larger measure they create the opening for the progress of their bodies by passing the soil through their alimentary canal. Taking the earth into their stomachs the process of digestion removes from it such nutriment as it may contain, while the remainder, nearly as great in bulk as that which was eaten, is thrown out as excrement. Every one is familiar with the casts or dung which these worms are in the habit of depositing on the surface of the ground near the mouth of their burrows when they for a little time escape from the earth. Each of these little heaps contains a portion of a cubic inch of soil which has been brought up from a depth of from 6 inches to 3 feet. As in single fields there are a hundred thousand or more individuals of these species to the acre, the amount of earth brought up to the level of the air is in each year considerable. In the regions where these animals abound they probably bring an annual contribution as much as one-tenth of an inch of earth from the underground to the top of the soil. There is thus laid upon the decaying vegetation or mingled with it in such a manner as to constantly bring the organic matter into the buried condition enough material from the depths of the earth to produce a slow overturning of the whole soil layer.

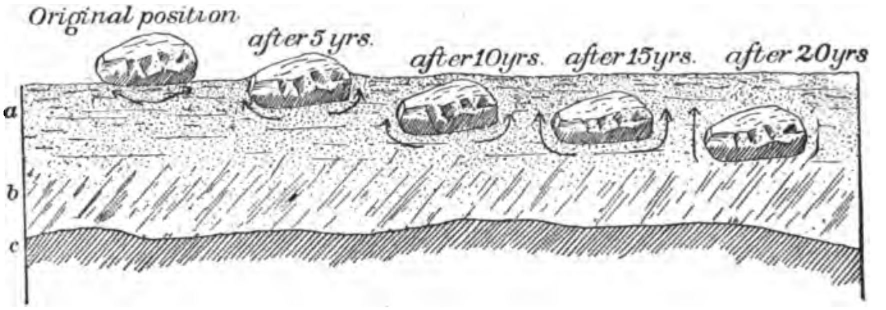


FIG. 10.—Diagram showing process by which a stone may be buried by the action of earthworms and other animals. *a*, true soil, 18 inches; *b*, subsoil; *c*, bed rock.

Although the effect of this action of the earthworms in any one season is slight, yet when continued for centuries the result is to bury all the objects of a small size which lie upon the surface to a considerable depth; ancient implements, such as stone arrow-heads which the early peoples have dropped upon the earth, are soon covered over wherever the earthworms abound. Old tombstones are gradually buried with the dust which they commemorate and even the smaller churches of England the floors of which were orginally a little above the surrounding ground, become in time so heaped about by the earth which the worms have drawn from underneath their foundations that their floors lie below the level of the soil (See Fig. 10).

The earthworms, as Mr. Darwin has admirably shown, have a singular habit of drawing down into their burrows the dead leaves which lie on the surface of the earth. In performing this work, though they are destitute of sight organs and imperfectly provided with any other kind of sensory apparatus, they exhibit a certain amount of discretion. They rarely seize on leaves which from their size or shape can not be dragged into the slender tubes which they inhabit, but they select for their use blades of grass and narrow-leaved forms, such as needles of the pines. The latter they generally lay hold of at the base where several leaves are joined together rather than at the extreme divergent point of the bunch, and in this they exhibit a certain amount of intelligence, for if they did not exercise this choice the fasicule of the blade would catch at the mouth of the burrow in such a manner that it could not be drawn downward. It is not certain what the end is which these creatures attain by this curious habit, but it undoubtedly serves to introduce a good deal of vegetable matter into the under earth.

The effect of earthworms upon the superficial detritus would be greater but for the fact that they rarely inhabit the forested parts of the country, and moreover they do not live in soils which are of a very sandy nature. The thick coating of decaying leaves in the woods evidently makes it difficult to escape to the surface in the manner which is required by their mode of life and the sandy soils contain too little nutritive matter to serve their peculiar needs. Where they do their work they are in many ways useful to the soil; besides introducing vegetable matter below the surface they greatly affect the earth by continually passing the mass through their bodies. In their stomachs they have certain hard parts which probably serve in the manner of a mill to pulverize the material. Moreover, the secretions which aid in the process of digestion operate to bring the mineral matter which they swallow into a state in which it is more readily dissolved in the ground water and thus put into the service of plants. As in the course of a century all the soil except its coarser parts is, in a field plentifully occupied by these worms, submitted to this organic process the aggregate effect on its fertility is great. The burrows which the creatures form in the earth also afford passages by means of which the water enters freely into the depths of the soil, and as this water settles down it draws in the air and so aids in that process of aeration which is favorable to the growth of plants.

The higher insects have very great influence in the development of soils, though on the whole it is less definite than that of earthworms. A large part of the multitude of species of this group of animals, particularly the beetles, for a considerable period of their life inhabit the under-earth. This subterranean condition continues while they are in the grub state, which in certain forms, as for instance in the 17-year locust, often endures for a year or more. During their tenancy of the ground they much affect its conditions by their movements and secretions. Many species of beetles while in the grub state burrow in the earth somewhat in the manner of earthworms. They devour vegetable matter and deliver the residue in their excrement to the soil; they often die under ground, and their bodies are added to the store of nutriment available for plants.

Certain groups of beetles have peculiar habits of conveying substances from the surface into their burrows where they are lodged at some depth beneath the earth. Thus the carrion species lay their eggs in the dead bodies of the smaller mammals and birds, whereby they provide for their young an opportunity for obtaining abundant food. After placing the eggs in the carrion they proceed to bury it so that it may not be consumed by other animals; the inhumation also serves to prevent the too rapid decay of the flesh. As this action goes on in forests and fields alike and in almost all countries, the soil receives a considerable amount of fertilizing materials which would otherwise be denied it.

Several species of beetles seek for the dung of the herbivorous mammals; this material they shape into balls, in which they lay their eggs. The rounded masses are often half an inch or more in diameter, and after these are shaped they are carefully and laboriously conveyed to vertical shafts which the parent insects have excavated in the earth to the depth of from 6 inches to a foot below the surface. In each of these little balls an egg is laid, the product of which is sheltered and nourished by the dung, so that the young creature is provided with a means of subsistence. A single pair of these beetles will in one season introduce into the earth several cubic inches of fertilizing material.

Although the solitary insects do a large amount of work within the soil, the principal influence exercised by this class of animals is brought about by the colonial forms, such as the ants, the ground bees and wasps, and the termites—white ants, as they are sometimes called. The greater part of the species belonging to these orders build their habitations and live the major portions of their lives in the detrital zone of the earth. They belong in nearly all lands, and are often so abundant and so active in their work that they much affect the character of soil in districts which they inhabit.

Of the forms above mentioned the ground bees are the least important. They excavate small burrows and fill their spaces with their winter stores, and a considerable part of their bodily and household waste is healthful to the plants. The shafts and galleries of their abodes, though generally protected with some skill against the entrance of water, help to provide the ways by which that fluid may enter and leave the earth. It is, however, characteristic of the bees that their colonies are never planted close together, and thus the aggregate effect of their underground life upon the soil is inconspicuous. It is otherwise with their kindred, the ants and termites, groups which often exist in amazing plenty and are found in most countries beyond the arctic circles, where the soil affords conditions which allow them to carry on their peculiar life; therefore, to this group we shall have to give somewhat special attention.

One species of social ant, the Myrmica barbata of Texas, commonly known as the "agricultural ant," appears, according to trustworthy authorities, to have the remarkable habit of clearing away the natural vegetation, or at least the slight annual undergrowth, from a bit of ground near its habitation. On this surface it plants particular species which afford nutritious grains. If the conclusions of the observers are correct, this creature is the solitary animal besides man which has invented any kind of agriculture. Singular as this habit appears to be, it is hardly more surprising than certain other customs of these curious insects. Where we find organized slavery and a well ordered system of keeping other insects, such as the aphides, which secrete nutritious juices, in well arranged dwelling places about the stems of plants on which they feed, it is hardly surprising to hear that the ants have come to a state of development in which they sow and reap. This peculiar relation of the agricultural ants to the soil is, however, limited to a small area, and is therefore without much effect on the conditions of the earth.

In general it may be said that the several species of ants dwell only where the soil is of tolerable depth and fertility and where it is at the same time of a somewhat sandy nature. They avoid the tough clay because it holds so much water as to menace the drowning of the colony. Where the soil is extremely siliceous and therefore barren, they avoid it, for in such very arenaceous districts there is a lack of sufficient food. In regions where the winter's cold is great these creatures construct their permanent habitations so that they may be lodged in chambers at a good depth below the surface, and thus be protected from the frost. In tropical countries some species of true ants, as well as the so-called white ants or termites—which are not indeed ants at all, but belong to the order Neuroptera—build their habitations altogether on the surface of the ground. Other species, such as the ordinary black ants of North America, have their dwellings partly above and partly below the surface. However varied the architectural habits of these creatures may be, and the variety in this regard is exceedingly great, they are all fashioned so as to take large amounts of earthy matter from the depths of the soil and heap it upon the surface. Thus our ordinary brown ants, which have their dwelling places entirely below the surface of the earth, may be seen after every season of rain, and to a certain extent after periods of drought, busily engaged in dragging up grains of sand from the subterranean chambers of their dwellings. This mineral matter they store about the mouth of the vertical shaft which gives access to the abode. On a field in Cambridge, Massachusetts, observations made during two summer seasons showed me that the average transfer of soil matter from the depths of the surface of the earth was in the aggregate sufficient to form a layer each year having a thickness of at least one-fifth of an inch over the area on which the observation was made, which is about 4 acres in extent.

The common species of American crawfish have, in certain parts of the country, developed a peculiar habit of boring long underground tunnels in soils which are at once of a moist and clayey nature. These openings are generally about an inch in diameter and consist of horizontal galleries occasionally extending for a distance of scores of feet and terminating at the end either in the margin of a neighboring stream or in a shaft which extends upward to the surface. These tunnels sometimes serve in a remarkably effective way to drain off the excess of soil water and permit the entrance of air into the earth—a process which, as we have heretofore seen, is of importance in the interests of plants. It seems to be commonly believed in the countries where these creatures abound that they are in some way the cause of the marshy character of the fields which they inhabit; the land they occupy is termed crawfishy and the blame for its over wet condition is laid upon the animals, although the effect of their action is often so far to remove the excessive water that the area is forest-clad instead of being a characteristic marsh.

Along the banks of the Mississippi and its tributaries, particularly those which drain into its principal affluent, the Ohio, crawfishes once abounded in great number and did good service in promoting the escape of the ground water from the clayey alluvial soil. Of late the pigs, which in this part of the country are allowed free range of the forests, have acquired the habit of feeding on these crawfish, particularly at the season of the year when they haunt the stream-beds. At such times pigs may be seen busily occupied in turning over the stones and drift wood beneath which their prey seek a refuge from their natural enemy, the water birds, but which afford no protection to these modern pursuers. The influence of this destruction of these natural drain-makers appears to be already visible in the increased wetness of many tracts of low-lying alluvial soil where trees once flourished, but where they are now dying out from excess of water.

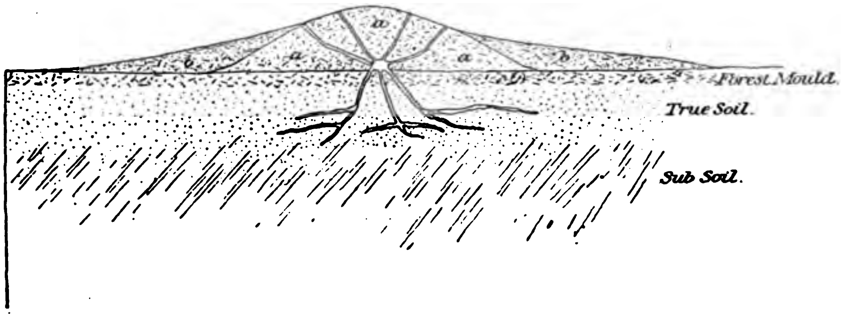


FIG. 11.—Effect of ant-hills on soil. *a a*, sand accumulated in hill; *b b*, material washed from hill, mingled with vegetable mold.

The effect of this transfer of material from the lower levels of the soil to its surface is perhaps even greater in the case of the larger species of the insects known as termites which build dwellings in part or in whole above the level of the soil. The edifices erected by the termites are often 10 or 15 feet high and a score or more feet in diameter. Although composed of earthy matter mainly taken from below the surface, the hillocks formed by our common black ants which abound in the temperate regions are not uncommonly from 18 inches to 2 feet in height and of a diameter of from 4 to 5 feet. In the case of this familiar species, the earth brought up from below becomes much intermingled with leaves and twigs which may fall upon the hills from the neighboring forest trees. (See Fig. 11.) As the mass of these hills is of very incoherent material, it is subject to a constant washing from the rain water, and so the material is gradually distributed over a wide circle about the elevation. In some cases the sand accumulated in the hill amounts to as much as 2 cubic yards in volume and when distributed by the water it is of considerable thickness over a radius of 5 or 6 feet from the center of the hill. Where these structures are numerous, as they are in certain districts in the United States, by their constant deposit of matter on the surface of the ground they bury a good deal of vegetable waste in the soil; at the same time the animals are constantly conveying into the earth large quantities of organic matter which serves them as food and the waste of this, including the excreta of the animals themselves, is of considerable importance in the refreshment of the soil.

One of the most curious effects arising from the interference of the ants with the original conditions of the soil consists in the separation of the finer detritus from the coarse mineral elements of the detrital layer. I long ago had occasion to observe that in certain parts of New England, where the sandy soils had not for a long time been exposed to the plow or agents of tillage, certain fields were covered to the depth of some inches by a fine sand without pebbles larger than the head of a pin, while the deeper parts of the section, say below the level of a foot in depth, were for a foot or so further down mainly composed of pebbles of various sizes with little finer material among them. This distribution of materials was not to be explained by the supposition that the original deposition led to the peculiar arrangement. It was easy to see that the ancient order of the deposits must have been disturbed by tillage, but it was clearly accounted for by the action of the ants. These creatures to the number of tens of thousands on an acre are during each season of activity industriously occupied in bringing the fine sands and tiniest pebbles to the surface, thus taking away small movable bits from among the coarser pebbles which they could not manage to move. It is evident that this process would in the course of a century bring about just such an arrangement of the fragmental matter as we need to account for. (See Fig. 2.)

In general, the work of ants in the sandy soils resembles that of earthworms in the clayey ground; both these groups of animals serve to bring lower parts of the soil to the surface where it is more rapidly subjected to the decay brought about by atmospheric action. As it is fine materials which are best fitted for the duties of nourishing plants, it is an advantage to the plants to have them brought near the top of the ground, where the roots of ordinary vegetation may seize upon them. In the work of the ants, however, we do not have that peculiar effect due to the characteristic habit of the earthworm, which takes the soil into its digestive ducts. Nevertheless, because they are much more widespread than their lower kindred, these insects in the aggregate produce a far greater influence on the soils.

Among vertebrated animals are a hundred species or more which by their habits modify soil conditions. Although the number of kinds in the backboned group of animals which occupy the soil is probably not the fiftieth part as numerous as the list of insects which live for a time or altogether in the realm of the under-earth, and the number of individuals is, it may be, not a ten-thousandth part as great, yet owing to their relatively large size, the ground-haunting vertebrates exercise an influence on the soils which is perhaps quite as great as that of all their lower kindred. This work of the vertebrates is effected in a great variety of ways: by burrowing in the earth, by storing vegetable matter underground, by overturning the surface of the soil in a search for food, and incidentally by the contribution of their excreta during life and their bodies after death, they greatly affect the conditions of the earth.

Some of the reptiles have the habit of boring in the earth, but their excavations as compared with those made either by the insects or mammals are of small importance. The most considerable work is done by the various species of tortoises, which generally have the habit of going under ground for winter quarters, and also to a certain extent in their search for food, such as grubs. The large tortoise of the southern part of the United States, commonly known as the gopher, makes considerable excavations, the exact purpose of which are not well known, though they are accomplished with much labor. All of our serpents find in the winter a refuge under ground, and although this is generally in some decayed root or beneath a sheltering stone, the effect on the earth is of some importance, because they frequently perish in their winter retreat.

A number of species of birds have the habit of burrowing to a certain extent in the earth. A great part of these, however, use the earth only as a place of shelter in their nesting time. The prairie owls, commonly credited with the habit of burrowing, appear usually to usurp the excavations formed by the so-called prairie dogs. It is not likely that the owls have any share in the formation of the excavation which they frequently inhabit. The bank swallows usually build their nests in a layer below the level of the true soil in places where a stream has exposed a steep face of the earth. The excrement of the parent birds and of the young contributes a considerable amount of material to the earth in which they dwell, and this store of nutriment may be sought by the roots of the trees which grow in the superincumbent soil.

It is, however, only where the birds resort to some districts for breeding purposes that they considerably influence the character of the soil. When, a few decades ago, the passenger pigeons existed in the Mississippi Valley in very great numbers, they had the habit of nesting in a gregarious manner, millions of them occupying the same tract of wood. This area of timber they possessed for 2 or 3 months while they reared their young. Feeding through the forests over a wide range of country, and often extending their search for food for 20 or more miles in every direction from their roost, these swift winged creatures, able to fly at a speed of 60 or 80 miles an hour, supplied their young with food conveyed in their crop and spent the night at the nesting place. The quantity of the excrement voided by these birds on the ground beneath the trees in which they nested was very great; at the end of the season it often formed a layer of guano-like material over a district perhaps a thousand or more acres in extent. The result of this action was after a few years to provide the under earth with an important store of plant food; at times the quantity of this material was so great as to destroy the lesser vegetation by the manurial salts which, although of utmost value to plants, can not be tolerated by them in excessive quantity.

Where these birds resort in great numbers to a shore for breeding they are sure to contribute a large amount of plant food to the soil. If the rookery be thinly occupied, as is generally the case with the eider duck and some other water fowl, the sufficient but not excessive manuring may produce a rank vegetation which shows that the soil has a profit from the contribution; on the other hand, if the birds be crowded together, the quantity of dung is generally so great as to destroy all vegetable life. When the breeding place is in an arid country, such as that wherein lie the guano islands of the Pacific Ocean or the Caribbean Sea, the accumulation of organic waste, dung, dead birds, egg-shells, etc., is so great in quantity that it can not be in any degree absorbed into the soil, but slowly accumulates and forms a coating which may in time attain the depth of scores of feet. Although this deposit can not in its pure state sustain any vegetable life whatever, it affords in the guano of commerce the very best material for refreshing soils which has been worn by tillage or for stimulating plants to very swift growth.

Of all the vertebrate animals the mammals are the most effective in their influence on the soil. Some hundreds of species have the habit of burrowing in the earth and most of these forms spend a portion of their lives under ground. It would require too much space to trace the extended variations of this habit in different species: we shall therefore only note its effects in the case of a few of our American forms. The larger part of our burrowing mammals belong in the two groups of moles and rodents or gnawing animals. Of these the moles are most interesting, because of their peculiar ways and the consequences of their underground habits. The moles include the only mammals which have adopted a purely underground habit of life and which, although they occasionally come to the surface, are not compelled to emerge from the ground for any organic purpose. They dwell for the most part in the upper layer of the soil where they subsist mainly on insects. They are accustomed to seek their food by extensive journeys through this superficial portion of the earth which can easily be displaced by a burrowing motion. They find their movements easiest and most profitable in the layer of soil which lies just beneath the roots of the grass and other lowly vegetation, for there they can make their way partially by pushing the earth behind them by the movements of their short stout legs and partly by uplifting the surface in the familiar ridges which to the eye mark the paths they follow. A single mole will in one season break some hundred feet of these ways beneath the sod. Where they find an abundance of food they will form a network of open passages, so that the solidity of the earth is materially affected by their action. Between these selected feeding grounds, in which they wander deviously, they form longer and straighter passages, utilized year after year in their journeys to and from their regular haunts.

The effect of the movement of moles through the soil is to stir the upper part of the layer somewhat in the manner in which this is effected by the plow or spade. Sometimes for a season this action appears to harm the plants whose roots are near the surface, yet on the whole the delving work done by these creatures appears to be eminently profitable to growth. It stirs the soil about the roots and favors the entrance of the air.

There is, however, another effect from the mole burrows which is not so advantageous. We have already noticed the protective action of vegetation which serves to greatly diminish the erosion accomplished by rain water upon the incoherent matter of the soil. The mat of superficial roots and the coating of decaying vegetation makes it difficult for the water to gather into distinct streams and yields the fluid gradually to the large brooks. When a mole burrows beneath the layer of mold, or the roots of the sward descend a steep incline, the water is likely to enlarge the channel so that it becomes open to the day and may develop into a deep ravine. In this manner the moles in certain districts favor the degradation of the soil coating and their action in this regard is often extensive and important. Owing, however, to the large part which these creatures play in the destruction of insects that prey upon the roots of plants, as well as to their activities in stirring the soil and opening it to the air, their general influence must be regarded as beneficial.

The greater part of the rodents—an order which includes more species than any other order of mammals—to a greater or less extent dwell underground; by far the greater portion of these, however, unlike the moles, derive their subsistence from the overground vegetation or from the roots of plants, resorting to the earth mainly for protection from their enemies or from the winter's cold. Some of these, as for instance certain species of field mice, dwell almost altogether beneath the surface, resorting to the open air only for such food as the plant roots fail to afford them; others, such as the hedgehog, habitually resort to their burrows in summer only for sleep, although in winter they occupy them during a period of some months. In certain parts of the country, notably in regions where weasels and other small predaceous mammals are absent or rare, the species of field mice exists in amazing plenty. Thus on the island of Marthas Vineyard, Massachusetts, the wild mice are so abundant that brushwood areas, often acres in extent, are completely honeycombed by their burrows, and many species of plants whose bark affords nutritious food in winter are almost extirpated by their attacks. All these species of rodents which dig underground shelters have a notable influence on the soil; they drag out the earth which fills those places and heap it at the mouth of the openings, and in this way they turn over a great deal of the soil and mingle the vegetable matter with the mineral material. A burrow affords an easy and extensive passage for rain water, and when the occupant deserts it it becomes filled with decayed leaves and other vegetable waste, and thereby much organic matter is mingled with the earth.

The underground habits of field mice serve to hide the measure of their activities from even the observant eye. A good conception as to their numbers and the extent to which they may affect the earth may be formed by a simple observation which can readily be made in any region where the snow accumulates in considerable drifts. It is the habit of these creatures to resort to the surface of the earth beneath the snow banks, especially where these accumulations lie upon grassy ground. Gathering to the number of hundreds in these parts of the surface where they are well sheltered from the cold by the thick nonconductive covering, they construct an amazing tangle of burrows cut in the sod and roofed by the snow. These excavations seem to be made in a certain order, mainly to procure the food which the roots of the plants afford. In certain places, particularly in the Berkshire Hills of Massachusetts, I have observed that, in addition to the narrow runways, each wide enough for the admission of one individual, they also make considerable clearings, sometimes as much as a foot across, which seem to serve as assembling places, where, crowded together, they may indulge their social instincts and perhaps help each other by their mutual warmth. Where field mice are abundant the skillful observer may with a little care in removing the superficial coating of vegetation disclose the burrows thus formed. These usually lie in the upper 6 inches of the earth, and are often so abundant that over extensive fields no square foot can be found which is not intersected by them.

All the species of wild pigs have the habit of uprooting the upper part of the soil layer in their search for seeds, nutritious roots, and grubs. Where these pachyderms abound they turn over the top soil often to the depth of several inches in a singular way, and by so doing they mingle decayed vegetation with earth. One individual of this group will in a year turn over an acre or more of any ground which tempts him to exercise his strength upon it. Various other mammals and some birds also have the habit of scratching or pawing the earth to obtain food. Some species wallow in the mud or in dry soil, seeking thereby to kill the insects which infest them. Various forms of the larger herbivora have the habit of resorting to dry ground, which they toss up into the air with their feet so as to dust their bodies with the powder. The stamping grounds of the ancient bison or buffalo of this continent were once frequent and conspicuous features in the regions which they inhabited, and the beasts can still be traced, even in Kentucky, from which they were driven more than a century ago, in the fields thick set with the curious ragged pits long ago excavated.

While we are considering the beneficial effects upon the soil brought about by animals which have the habit of conveying fertilizing matter to the earth or of overturning it, we may note the partly injurious influence which the beaver exercises in the country where it abounds through its curious custom of building dams across streams. When this continent was in its primitive state these rodents, the largest of their kind, occupied with their habitations the valley of almost every small stream of tolerably gentle declivity. At each of these beaver lodges there was a barrier or dam a few feet high which they constructed across the brook. This held back the waters of the pond, which had an area ranging from a few square rods to many acres in extent. On the line of a brook these dams were often placed one above the other in tolerably close order to the number of dozens. The result was that a great deal of the level land near the water ways was inundated when the white man came to the country. Until these creatures were extirpated or driven to seek secluded places by the incessant pursuit of hunters and so were forced to give up the habit of dam-building and until the structures which they had erected had been removed by decay or by the hand of man, it was almost impossible to journey through many valleys which are now moderately dry. The influence of the dam-building habit of the beaver was not altogether prejudicial to the soil, for the reason that while the swampy places they created were unfavorable to soil-making, they served to restrain the descent of the flood waters, and thus in a measure spared the greater rivers the inundations to which they were subjected after these industrious creatures were expelled; moreover, their reservoirs served to retain the soil materials brought down by the mountain torrents and thus diminished the waste of the precious material to the sea.

All the vertebrate animals of the land when they die leave the precious store of nutriment contained in their bodies as a heritage which is sooner or later to come to the soil; in the greater number of cases this waste immediately goes to satisfy the hunger of other wild animals, but the smaller forms are generally buried by the carrion beetles and the bones of all are left to decay on or in the ground. In time these hard parts are dissolved by the water and conveyed to the roots. The quantity of nutritious bone dust which is thus contributed to the earth is, when measured in terms of geologic time, very great. If all the skeletons of vertebrates which have thus gone into the soil since the close of the last glacial period had remained upon the surface they would probably cover the land with a layer of bony matter some feet in depth, but the return of this material is so rapid and constant, that it is rare that the observer remarks the presence of bones in the wilderness places.

Before leaving these considerations as to the effect of organic life on the soil, we must study the action of certain peculiar groups of lowly creatures known as bacteria, forms which are classed as of a vegetable nature and which are in general somewhat related to the ferment of common yeast. It is only of late that naturalists have begun to investigate the members of this group, for they are among the least visible things of the world; yet it is already determined that they play a very large part in the life and death processes of organic bodies. It is now known that they are the cause of most malignant diseases; they are also active in the process of digestion. Recently their operations in the physiology of the soil has received some attention; it has been found that they exercise an important influence on its economy. Thus the processes by which the nitrates of potash and soda are formed in the soil is believed to be due to the action of bacteria. The precise chemistry of the action is not yet well understood, but this is not a part of our inquiry. The result is of the utmost importance to the soil processes, for the fertility of the latter depends upon it to a considerable extent. In regions of ordinarily abundant rainfall these nitrates, being very soluble in water, are rapidly removed from the soil. While the solution is passing by the roots of plants the nitrogenous matter is seized upon and the rest escapes through the streams or else, by decomposition, is returned to the air. When, as in the arid lands of southern Peru and certain other parts of the world, the rainfall is only enough to nourish these creatures and not sufficient to leach away the nitrates, they accumulate and form a deposit so large in quantity as to be of great economic importance. Like other materials we have mentioned, which in small quantities are very helpful to plants, but in excessive proportions are very hurtful, these nitrates destroy the fitness of the area where they abound for the ordinary uses of vegetation. These nitrous soils are the source whence are derived the salts required in the manufacture of gunpowder as well as in many other important arts.

The supposed influence of the microbes in the production of nitrous soils is a matter of great interest, for the reason that thus far no other explanation as to the ways in which the nitrogen of the atmosphere can be brought into this form has been found. Should it be clearly proved that this important action is due to organic life, it will add greatly to our conception of its work in the processes of the earth.

In this further discussion of the soil problems it will be necessary somewhat to repeat the discussion of certain points which have previously been considered. As the points of view are different from those taken before, it will be better to restate some of the facts here than to refer the reader to the previous sections of this essay.

We have now considered, at least in a general way, the effect of animals other than men on the formation and preservation of soils. Our own species has in its civilized condition invented a set of relations with the earth the like of which do not exist in the case of any other being. It will, however, be well for us to consider the effect of human agencies on the soil coating after we have completed our study as to the geological phenomena which influence it. In this domain of our inquiry which now concerns us there remain for presentation the conditions dependent on the passage of water through the soil and those arising from the varied nature of the rocks from which the mineral elements of that coating have been derived. We have also to note the diversity and character of the earth due to the extent to which the materials of which it is composed have been derived from rocks immediately underlying the particular area or have been, as is the case with alluvial deposits, brought from a distance by the action of various transportative agents. These questions will form the subject-matter of the next chapter, and will complete our rapid study of the general physiology of soil deposits. It should here be noticed that so far our inquiry has concerned only soils whose mineral parts are directly derived from rocks which lie beneath a given area. We have now to consider certain classes of soil deposits which are of a different origin.

EFFECT OF CERTAIN GEOLOGIC CONDITIONS ON SOILS.

When the soils of a country outside of the glaciated districts lie upon bed rocks of gentle slope the mineral materials of which they are composed have generally been derived from deposits immediately beneath the surface. Although a considerable part of the soils of the earth belong to this group of accumulations of nearly horizontal attitude and therefore of immediate derivation, the larger part of them are more or less affected by the presence of substances imported from a distance, and probably much more than half the total soil areas of the earth have their mineral detritus composed of materials which have journeyed from afar and so may be classed as deposits of remote derivation. In this class come all the glacial soils the mineral matters of which have always been conveyed from a considerable distance. Here we must also place the whole group of soils which have been formed by the floods of rivers bringing sediments from the torrent portion of their drainage systems to the lower part of the valleys in which they lie. All this transportation, except the small amount which is affected by winds, is substantially due to the action of water either in its frozen or fluid form descending from the highlands to the sea. This carriage of soil detritus is accomplished by the action of solar energy, which is applied in the form of heat in the manner already traced. In most cases this carriage is effected by fluid water, but it is sometimes brought about by glacial ice.

GLACIAL AGGREGATION.

When the transportation of rock detritus is brought about by ice and the materials are deposited in the form of till or bowlder clay, the result generally is that the mineral components of the soil are in their chemical nature far more varied than where they are derived from rocks which lie immediately below that layer, because the ice carriage is effected under conditions which tend to mingle on a single square mile of surface the detritus worn from an area of ten or more square miles. On the other hand, where the glacially transported detritus has at the end of its journey been assorted by water, as is the case with much of the drift, the sorting action usually gives a singularly uniform character to the detritus found in any particular area. We then note that the material which the vegetation seeks to convert into true soil consists in the main of pebbles of sand or of clay, each with but trifling admixture with the others. The result is that the unassorted bowlder clays, even where very stony, generally afford fertile fields moderately well fitted for the needs of a great variety of crops and quite enduring to tillage. These bowlder clay soils are apt to have a fair share of all the elements which are demanded by plants. On the other hand, the stratified drift, because it is composed mainly of one kind of rock material, often affords nothing like the variety of constituents required by varied crops.

In New England, where the white settlers at first selected stratified drift areas for tillage for the reason that they were not encumbered with bowlders, it was soon found that such sandy soils, though easily made ready for the plow, were quickly exhausted and could be brought to yield fair crops only by extensive fertilizing. The greater part of these sandy soils have been abandoned, and people have resorted for plow land to the areas which are underlaid by bowlder clay. Such fields, though stubborn and demanding a great deal of labor to clear away the bowlders, are very enduring to tillage, because by the slow decay of their pebbles of varied mineral constitution there is constantly yielded to the soil something of the substances required by the different crops. The observer readily observes the fertilizing effect arising from the decay of bowlders in the soil indicated by the belt of exceedingly fertile earth accumulated in the form of a narrow strip around the base of the great erratics in New England pastures. We have already noted this feature in a previous chapter, but it is worth reiterated attention.

ALLUVIAL AGGREGATION.

Another class of soils of remote derivation is found in alluvial plains which border nearly all true rivers. The history of this group of detrital deposits is so important that it should be traced in some detail. To understand the formation and the physiology of alluvial soils we must begin our inquiry in the torrent sources of the river and observe what takes place in these fields where the débris of which alluvial deposits are composed is broken from the bed rocks. In this mountainous section of a river system we find that the slopes bordering the streams are generally very steep and bear but a scanty coating of detritus. Owing to the action of frost, rain, the expanding roots of trees, and of other inorganic and organic agents which aid gravitation in urging the incoherent mass down the incline to the channels of the stream, this mountain soil covering is in tolerably continuous motion toward the torrent beds. When the slopes are very steep the movement is often sudden, in the manner of avalanches or landslides; when the descents are less precipitous the motion is gradual but inevitably to the same end. At the base of the converging slopes which form both sides of the mountain valley the torrent is ready with its swift currents flowing down the steep slope to seize on all the detritus which is brought within its grasp; it urges the débris downward to the lower levels of the country. Unless the fragments of stone are very large they are hurried down the declivities in the times when heavy rains have swollen the brooks; beating against each other and against the rocky bed and sides of the channel the débris is constantly reduced to fragments of smaller size and thus becomes more readily transportable. In nearly all cases, however, the diminution in the size of the fragments is less rapidly brought about than is the reduction of the carrying power of the stream, which diminishes with the decline in the declivity of the descent. It is asserted by those who have carefully studied the subject that the capacity of a stream for conveying fragments of stone is in proportion to the sixth power of its velocity; although this is perhaps an excessive estimate, it will serve to show how rapid is the diminution in the ability of a stream to convey coarse detritus when its current is much slackened. (See Fig. 17 and Pls. XXIII and XIV.)

As the torrent emerges from the higher parts of the mountain district, where its rate of descent has generally been from 100 to 500 feet to the mile, and comes among the foothills of the range its fall usually diminishes to from 20 to 50 feet to the mile. The consequence is that the speed of flow of the water is rapidly slackened and it can no longer urge forward stones which it easily bowled down the steeper slopes whence they were riven.

We can note the growing incapacity of the stream to dispose of the débris which it bears if we follow down any mountain torrent until its waters pass out upon the plain land where lies the river system into which it discharges. In the steeply descending portions of its upper path there is no margin or border of débris which is at rest on either side of the stream. Except here and there where some large mass of rock has become wedged in a narrow channel, all the materials on the mountain slopes and in the bed of the torrent are in times of flood in more or less motion toward the lower levels. When in descending we come to where the valley widens and the speed of the waters is lessened we notice that the larger stones even in the flooded state of the brooks are left stranded on the side of the channel where the current is less swift. If there be space for the accumulation between the stream and the neighboring steeps these fragments that are too large for the current to carry onward will form a little margin or terrace, the surface of which speedily becomes occupied by vegetation. Examining this mass, we find that it is essentially composed of large stones more or less rounded, the interstices to a certain extent filled with smaller pebbles and sand. This finer material has been lodged in the spaces when the waters have risen above the surface of the rough plain. (See Fig. 12 and Pl. XXV.)

Following down the stream, which, owing to the constant lessening in its rate of fall, is rapidly diminishing in the energy of its flow, we find that these detrital plains usually increase in extent, and are composed of finer and finer materials the farther we pass from the torrential system. When we attain to the true river section of the drainage where the

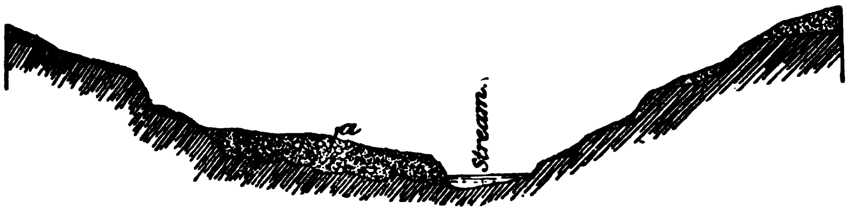
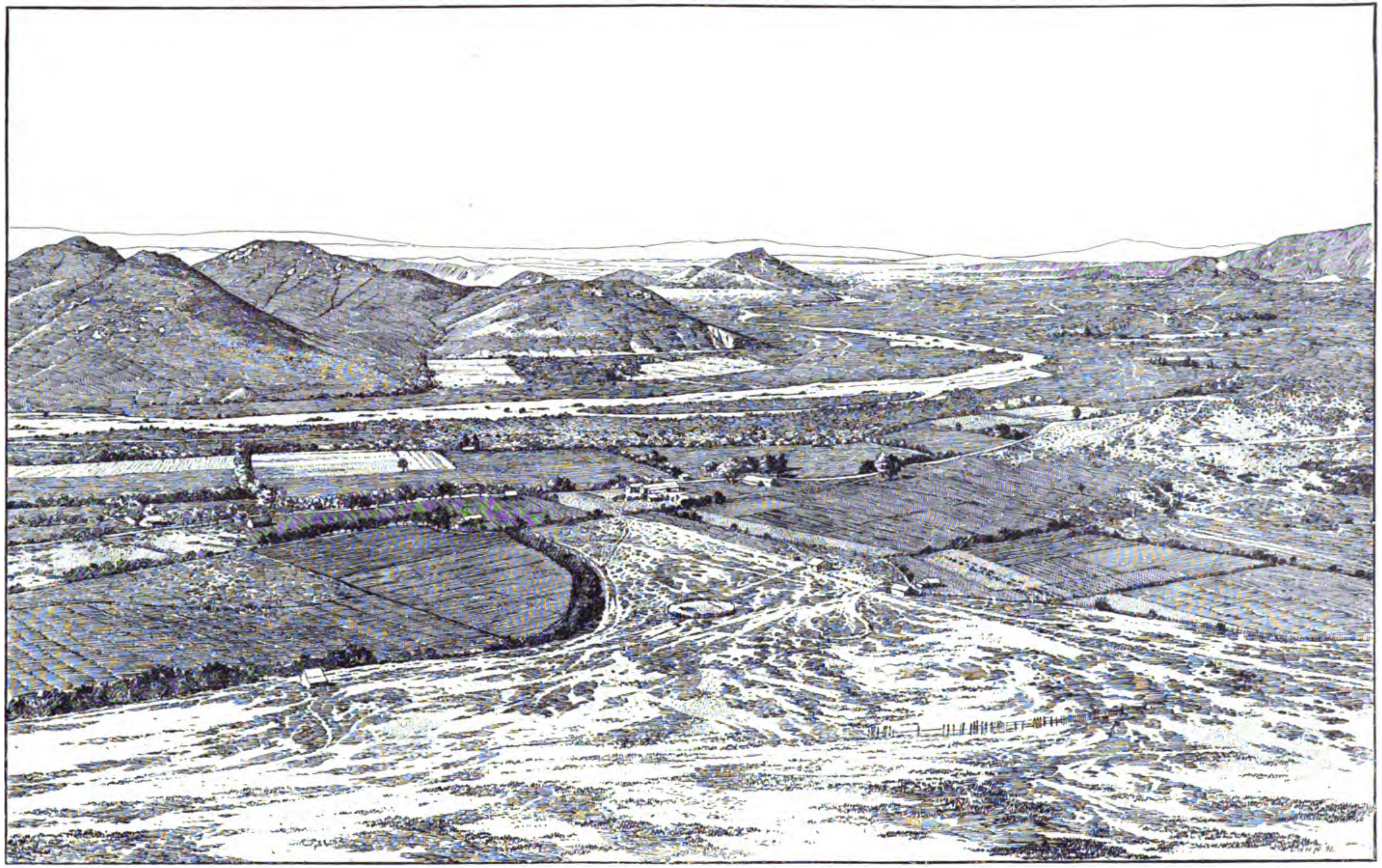


FIG. 12.—Section through the coarse alluvium formed beside a torrent bed. a, terrace.

stream flows smoothly with a descent of from 6 to 18 inches in a mile, the alluvial plains usually widen and exist on both sides of the channel: here we find the débris to consist of very fine gravel, coarse sand, and clay, the latter being in relatively small proportion. If the lesser river finally passes into one of the greater streams, such as the Mississippi, we observe that there is a progressive diminution of slope as we approach the sea until the decline amounts to no more than about half a foot to the mile. In this part of the river system the alluvial fields are very wide and the detritus of which they are composed is very fine grained, the greater part of it almost impalpable mud, and the few pebbles which occur rarely in size exceed a tenth of an inch in diameter. (See Figs. 13 and 14, and Pl. XXVI.)

The student who is observing the alluvial plains quickly notices that these masses of detrital materials are in constant course of destruction and renovation through the action of the river which built them. On the convex side of the great sweeping curves through which the stream marches the speed of the water is slackened and a portion of the sediment held in solution is laid down in the shallow water next the shore. Generally this débris is deposited in time of flood in the spring of the year. No sooner do the waters recede than certain plants of swift growth, which find their appropriate conditions on the verge of the river, extend their roots through it and cover it with their thick-set



BROAD ALLUVIAL VALLEY IN A MOUNTAINOUS DISTRICT, THE AREA PARTLY IMPROVED BY IRRIGATION DITCHES.

stems, and thus bind the new-made land firmly together. By this action a single flood may add a strip of land to the margin of the convex shore having the width of some score of feet, a length of several miles, and a depth of a foot or more. The next rise of the waters may find the willows, cottonwoods, and other water-loving plants growing thickly over the surface of the new-formed ground. The turbid water entangled among the stems has its current slackened, and another deposit of alluvium is laid down. Thus in the course of ten years the terrace may have risen to the height of 10 or 15 feet, and may be so far united to the general mass of the river plain that the process of its growth and its recent origin are not discernible. (See Fig. 14.)

When land is making on the convex side of the bank where the current is relatively slow, it is commonly wasting on the opposite side of the river against which the stream is impinging with swifter motion. Here it cuts away the alluvial matter which it has laid down in some previous state of its history. As the material falls into the flood many of the fragments formerly deposited because they were too large to be carried any farther in the waters at the speed attained may be observed to fall to pieces, owing to the chemical decay which has come

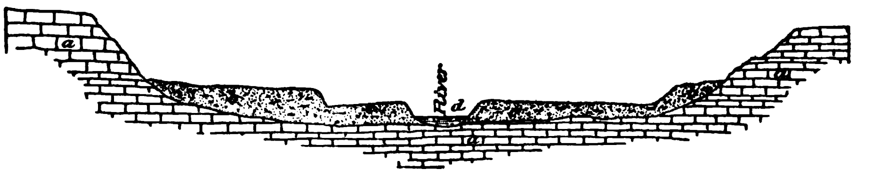


FIG. 13.—Section across a river valley showing terraces of alluvium. *a a*, bed rocks; *b b*, upper older terraces; *c c*, lower newer terraces; *d*, low-water level of river.

upon them during their repose in the alluvial plain. Much of the finer matter is so far oxidized that it can readily be taken into solution and borne away to the sea. The insoluble fragments are carried farther down stream until they attain a place like that before described, where they may again be built into the terrace. In this manner, cutting away the alluvium in one place and building into the bank at another, the river gradually swings to and fro over the whole width of the valley floor, slowly but continually destroying and rebuilding its marginal plain. Inasmuch, however, as in most cases the stream is steadily deepening its bed, portions of the old plain are occasionally left on the side of the valley above the level to which floods attain; sometimes these terraces lie at a considerable height above the latest level of the water, even in its time of flood. (See Figs. 13 and 14.)

The total area of these alluvial soils on this continent is probably over 200,000 square miles; of this the greater part is subjected to occasional overflows, not sufficient to destroy its value for tillage, and a small portion, perhaps one-tenth of the whole, consists of terraces not liable to inundations. The physical conditions of this interesting class of soils formed on alluvial plains are peculiar. Like glacial deposits, they fall into the class of materials which we have termed of remote derivation, that is, they are, for their mineral ingredients, not dependent on the bed rocks which underlie them, but are in this regard conditioned by the nature of the deposits in the upstream districts whence the river drains. In any one acre of alluvial soil on the banks of the lower Mississippi we may reasonably believe to lie some bits of matter which have been derived from every considerable field of the surface drained by the river above the point where the deposit lies. Thus, as regards their mineral materials, and to a certain extent also as regards their organic matter, river deposits are more composite in their nature than those originating in any other manner. Like glacial soils, they represent the waste from over a considerable area, but for the reason that the ice sheet, at least in its continental form, moved in a somewhat rectilinear manner while the streams of fluid water flow convergingly, alluvial plains have generally drawn waste from a far wider field than the glacial accumulations (see Fig. 14).

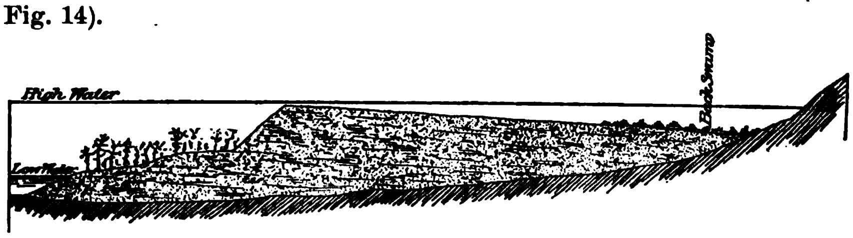


FIG. 14.—Section across alluvial plain on one side of a large river.

While glacial waste, owing to the lack of oxidizing agents in the ice or in the water which is produced by its melting, is generally undecayed, the material deposited by the river is usually somewhat advanced in decomposition when it is laid down. The conditions of this deposition tend to bring about a mingling with the mass of mineral matter of much vegetable and some animal waste. These interbedded organic materials, as we have already seen, serve greatly to promote the changes which lead to the solution of mineral matter in water, and its appropriation by the roots of plants. We may indeed consider these deposits of river-borne waste as admirable natural laboratories in which the great work of dissolving mineral substances is carried on. The gases engendered by the decay of organic materials favors this rotting action, and the porous character of the deposit permits the rainwater to pass freely through it. By so passing the water brings the soluble materials into a condition in which they may be appropriated by plants or flow forth with the drainage into the neighboring stream and thence to the sea.

Alluvial soils, at least when first subjugated, have in general a high average fertility. The variety in this regard is greatest in the deposits formed beside the banks in the headwater district of a river system, for in these situations the local peculiarities of rock in particular districts have a dominating influence on the chemical nature of the mineral

VIEW OF A MOUNTAIN VALLEY, SHOWING THE BEGINNINGS OF THE RIVER ALLUVIAL PLAINS.

elements of which the terraces are composed. In such an alluvial district as that of the Lower Mississippi, where the detritus represents an average of the waste from the whole of the great valley, there is naturally a greater uniformity in the character of the materials; yet even in this district there is a certain diversity due to the sediments brought in by the tributaries which join the main stream near the site occupied by the alluvial fields.

Soils of this nature are also liable to modifications due to a variety of special conditions. Where covered by vegetation, as is usually the case, and where visited by floods in the rainy season of each year, the current of the turbid water, having been checked by the resistance which the friction of the vegetation offers to its motion, deposits a layer of fine mud on the surface and thus affords refreshment to the soil. When a similar flood passes over open lands the motion may remain so swift that the most of the fertilizing matter suspended in the water will be carried forward, and only the coarse sand deposited, which is of little value to plants. In general, however, alluvial lands have proved themselves to be the most continually and largely productive of all the soils which have long been taxed by tillage. This endurance to the demands of agriculture is doubtless to be attributed to the great depth of the thoroughly oxidized materials which compose these deposits, to their horizontal position, which insures them against the risk of washing away, and to the fertilizing inundations which frequently visit then.

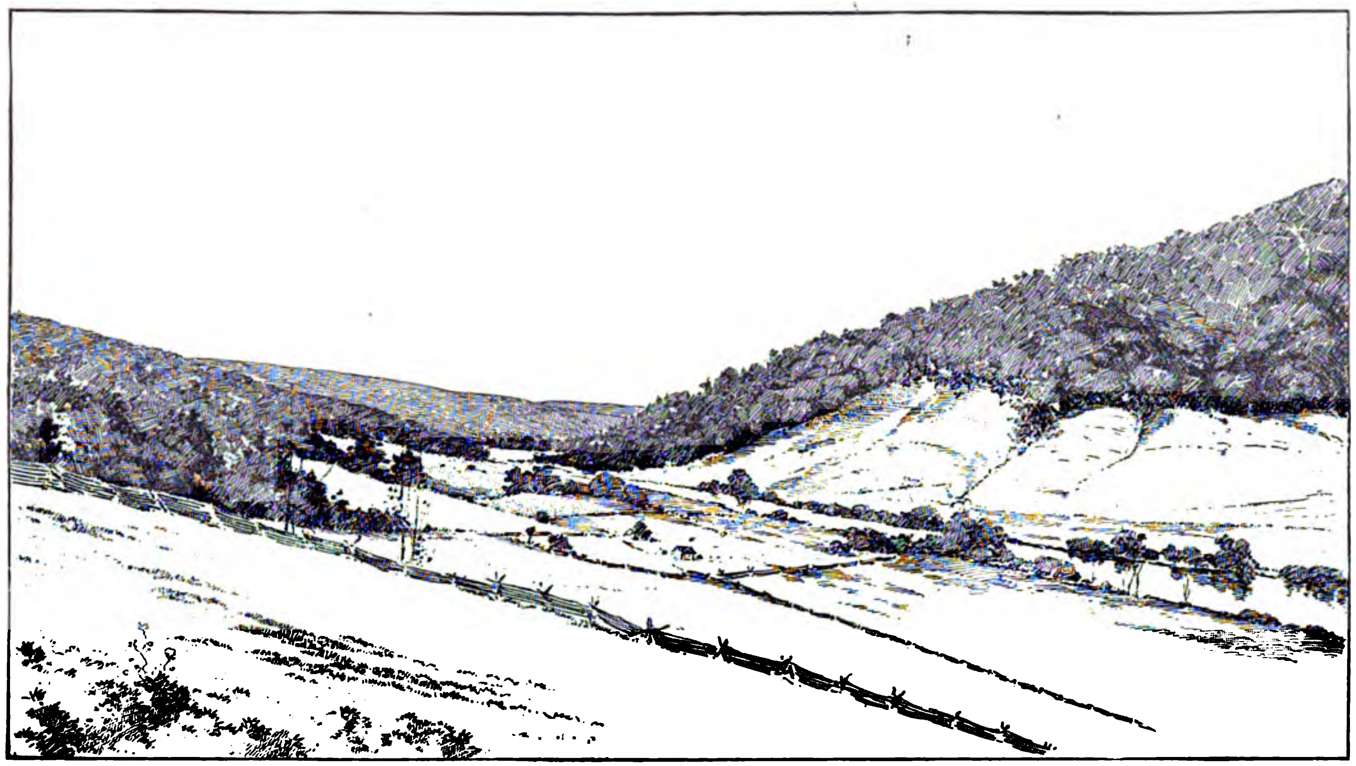
We shall now turn somewhat aside to consider the action of the water, which, after performing the important underground work which we have traced in preceding chapters, escapes from the soil, joins the streams, and passes in them to the sea. We have seen that all organic life depends upon the peculiar capacity which water has for taking a great variety of substances into solution. It is hardly too much to say that the truly vital parts of animals and plants are solutions containing that portion of the soil which is in condition to enter into living forms. The frames of such animals are built up of material which has passed or is ready to pass into the dissolved state. The insoluble portion of the soil mass is essentially without effect on life, except as a reservoir of water and a laboratory where the materials are preparing for the state in which they may be vitalized.

When rain water departs from the soil it bears away with it more or less mineral matter. Evidence of this may be had by the simple experiment of completely evaporating a pint of water taken from the rain before it has touched the earth, and at the same time another equal quantity from any spring which drains from an ordinary soil. At the end of the experiment we find that the rain water leaves little or no residuum except possibly a few bits of matter which, floating as dust in the air, has been caught in the falling drops, while the soil water leaves a layer of sediment on the bottom of the vessel. Analysis shows this material to have been derived from substances in the soil. A familiar instance of this action may be seen in a teakettle the water of which is supplied from a spring or well; after a time a crust will be found in the bottom, composed of the mineral matter originally held in the water, which has gone away in the form of steam.

The mineral matter dissolved in the soil is first offered to roots which in most cases plentifully interlace the path along which it escapes to springs and thence to streams. Each year the share of rain water which finds its way into the soil, amounting on an average to about 2 feet in total depth, goes through that layer and flows to the sea after gathering a considerable share of mineral matter. The amount of solid material suited to the needs of plants which is thus each year withdrawn from the land and given to the ocean is very great. It is probably in any one season nearly as much as is taken from the soil and built into the vegetation of the forest, and even that which enters the vegetation is but temporarily beyond the reach of this danger, for when the plants decay the mineral material is again ready to be dissolved.

At first sight this great excurrent tide of fertilizing material may seem to be a most unfortunate feature in the economy of the earth, but on closer consideration we find that the apparent loss is not real; the process, indeed, when considered in a large way, is seen to be of a conservative nature. The mineral matter which is taken from the earth by the percolating ground water is first turned to good account in supplying the roots of plants; when it has served these needs it is necessary that it should be drained away, for it would become charged with a deleterious excess of substances which are taken into solution, and which, if retained in the soil, would be injurious to vegetation. An instance of this is familiar to persons who have kept plants in pots. It is well known to all who have had the care of potted plants that it is necessary to provide for the ready escape of the water from the vessels. Some of the effects of an insufficient passage of the water through the soil may be observed in swamps, and will hereafter be noted in connection with observations on the arid land of the Cordilleran district and other places where the rainfall is not sufficient to provide the normal current of water through the soil. Although it is necessary for the plant to have a certion amount of mineral matter in the water which bathes its roots, any excess of such material appears to prove poisonous. When the water becomes saturated with the substances it may dissolve, even to the extent to which the sea is so charged with such materials, the effect on plants is generally destructive.

When water escapes from soil into rivers and goes thence to the sea it bears with it the mineral matter which it has in solution, and on entering the ocean becomes mingled with a great store of such substances which the deep holds in its keeping. We are in part made aware of this charge of dissolved mineral matter by the evident salinity and hardness of sea water. In this great storehouse of ocean it has been found by careful chemical tests that there is a share of the mineral substances



BEGINNINGS OF ALLUVIAL TERRACES IN THE UPPER PART OF THE CUMBERLAND RIVER VALLEY, KENTUCKY.

contained in soil water. In fact, practically all the elements which exist in appreciable quantities in the crust of the earth and a great variety of the compound substances which enter into organic forms, such as lime carbonate, potash, soda, etc., are known to exist in a dissolved state in the ocean waters. It is probable that in them is contained a variable proportion of every element which exists in the earth. From this great reservoir of the sea the marine plants, each after its kind, extract substances, appropriating them through their fronds in the same manner as the land plants take their share by means of the roots in the soil, but perhaps in greater variety. It may again be noted that, as sea weeds have no roots, the whole of their surface serves for this purpose of absorption, whereas in land plants the roots alone have this power of appropriation.

Sea weeds, like land plants, are mediators between the mineral realm and the animal kingdom. Animals are altogether incapable of taking mineral substances directly from the water; they appropriate them only at second hand, by feeding on the vegetation or on other animals which have obtained them from vegetation. Although at first sight marine plants appear, on account of their usually small size, to occupy a limited place in the sea, the volume of their life is vast; they grow rapidly, they appropriate mineral substances which are brought to the ocean waters, and so feed upon the materials which are placed in solution through the action of the land vegetation. Thus in a simple and tolerably direct way the removal of mineral matter from the soil serves to provide marine life with the necessary basis for its development.

There are other and important, though remoter, effects arising from this vast and ceaseless transfer of the minerals of the earth to the sea. The marine plants and some of the animals have the habit of appropriating large quantities of special substances, such as iron, lime, potash, soda, etc., and even particular metals, such as silver; and on certain fields of the sea floor, where the remains of marine vegetation are built into strata, the sea weeds form deposits remarkably rich in these elements which they appropriate during their lifetime. Thus the coral animals build great islands in the ocean and vast fringing and barrier reefs along the shores. The limestone of these creatures is derived from the store of that material which is dissolved in the land waters, mainly by virtue of the carbonic dioxide arising from decaying vegetation, and which is brought by rivers to the sea. In each cubic foot of this lime of the coral reefs it is likely that we could find, if we had the means of ascertaining the facts, one or more molecules derived from each of the river basins of the earth. So incessant has been this process of change that it is also probable that every cubic foot of limestone now lying in the beds exposed on the land contains elements which in their previous wanderings have journeyed through every sea, which have been in turn built into strata in all the quarters of the globe.

When animals possess, as many of them do, the habit of secreting in their skeletons or shells such important substances as lime phosphate, perhaps the most necessary of all the soil substances to the development of crops, the beds which are formed of their remains often afford most fertile soils. Thus in central Kentucky, where the soil of the country has an uncommon fertility and endurance to tillage, its quality is mainly due to the presence in the limestone beds which underlie the area of certain layers peculiarly rich in phosphoric acid. Some of these strata, from a few inches to a foot in thickness, contain from 10 to 20 per cent of lime phosphate, and as these portions of the horizontally lying rocks decay the fertilizing material is carried down the slopes of gently inclined hills and, dissolved in the soil water, is made free to all the plants. (See Fig. 15.) It is hardly too much to say that in each kernel of which wheat or other grain is temporarily stored the molecules of lime

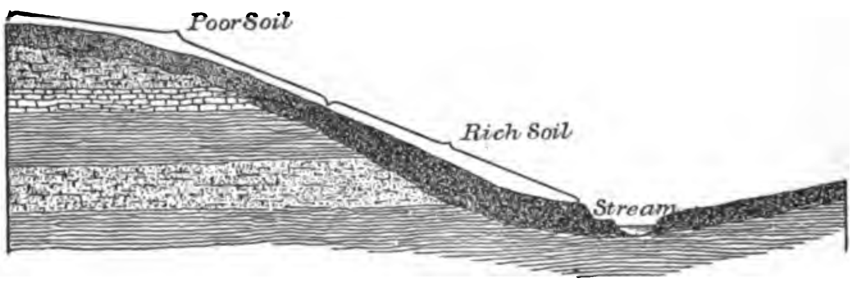


FIG. 15.—Diagram showing the effect of a layer of rock yielding fertilizing elements to soil. *a a*, sandstones; *b b*, clay slates; *c*, limestone yielding fertilizing materials.

phosphate which have been brought together by the action of animal or vegetable life on the sea floor. Our civilization in good part rests upon the grains we win from the field. It would not be possible, therefore, to maintain the status of higher men without the compact and nutritious foods which we thus obtain.

In the above considerations concerning the origin of soil fertility we have naturally found our way to a division of the subject in which we are to consider the effect of the diverse character of underlying rocks upon soils which are formed by their decay. The range of facts which will have to be explored in order to make a survey of the whole of this field is so great that it will be necessary to limit our undertaking to certain characteristic instances which may serve as types of the condition, leaving the reader to make his own application of the principles we thus acquire to the particular cases which he may need to explain. First of all we note the fact that the classification of soils as regards their mineral constituents into those of immediate and those of remote derivation, while true in a general sense, needs a certain amount of qualification.

OVERPLACEMENT.

Almost all soils except those on very level plains have derived their mineral parts in some measure from the rocks which do not lie immediately beneath their site. In the glaciated districts as well as those

OX-BOW SWING OF A RIVER IN AN ALLUVIAL PLAIN: THE GANGES, INDIA.

covered by river alluvium the transportation of mineral elements is from distant points and is in a way complete. In other soils, which may in general be accounted of immediate derivation, where the surface has a considerable slope, a certain migration of the detritus is brought about by the slipping of loose earth over the surfaces on which it lies. As already noted, this action is tolerably constant and may lead to journeys of the disintegrated rock for distances of a mile or more. Distinct evidence of this movement may often be found where a hilltop is capped by some layer of enduring rock, while its slopes are underlaid by a looser deposit, such as clay. In such a condition of the surface we often find masses of the capping layer which have separated from its steep face and have slowly journeyed down the incline below until they have attained the bed of the neighboring stream. (See Fig. 16.) It is easy to prove that these masses, which are often many hundred cubic feet in contents, have journeyed slowly over the distance they have traversed and with a very uniform motion, and not suddenly, as in the manner of a landslide. Examining the procession of blocks, we see

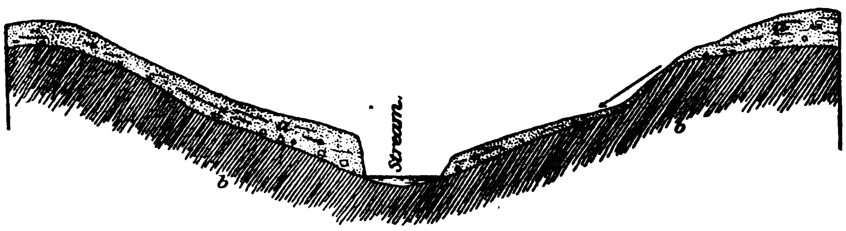


FIG. 16.—Diagram showing the direction and the rate of motion of soil. *a a*, soil; *b b*, bed rock. The arrows show by their relative length the rate of movement at various points.

that they have not been overturned, but that they generally lie substantially in the position of their original bedding. We also note a gradually and progressive decay of the fragments as they lie farther down the slope. Near the cliffs whence they came they have sharp faces and are very little decayed; a few hundred feet from the escarpment they are more rounded and the decay has penetrated deeper; near the stream they are often so rotten that when they actually attain the torrent bed they are easily broken up by its swift-moving waters. These facts confirm the conclusion that the whole of the soil layer is in gradual motion down the slope on which it lies. In this movement it is impelled by gravity abetted by frost action, the expansion of roots, the overturning movement of uprooted trees, and the burrowing work of a host of animals.

Excellent examples of this movement of soils down the declivities bordering a stream are afforded by the descent of blocks of stone from the hilltops in almost all districts where horizontal strata underlie the surface of a country. It is indeed usual in such regions for the harder layers to crown the elevations, for the simple reason that such beds, by resistance to decay, determine the position of the hilltop. Perhaps the best instances of this in this country are exhibited in the region occupied by the Millstone grit or the thick conglomerate which lies at the base of the Coal Measures. These beds often rest upon shales and form steep cliffs, such as are found along the western escarpments of the Appalachian coal field. Fragments from these cliffs, sometimes as large as an ordinary house, may be observed journeying down the inclines to the streams. They often bear trees and are surrounded by and partly imbedded in the soil. Less conspicuous instances of the same nature may be traced in almost any upland country south of the glaciated region. (See Fig. 17.)

Besides the migrations of mineral matter brought about in this manner, there is on steep slopes a constant movement of substances held in solution by the ground water. This water, creeping down the hill with its charge of dissolved material, serves to qualify the character of the nourishment afforded to plants by the substances extracted from the immediately subjacent rock. It thus often happens that the presence of a layer

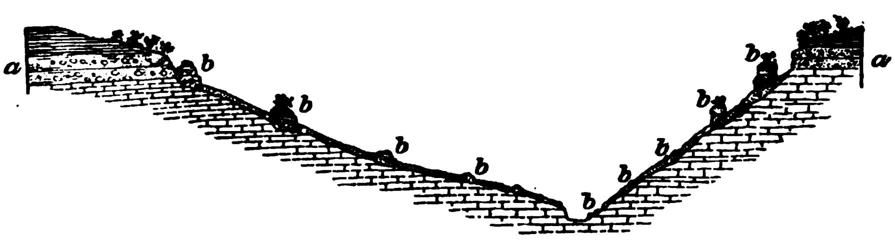


FIG. 17.—Diagram showing progress of fragments down a slope to a stream. *a a*, bed of hard rock; *b b*, fragments moving down slope.

of fertilizing material near the summit of a slope will serve to enrich the soil for a great distance down the incline. Thus in central Kentucky the layers of phosphatic limestone, even though their fragments do not slip down the hill, will be found to have effected the fertility of soil derived from rocks barren of nourishment which lie farther down the declivities in which the enriching layers outcrop. In this way, though the particular beds which afford the important mineral element may be so soft that they yield no fragments to the detritus below their level, the effect is almost as valuable to plants as where they contribute to the visible débris. It is a fact worthy of note that owing to this movement of materials down the slope the substances derived from a particular kind of rock may affect the soil at some distance below the site of the layer rather than that which immediately overlies the bed; the outcropping edge of the rock deposit may itself be covered to a considerable depth by the barren débris derived from beds which lie higher up the declivity. The mode of this action is indicated in Fig. 15.

Where, as in the case of hillsides sloping steeply toward the stream, the motion of the soil is rapid and the torrent at the base sufficiently powerful to wash the débris away as fast as it comes to the channel, the soil material may be so speedily removed that it does not accumulate in a thick layer, and so the chemical processes do not have time to bring the débris into the state where it may be taken into solution. Such slopes are often in the main covered with a rubble of angular fragments, mingled with a little true soil, which supports a scanty vegetation, the condition of the débris showing plainly the lack of sufficient time to bring the rock waste into the finely divided state in which it may be appropriated by the roots. If in a valley exhibiting these conditions, which may be said to be normal in mountainous districts, as well as in many countries where the hills are steep, we penetrate to the headwaters of the stream, where its dwindled torrents are not able to bear away the detritus which marches down the slope, we find very different soil conditions. In these "coves," as they are termed, the soil is often very deep and of great fertility.

In the state of nature the difference between the soil in the lower and the upper parts of a mountain valley is often attested by the character of the forest growth; on the rubble-covered hillsides, where débris is rapidly removed and therefore always shallow and imperfectly de-

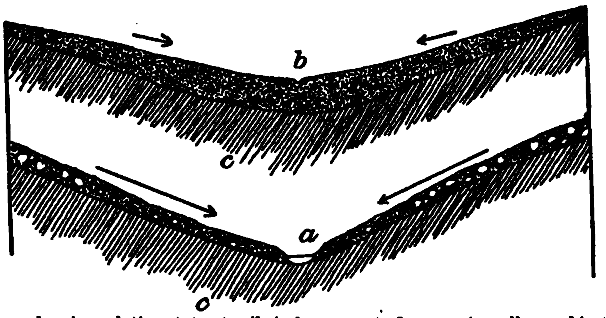


FIG. 18.—Diagram showing relative state of soils in lower part of mountain valley and in the "cove" at its head. *a*, section of lower part of valley; *b*, section of upper part of valley; *c*, *c*, bed rock. The relative size of streams is indicated by the section of the beds. The arrows show by their relative length the proportional speed of the soil movement toward the streams.

cayed, stunted red and black oaks and rigid pines mainly possess the field, and to the expert eye attest the barrenness of the earth. In the coves, however, black walnuts of gigantic size, tulip trees with their great boles, and other plants which grow only in deep and well decayed deposits of detrital matter show an entire change of soil conditions. If the land in the valley be cleared of its wood and cultivated we note an equally sharp contrast in the crops which it bears. On the steeper slopes, washed at their base by permanent and powerful streams, the fields afford only scanty pasturage and generally after a brief trial they are again abandoned to the natural growth, while in the coves the soil often proves excellent for the culture of grain, tobacco, or other exhausting crops. The reason for this fertility of the cove soil is to be found in the fact that the smaller streams, having near their headwaters but little cutting power, are unable to convey the detritus away as rapidly as in the lower parts of the valley; the débris thus has time to be comminuted by decay and converted into fertile earth. The difference between the above-described conditions is diagrammatically indicated in Fig. 18.

Without discussion it will be evident to the reader that where the underlying rocks of a district are in the horizontal attitude the soils will be much more uniformly distributed than they are where the strata are tossed about by the irregular movements which take place in the formation of mountain chains. In such disturbed regions the different beds often stand at high angles to the horizon, and the distribution of the débris from them is naturally extremely diversified. Thence it comes about that in a country of great mountains, such as Switzerland, where the population is dense and the people are driven to search carefully for every bit of tillable soil, small patches of earth of excellent fertility are often located in districts which are prevailingly unfit for tillage. Each of these bits of remunerative soil is usually due to the peculiar nature of the rock which is exposed to decay at or near the place where the fertile field exists. Wherever the beds which afford these conditions are by the twistings and breakings of the strata subject to the action of the atmosphere it is likely to give rise to the existence of similar patches of fertile soil. It often happens that when the outcrop of rocks is too steep to permit débris to remain upon its surface the materials falling to the base of the precipice will gather into a talus; there, broken to fine fragments by the violence of their descent, this rocky matter may afford the basis of an excellent soil. Many of the best vineyards and fields of Switzerland and of other mountain countries are upon slopes of this nature.

Owing to the fact that land in this country is still low priced, but few of the mountain taluses have been subjected to tillage, and therefore the peculiarities of soil which are due to the slipping of materials down the slopes of mountains have not been made the subject of inquiry. With advancing culture, however, it is certain that we shall have to imitate the peoples of the Old World and seek every opportunity to utilize rich lands, however limited in area or difficult of cultivation. When this stage of our national development arrives thousands of talus slopes in the Appalachians and the Cordilleras will richly repay care. Soils of this description are particularly well suited to vineyards. They serve also very well for orchards and generally for tree plantations of every description, and this for the reason that the stronger rooted plants, such as the vines and timber trees, are able to send their underground branches to great distances through the rubble in their search for an appropriate food supply.

INHERITANCE.

We have now to consider a peculiar feature in the history of soils derived from rocks upon which they lie, or at least from a place no farther away than the upper part of the slope on which they rest. It is evident that the continued wearing to which soil materials are subjected leads to a rapid deportation of their mineral materials, either by solutional action or by the direct cutting away by streams. The rate of this removal of soil can be quite accurately gauged by estimating the amount of water discharged from the mouth of a stream which drains a valley and determining the amount of mineral matter which it contains for each day in the year. This task has been approximately accomplished for all the great rivers of Europe and for the Mississippi in this country. The rate of the downwearing of the land, according to the diverse inclination and other conditions of the area, varies from about 1 foot in 800 years in some of the rivers which flow from the Alpine district in Europe to about 1 foot in 7,000 years in the Mississippi valley. Taking the world over, the lands are probably wearing down from the action of the rain at the rate of about 1 foot in from 3,000 to 5,000 years, the variation in the rate of erosion being due to the amount of rainfall, the steepness of slope, solubility of rock material, and other influences. The range in the measure of the action is doubtless great; it probably extends from 1 foot in 500 years to 1 foot in 10,000 years or more. In some rare instances, as in the very dry and rocky districts of desert lands, the rate of erosion may be even slower than 1 foot in 20,000 years. Although the subsidence of the surface may seem to the reader exceedingly slow, as indeed it is when measured in terms of human history, it is in a geological sense of a moderately rapid nature.

To appreciate the effect of this process of lowering the land surface through the action of ground water and streams in bringing about a downward migration of the soil we may consider the condition of that part of the Mississippi valley which has probably been above the level of the sea for almost all the time which has elapsed since the close of the Carboniferous period. It is likely that the section of the great continental valley, which includes the upland country of West Virginia, Kentucky, and Tennessee, has thus been in the condition of land through the ages from the end of the Coal-Measure time to the present day. This great interval can not well be reckoned at less than 10,000,000 years; it is indeed more likely that it represents nearly twice that duration. Although the rate of erosion in the Mississippi valley, considered as a whole, is at present not more than sufficient to lower the surface to the amount of 1 foot in 7,000 years, it seems likely that the rate of downwear in that portion of the valley which we are now considering is as rapid as 1 foot in 4,000 years. Assuming that the present rate of wearing is substantially that which has on the average prevailed since the region was finally lifted above the sea level, we find that in 10,000,000 years the original soil surface must have been lowered by the amount of 2,500 feet.

It should be clearly understood that the computation given in the previous paragraph is intended only to afford a very general idea as to the probable rate at which the downwearing of the surface of a country goes on; the average rate, as assumed, may have been several times greater or very much less than that indicated. It is not improbable that at various times in the geologic past the speed with which this surface has been worn away by the elements has been sometimes far swifter and again much slower than it is now.

At first sight it may seem extraordinary and hardly credible that such a great amount of rocky matter has gone away from this district; there are, however, many evidences which point to the conclusion that not less than this great thickness of beds has, under the processes of atmospheric decay, disappeared from this part of the continent. Among the many considerations which serve to substantiate this conclusion we may note that the coal fields of the Appalachian were undoubtedly continuous across the table land of central Kentucky where Silurian strata are now exposed. This is shown by the fact that the flinty and other enduring débris of these wasted beds are plentifully intermingled with the other soil materials which lie on the flat hilltops of this country in positions where it has been protected from the assault of the streams. The total thickness of this destroyed section can not well have been less than 2,000 feet and may have much exceeded that depth. (See Fig. 19.)

It need not be supposed that the region we are considering ever had a surface 2,500 or more feet above the sea level; it is more likely that

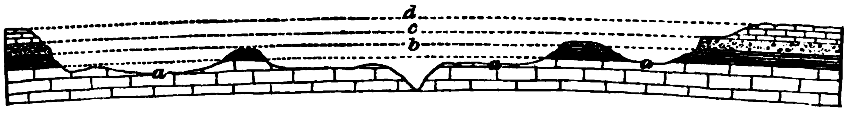


FIG. 19.—Diagram showing the successive variations of fertility in the soils of central Kentucky during the downward movement of the rocks. *a*, *a*, *a*, parts of the present surface enriched by decay of limestones; *b*, next preceding stage, when soils rested on Devonian shales and were moderately fertile; *c*, yet earlier stage, when soils were formed on millstone grit and were very lean; *d*, earliest stage when soils rested on the coal measures, and were moderately fertile. For simplicity of illustration several stages of variation are omitted.

it has slowly uprisen above the ocean as the beds which covered it have worn away; but it is necessary to conceive that the soil which we now find upon its surface has steadfastly moved downward as the beds have been removed by the action of the agents which wear away land. The descent of the soil coating has been accomplished by the solvent action of ground water and the cutting work of streams. It is likely that both these forms of erosion may at one time or another have operated on all or nearly all parts of the descending surface. Although at one time stream beds where the water does its rending work occupy but a small part of the surface, perhaps on an average not over one-sixtieth of the area, the streams are constantly swinging to and fro and so in process of down wearing they come to lie in positions far removed from their present sites. Only the main divides which separate the waters of considerable rivers can fairly be supposed to have been exempt from the action of these migrating channels. (See Fig. 20.)

As soil descends with the wearing away of its materials it of course is subjected to a constant change in its mineral character. Thus while soil of the district now occupied by the rich limestone territory of central Kentucky lay upon the Millstone grit it was doubtless of a sandy and rather sterile nature; when in its descent it came into the limestone bed it must have been fertile; still farther down, encountering the Devonian or Ohio shale, which, because of its mineral character, is rather unfit for plants, the soil would again have been reduced to a sterile state. Finally in downward migration the surface entered the rich fossiliferous beds of the Silurian age and from the storehouses of the ancient marine life it acquired the exceedingly nutritious character of the so-called blue-grass soil; thus with the process of down going the character of the superficial deposits which determined the fertility of the earth was subject to very great alterations. As forest trees and other plants are distributed in strict accordance with the character of earth they grow in, each alteration in soil brought about in the manner above noted leads to a change in the species which inhabit the area. In the field which we have been considering soils formed of the Millstone grit are occupied by stunted red

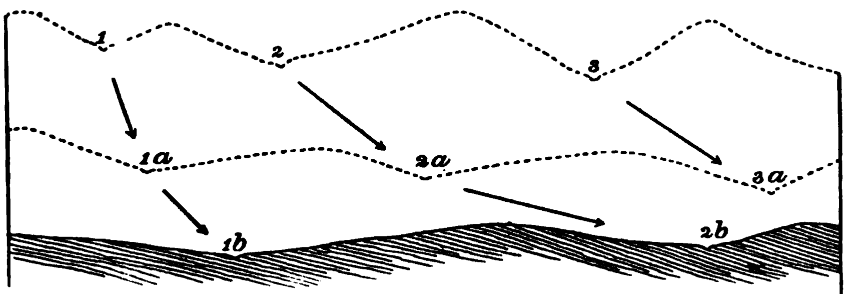


FIG. 20.—Diagram showing the lateral migration of streams in their descent through inclined rocks. *a*, present surface; *b*, *c*, former surfaces. The figures 1, 2, and 3 show the original positions of the streams; 1 *a*, 1 *b*, 2 *a*, 2 *b*, etc., show the successive positions of these streams. The arrows indicate the direction of the migrations of the streams.

and black oak and scrubby rigid pine; where the débris is of limestone we find walnuts, coffee nuts, and blue ashes, and other trees suited to the rich earth. We therefore perceive that each change in the nature of soil brings about a revolution in the character of its vegetation. (See Fig. 20.)

As soil migrates downward the greater part of the débris which it inherits from the rock through which it passes is dissolved and goes away to the sea. There are, however, certain materials which may remain for a long time in the soil because they are peculiarly insoluble. Thus in the limestone soils of Kentucky, the greater part of which are derived from the rocks on which they now lie, we often find many flinty and cherty bits which came into the layer when it was in a geological position a thousand feet or more above the site now occupied by the soil. Dense pebbles of pure quartz or flint, containing no admixture of other more oxidizable materials, may survive the assaults of the elements for an almost indefinite period. They are indeed almost completely insoluble in soil waters, and when buried in the dense clay they are little exposed to any agents of decay. It is often possible by the silicified fossils found in this material to prove that it has descended from a height of several hundred feet above its present position. Other evidence to the same effect is afforded by the occasional fragments of coal which are found in certain parts of the country lying upon the Lower Silurian limestone. One such deposit exists in the southern part of Campbell County, opposite Cincinnati, where frequent fragments of the material are found plentifully commingled with the quartz pebbles so characteristic of the Millstone grit.

It sometimes happens that the barren waste from vanished strata is inherited in such quantities upon the present surface of rocks which yield a fertile detritus that the soil has its fertility more or less impaired. The rocks which are now supplying newly made mineral waste may themselves be of an enriching quality, but the plants are embarrassed by the amount of pebbles through which they have to pass to gain the nutritious material at a lower level. It will be readily understood that these conditions are found only where the surface on which the soil rests is level or lies nearly in that attitude. Where the declivity is considerable the movement of débris towards streams inevitably leads to its destruction.

In consequence of the downward migration of the soil the oxides of iron are sometimes accumulated upon or near the surface in such quantity as to impair its fertility. Particularly in limestone countries these ores of iron may often be inherited by the surface from beds which originally lay over the country. It is characteristic of these ores of iron that they are readily dissolved in the soil water because of the charge of carbonic dioxide which the fluid contains. Under ordinary circumstances in this state of solution they are in small part appropriated by the plants, while the remainder is carried away through the streams; when, however, the soil water containing iron oxide comes in contact with limestone the iron is deposited in the form of a carbonate, while in its place the water takes a charge of lime which it bears away to the sea. In these conditions there may be only iron ore exposed to the action of the roots of the plants, and thus what would otherwise be a fertile soil becomes unfit for agriculture. As long as the detritus rests upon limestone these injurious conditions may persist. If in its down wearing it passes into clayey or sandy beds the excessive charge of iron may disappear.

If the soil be excessively humid, as it is in swampy districts, the iron, whatever be the character of the under soil, may, by virtue of another chemical process, be retained in the earth. The decomposing vegetable matter of the morass, by a reaction which it is not necessary to explain, takes the iron which is contained in the water and deposits it as an oxide in the form of an incrustation on the decaying leaves and other vegetable waste lying in the swamp water. As these vegetable forms crumble in their further decay the iron oxide may be accumulated as a sheet upon the bottom of the basin. When the downcutting of the stream which drains the swamp occurs, as it is pretty sure to occur in a brief geologic time, the ore is left as a deposit on the surface of the soil. These swamp deposits of iron ore are less detrimental to vegetation than those formed in the manner above described, for the reason that they commonly contain considerable amounts of lime phosphate, which is a most desirable substance in every soil.

Besides the iron ores, manganese is also inherited in much the same way from the rocks previously occupied by certain existing soils, but the oxides of this metal more rarely occur than those of iron, though they are often associated with them, and the effects of the accumulation are thus not so disadvantageous to vegetable life.

In general the downward movement of the mineral matter contained in soils tends to promote their fertility, and this for the reason that the variety of mineral materials in any one layer of rock is generally insufficient to afford the wide range of substances desirable for the uses of a varied vegetation. Within each area of ordinary soil we commonly find a share of the substances derived from the higher levels of the strata through which it has passed; in this manner it is likely to be supplied with a wider range of ingredients than the rock on which it lies can afford. There are also several curious equations of action which tend to prevent a soil from becoming surcharged with detritus of an insoluble character, such as flinty pebbles or fragments of chert. When the débris lies on a slope the constant passage of waste to the neighboring stream clears the surface of such accumulations; when the area is level the insoluble materials gradually sterilize the soil so that the vegetable growth becomes scanty and the consequent supply of the CO_2 to the water so small that the solvent action of the fluid on the bed rocks is much reduced, and so the surface migrates downward with lessened speed. With a diminished rate of descent the hard bits have a better chance to completely decay, and they are less apt to form a thick coating upon the surface. On this account we rarely find any soil completely sterilized by the insoluble fragments which it contains. Though it may not be fit for agriculture, it can generally support a scanty forest growth. But for this partial arrest of the downward working of the surface certain soils would be so thickly covered with insoluble rock débris that they would be entirely barren. We thus see that the character of a soil to a certain extent determines the rate of down wearing of the country, while conversely the speed of the descent in a measure fixes the nature of that layer.

The foregoing considerations should give the student a larger conception of the historic features of the soil coating than can be acquired by any more limited view of their conditions. He should clearly see that this mass of débris, which at first sight seems a mere rude mingling of unrelated materials, is in truth a well organized part of nature, which has beautifully varied and adjusted its functions with the forces which operate upon it. Although it is the realm of mediation between the inorganic and the organic kingdom, it is by the variety of its functions more nearly akin to the vital than to the lifeless part of the earth. It is not unreasonable to compare its operations to those of the plants which it sustains, for in both there are the harmonious functions which lead matter from its primitive condition to the higher estate of organic existence.

CERTAIN PECULIAR SOIL CONDITIONS.

So far our attention has been mainly given to the three groups of soils which are the types of the detrital coating in most parts of the world, viz, the alluvial, the glacial, and the locally derived deposits. In certain cases, however, we find soils which have been affected by local though it may be wide-reaching conditions, and which constitute fields affording problems of great economic as well as scientific interest. Among them we shall note the two divisions of arid and inundated lands, or those which suffer from an insufficient or an excessive water supply, and also those formed of materials transported through the air, together with certain other less important types of structure which will have to be at least incidentally considered.

It has already been shown that the prime mover in the formation of soils is the water which penetrates into and circulates through the superficial portion of the under earth; it is therefore natural that any great variation in the amount of this fluid should give rise to considerable differences in the constitution of the mass which it in good part creates and makes useful to plants. Such, indeed, we find to be the case. When the amount of the underground water and its other conditions are such that from time to time it fills the soil and then almost altogether escapes to the streams and air, we have what may be termed the normal conditions of the layer. Where the water is not supplied in such quantities as are necessary to these movements, or where the supply is so excessive that the earth is kept in a soaked state throughout the year, the effect upon the earth is perturbing and detrimental. Owing to the irregular distribution of the rainfall and in part, especially in the case of inundated lands, to the slope of the surface, about one-third of the continental areas have an imperfectly functioning soil coating. The arid lands or those which suffer from insufficient ground water occupy somewhere near three-tenths of the continental area. The swamps or other inadequately drained lands include about one-thirtieth of the surface which is above the level of mean tide.

The arid portion of the earth is mainly grouped into five great fields, which lie in central and western Asia, northern Africa, central and western Australia, western South America, and the Cordilleran district of North America so far as that field lies in Mexico and the United States. There are other portions of the earth which are desolated by drought, but they are all of small area. In none of these arid regions do we find that absolutely no rain falls; but in them the quantity of the fall is too limited to serve the needs of all save a few kinds of plants which have habits of growth fitting them to live with little moisture.

The amount of rainfall in desert countries varies from less than 1 inch to about 10 inches per annum, and in most cases the supply comes to the earth in some one season, sometimes in a single brief rainfall. When the rain is precipitated in this fashion, even as much as 20 inches falling in a season of 1 or 2 months, though it may nourish certain forms of plants adapted for development in the short time during which the soil is moistened, the region may be classed as arid, for it will be unable to maintain our ordinary forests and except when artificially irrigated will be generally unfit for tillage.

Arid soils commonly exhibit certain peculiarities which are not found in those of ordinary humidity; they are usually of more than average depth, for the reason that while the amount of water may be quite sufficient to promote the chemical decay of bed rocks, there is not sufficient passage of the fluid through the débris to bring about much deportation of the material in the state of suspension or solution. Even where the mass of débris is tolerably deep and open in its structure continued droughts preceding the time of rain and the general absence of a layer of vegetable mold commonly cause the soil to present a dense baked surface which may shed the rain like a roof. So, too, the lack of any but ephemeral vegetation, or of stunted plants which furnish little organic débris, diminishes the amount of mold which is contained in the detritus, so that the mineral elements of the soil are insufficiently mingled with organic matter. Held below the compact surface and with no great amount of transfer of the soluble mineral matter to streams, the soils of this arid nature in time become superabundantly charged with the various saline matters which are of much importance to organic life. Although the process by which these substances are brought into a soluble form goes on more slowly than in the case of ordinary soil, because their removal is not brought about, they slowly accumulate until they become in quantity far greater than in ordinarily humid parts of the earth.

When the potash, soda, and other soluble materials stored in the arid soils become excessive there is a curious action manifested by which they are uplifted to the surface and form a coating upon it. This coating may appear as a thick and enduring crust, such as occurs in certain parts of the well known alkaline plains of the arid region of the Cordilleras. The process by which these saline materials are brought to the surface is as follows: When in the season of brief rains the soil becomes for a time tolerably wet a large part of the alkaline matter is taken into solution in the ground water. The dry air evaporates a portion of the fluid next the surface, and this, passing into the form of vapor, leaves its mineral contents at the place where it went into the atmosphere. As the interstices of the soil are left empty by the disappearance of water, some of the fluid from below rises to the surface and in turn goes through the same process. In arid as in other soils the spaces between the grains act in the manner of those in a lamp wick to draw up the lower fluid to the point where it escapes by the action of heat in the form of vapor: as in the lamp the solid material contained in the oil forms a crust at its top, so the mineral matter of the soil water incrusts the surface of the earth.

In the manner described in the preceding paragraph, the alkaline materials of arid soils in times of drought migrate to the surface; if the rainfall be sufficiently heavy, it may in the next wet season dissolve the crust and return the material to a lower part of the soil; if the rainfall be less in quantity, it may happen that for at least a term of years the crust will remain on the surface of the soil. The effect of this excess of soluble material is gradually to add to the sterility of the earth in which it occurs; but this influence is frequently transitory; it endures but for a short time after the soil is by art provided with sufficient water to wash away an excess of soluble materials. These alkaline districts are in most cases admirably suited for betterment by irrigation; it requires but a thorough washing out of the excess of saline matter, such as can by irrigation be quickly brought about, to convert such a district into fertile ground. In general these earths which contain an excessive amount of soluble material lie in the more level portions of the country; where the soil is upon steep slopes, the effect of gravity, acting upon the surface water as well as that which penetrates the ground, is to urge the fluid more rapidly down the slope and thus to secure the deportation of the alkaline matter; consequently the more steeply lying land of the district may be exempt from alkaline crust, while the flat country may be covered with the coating.

It is a noteworthy fact that in the region of the great basin of the Cordilleras the valley deposits are coarse and pervious to water in their margins near the bases of cliffs, but fine and impervious in the centers of the several basins whereunto only the finer portions of the detritus worn from the mountains has been conveyed by the action of water and air (see Pl. XIV).

In many parts of the United States the ordinary brick used in masonry, after being built into a wall, frequently exhibits an alkaline crust, the formation of which is exactly comparable to that found in the arid plains of the Cordilleran district. When a wall composed of these brick becomes soaked by a beating rain various soluble substances are dissolved by the water which has penetrated the masonry. During dry weather this water evaporates on the surface of the wall substantially as it does on the surface of the soil, and a similar coating is formed. Unless pains be taken to scrape away this facing crust the greater part of the matter will be returned to the brick during the next spell of rainy weather, and so sometimes for 20 years or more the alkaline matter will perform a succession of journeys into and out of the baked clay.

It must not be supposed that the formation of this alkaline coating is altogether peculiar to arid districts, though its results are most evident in those fields. The same action takes place on all soils whatsoever in the change from wet weather to dry. Even in regions of ordinary rainfall where the earth is fairly rich in soluble salts the attentive eye will detect the beginning of such a coating. It is the frequency of rainfalls which prevents the sheet from becoming a distinct feature. It is perhaps worth while to note the fact, though it has been before adverted to, that it is to this constant elevation of the plant food nearly to the top of the soil which enables our grain-bearing plants to find sustenance in large quantity near the surface.

In certain rare cases the process of watering arid land, if a sufficient exit for the fluid is not provided, leads to the formation of an alkaline crust; thus in the delta of the Nile, where the quantity of water available for irrigation is scanty and the price set upon it high, people have endeavored to economize by providirg insufficient exit for irrigated land. In this case the alkaline materials derived from the deeper portions of the soil form a coating on the surface during the long dry season, and the vegetation suffers from an excessive amount of mineral matter in the soil, which is in a state to be taken into solution. When these alluvial deposits were formed they contained no excess of soluble material, but lying for ages in the deposits they have become more decayed and thus a relatively large part of the mineral matter enters into the soluble state; it is evident that this affords an excellent example of the progressive decay of detrital materials deposited in the river plain.

Much of the exceeding fertility which characterizes the lands of the arid district when they are properly irrigated is doubtless to be accounted for by the peculiarities of climate of the region in which these fields lie. In such a district the sky is prevailingly cloudless and the measure of sunlight which comes to the surface is much greater than in humid regions. The result is that if their roots be well supplied with water, many plants flourish in the dry air with much greater luxuriance than where the moisture comes to them altogether from the rain which falls on their leaves or on the ground about them.

In most cases the soils which are now arid have not been in that state for any considerable geologic time. Their present condition is due to climatic changes which appear to have come about with the decline of the glacial period. This alteration is most conspicuous in the Cordilleran region of North America. It is also evident on the arid western coast of South America. It is especially marked in the district of the Rocky Mountains, in northern Mexico and the United States, where we find the surface dotted over with old lake-beds the waters of which once covered a large part of the area, making the country one of the most extended and beautiful lacustrine fields in the world. Many large lakes, like that in its shrunken form known as Utah or Salt Lake, occupied extended plains and valleys which now contain only the diminished remnants of those seas. In place of fresh water these lakes now present alkaline or salt pools of trifling extent. When these inland seas were full of fresh water there must have been a relatively great rainfall in this region now arid. The valleys which at present are the seat of streams only during the brief rainy season were then occupied by large and permanent rivers, so the soil generally must have been the seat of luxuriant forests. The result of these variations is that the existing detrital deposits of that region are in part at least derived from a time when soil-producing agents were more active than at present. It seems very doubtful if the existing soils of this area could have been formed in the conditions which now prevail.

The insufficiently leached soils of the arid region shade off indistinctly into the better watered soils which surround them. Sometimes, indeed, where the region is far too arid to permit the growth of forests or the use of the land for tillage, but where it is of an open texture, the rainy season being characterized by a brief but abundant downfall of water, the leaching process, though limited in duration to about a month, is sufficient to prevent the soil from retaining an excess of alkaline material. Whatever be the precise nature of these arid soils, and they are almost as varied in their qualities as those of normal humidity, they commonly prove of unusual fertility when redeemed by a proper system of irrigation. This fertility is due to the fact that they have not had their soluble material freely transported to the sea by the excurrent ground water. Moreover, a large part of their mineral constituents are in a decayed state, and thus readily pass into a condition fit for plant food as soon as the mass is supplied with water and intermingled with the waste of decaying vegetation.

Passing from the arid soils to those which are excessively humid, we traverse a wide gradation in the conditions of these detrital deposits as regards the amount of their water supply. The range is very great in the quantity of rain which falls upon the surface of soils classed as neither arid nor inundated; it may be taken as varying from 15 to 600 inches per annum. This difference has no such effect as would at first sight seem likely to ensue, for the reason that whatever the amount of water which falls upon the surface the excessive supply has no effect upon the deposit, after the interstices of the soil are filled, save to swell the streams and thus increase their carrying power. The soil takes in rain water up to a certain point, which is determined by the speed at which the fluid can drain from the detritus into the streams; any additional amount is surplusage and has no influence on the under earth. On the other hand, when the quantity of water in the soil is less than is required for the maintenance of its functions, unless, indeed, it has become baked by enduring drought, the pores of the earth greedily drink in not only the rain but even the dew which falls each night. This provision for the dew is generally disregarded in the account taken of the water supply of a country; yet it is often of as great value as the rainfall, and sometimes maintains a moderate fertility in a land which would otherwise be sterilized by drought. During the time when the dew is falling and lies upon the ground and the foliage, a period that commonly lasts for about half the day, evaporation from the earth and from the leaves of plants is arrested. Moreover, many of the lesser plants have their leaves and stems so arranged that their expanded surfaces gather the water and lead it down to the roots, and thus moisten the earth in the most advantageous manner.

When during any period of drought in the upper part of the soil, however dry, the capillary or wick-like action of the spaces between its grains causes the water to rise from the lower levels to the field occupied by the roots. Herein lies one of the advantages of securing a deep soil by proper methods of tillage; the water can be stored in the interstices of the lower levels, and when demanded can be brought to the upper levels where the roots can obtain access to it. Forest trees can penetrate the under soil and seek out the stores of water in the lower earth, sometimes to the depth of 10 feet or more; but more delicate annual plants, which afford the greater part of our crops, can not in their brief period of growth push their roots more than 6 or 12 inches below their crowns.

SWAMP SOILS.

As long as the measure of humidity is such that a soil may occasionally become moderately dry, so that the air can penetrate into the interstices, it may be regarded as still in the class of normal deposits of this nature, wherein the supply of water is such that the alternate wetting and drying can not take place, but the interspaces being continually filled it enters into the group of swamp soils. In this class of deposits the exclusion of air makes the matter unfit for the needs of most plants; their roots can not secure the æration which they demand; in fact, there are only a few rather singular species which can make their roots serve them in a soil which is continually filled with water during the growing season.

Swamp lands exhibit considerable diversity as regards the origin and nature of the deposits which constitute their soils; in all cases, however, they are characterized by a greater proportion of organic matter on their surface, or in their upper part, than is found in ordinary soils. This is due to the fact that when animal or vegetable matter is immersed in water it decays more slowly than when it is in succession wetted and dried. Woody substances when submerged in water gradually pass into the state of peat or muck, and beyond that stage of decay change goes on very slowly or is entirely arrested. The normal result is that in these inundated areas there is an ever thickening deposit of half-decayed plant waste, which generally contains not more than from 5 to 10 per cent of mineral matter—far too little, indeed, to give it the qualities of a good soil. Although the roots of certain plants find their needed sustenance in these swamp accumulations they are essentially unfit for the growth of the ordinary forest trees, and for nearly all the tillage plants until they have been drained and subjected to an exposure of the air for a considerable period. When unwatered and allowed to undergo a sufficient decomposition from the action of the atmosphere they invariably prove to be of great fertility, and endure the tax of culture remarkably well. A large part of the best lands in Europe have been won to tillage from ancient morasses. In this country the area of such lands which are suited to improvement by means similar to those which have been successfully adopted in the old world exceed 100,000 square miles. In general lands of this class constitute a most important reserve, from which extremely fertile fields may in time be obtained, capable in the aggregate of supplying food for a population nearly as great as that now contained in this country. It is therefore worth our while to glance at the history of these morasses, noting the diverse conditions under which they are formed and the effect of these on their possibilities of reclamation. A more detailed explanation will be found in the general account of inundated lands in the Tenth Report of the Director of the U. S. Geological Survey.

The simplest class of swamp deposits is formed where a thick forest growth, in a region of no great excess of rainfalls and of approximately level surface, leads to the retention of water in the soil to an injurious degree. In such an area the dead leaves and branches encumbering the ground so delay the passage of water to the streams that the clearance is not effected from one rainy period to another. In this case the plants, particularly mosses, reeds, and rushes, possess the ground; species of trees originally inhabiting the district are generally expelled, and the field remains deforested or is occupied by those varieties only which can live amid the hostile conditions. In many parts of the world this action leads to the deforesting of extensive tracts of tree-covered ground, a sheet of bog earth taking the place of the original growth. In earlier states of this process the pioneer may easily convert the ground into tillable earth by clearing away the forest and breaking up the thin sheet of swampy matter with the plow. When the deposit has so far thickened as to drive the forest trees away, however, the layer of spongy matter is generally too deep for immediate tillage, and the field must be improved by ditching. This class of wet woods is less common in the United States than in the region to the north; yet such areas, often of great extent, are common in the part of the country east of the Mississippi and north of the Ohio and the James rivers, and are of occasional occurrence in more southern and western fields. Morasses of this sort are most apt to occur in cold climates where the snowfall is great in quantity and where the summer is moist. Under these conditions the ground has not time to dry during the short summer season. They are particularly likely to be found where the area has newly been elevated above the level of the sea and has the characteristic nearly flat surface proper to ocean floors. Whenever the surface slopes toward the streams with a descent of less than 5 feet to the mile, unless it is

VIEW IN THE DISMAL SWAMP OF VIRGINIA, SHOWING CHARACTER OF VEGETATION IN THAT DISTRICT.
The growth on the right of the canal is a canebrake.

underlaid by very coarse porous soil, it is likely to take on this upland swamp character. The great dismal swamp of Virginia and North Carolina lies on a fine sandy soil with a slope of about 20 inches to the mile, yet it is covered by a thick layer of peaty matter (see Pls. XXVII, XXVIII and XXIX).

Next after the sloping upland group of swamps we may note those inundated lands which lie on the alluvial plains of our greater rivers. These are due to the frequency or persistency of floods which rise above the channel of the river. They are usually most extensive and difficult to win to the uses of culture along the lower banks of a river where its waters are checked by the nearness of the sea, and the height of the plains is lessened by the fact that the slowing current has allowed all but the finer sediments to lodge in the upper parts of the valley. As is well known, these fluviatile plains are almost always highest nearest the margin of the river, and they slope thence toward the hills which bound the valley in the manner indicated in Fig. 14. Although the elevated border of the terrace may have sufficient height above the river to furnish the drainage necessary for a normal soil, the lower lying back country is usually so depressed as to have a swampy nature. The waters from these "back swamps" are with difficulty discharged, for any small stream which may cut through the elevated strip next the river is likely to be from time to time closed by the sediments of the main stream or blocked by driftwood which readily enters the passage which its mouth forms through the alluvial plain. Generally the drainage of these swamps is effected by a gentle drift of waters parallel to the river which goes on until the volume is great enough to secure a permanent exit to the main stream. As this current is checked by the mass of living and dead vegetation through which it passes it often comes about that these back swamps are maintained when there would be dry land in case the path for the escape of their waters was free (see Pl. XXIX).

The fluviatile swamps include another class of morasses formed when the stream abandons a portion of its channel seeking a shorter way to the sea. These swamps do not differ from those formed in lakes and will be considered under the head of lacustrine deposits. It is characteristic of the back-swamp deposits of the river plain, as in general of all of this class of sediments, that they commingle organic and inorganic matter in a very perfect way. Thus these fluviatile swamps contain a much larger proportion of inorganic sediments than the commoner class of morassal deposits formed in lake basins. The result is that these soils when drained are in almost all cases at once fit for tillage without the time-consuming and costly process of removing the excess of vegetable mold. When adequately drained they can usually be made serviceable to the farmer at once. The greater part of the delta of the Mississippi is occupied by morasses of this nature. The fertile lands at the mouth of the Rhine are also to a great extent winnings from the same class of inundated soils.

The last group of fresh-water morasses which needs be mentioned in this paper is that which owes its character to the lacustrine conditions of its deposits. Whenever a water basin is formed without distinct current movement, a number of aquatic species of plants differing in various parts of the world, but all fitted for growth in very humid soils, seize upon the earth at the margin of the basin and proceed to accumulate a layer of vegetable mold upon and beneath the surface of the water. If the level of the lake be variable in a considerable degree, or if from its size and form of shore all parts of the coast line be subjected to strong waves, these plants may not succeed in beginning the work of filling in the basin with vegetable matter; but it commonly happens that in the shallowed parts of the shores the mosses of the genus Sphagnum and some few flowering plants find a foothold and create a layer of living and dead roots, leaves and stems, forming a tough peat. This deposit, though it begins to grow on the shore, gradually extends out over the surface of the water on which it floats. As it grows on the top it settles down into the lake and finally comes to rest upon the bottom. While this top sheet is forming and extending its margins by continued growth in its upper parts, it is decaying in its under portion and

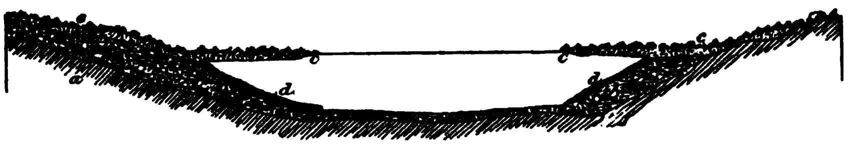


FIG. 21.—Section across ordinary lake in glacial drift. *a*, bed rock; *b b*, drift; *c c*, growing peat floating in water; *d d*, decayed peat on bottom; *e e*, climbing bog.

the fine carbonaceous mud is settling to the bottom. When the process is finished the lake is closed with the peaty accumulation. Only the larger areas of water, which have at the same time more considerable depth and thus by their powerful waves break up the advancing sheet of organic growth, can keep their basins open, however wide they may be, for their bottoms are shallow, the growth of reeds, rushes, or lilies is likely to form a natural breakwater in front of the peaty layer which serves to fend their assault from the spongy advancing shelf. In this manner at least nine-tenths of the very numerous lakelets which existed in the northern part of the continent at the close of the glacial period have been closed with organic waste. (See Fig. 21.)

Unlike the peat which forms in the swamps of alluvial terraces, that of the lacustrine swamps generally contain but little mineral matter. It is indeed so devoid of it that it can not be used for tillage until the ground is not only drained but the peaty layer burned away or allowed to decay in the slower manner in which atmospheric action effects this end. Deposits of this nature are often so deep that the task of removing the vegetable matter is practicably impossible of execution. In this case the only way in which these areas can be made of profit is by using them as nurseries of certain species of trees, to which they are often

RECLAIMED FIELDS IN THE CENTRAL PORTION OF THE DISMAL SWAMP, VIRGINIA.

well adapted. The juniper and the bald cypress, the tupelo, the water maples and the willows and the birches, as well as a number of other useful timber trees, have developed a certain endurance to the excessive humidity of swamps. In certain cases, as in that of the tupelo and the bald cypress, the tree has developed a peculiar form of roots which causes the aeration of sap in such a manner that it can withstand an amount of moisture sufficient to destroy many other species. It is probable that the greater part of our lacustrine swamps will in time be made to serve as nurseries of timber.

Another form of agriculture in which these peat swamps can be made of use is indicated in the method in which cranberries are extensively reared in Massachusetts, and elsewhere along the coast as far to the south as southern New Jersey. This form of tillage is perhaps the most original of any which has been invented in this country. In preparing swamps for this mode of culture, the top part of the original bog, that containing all the living roots and stems, is cut away, and the lifeless muck which lies below the removed layer is covered with a layer of sand several inches in depth, which is evenly spread over its surface. In this layer of sand the plants are rooted, and through it may descend to the underlying vegetable matter. The advantage of the sandy layer consists in the fact that the weeds do not readily root in it; moreover, it affords a firm footing to the laborer. It is likely that this method of tillage may advantageously be followed in the case of other economic garden plants, which, while they require dry ground for their crowns, luxuriate in a soil abounding in vegetable matter.

The soil bed of modern fresh-water swamps, the layer which lies beneath the accumulation of peaty matter, is commonly not of a fertile nature. This is owing to the fact that the movement of water which takes place through it is generally slight; little air penetrates into the interstices, and so the decay of its stony material goes on slowly; there is none of that constant overturning of materials, which, as we have seen, takes place in ordinary soils, such as those on our uplands. The deposit formed on the bottom of our swamps does not constantly descend by the process of mechanical and chemical erosion through the strata on which it lies, and thus there is no renewal of the fertility of the bed due to this action. Influences, however, are at work which bring about the formation, just above the bottom of the swamp, of a deposit of greater or less thickness which commonly contains a considerable amount of lime phosphate, a substance of great value in the production of most economic crops. The mode in which this accumulation is formed is not yet well understood, but it seems to be in general as follows:

In the water of most modern swamps as well as stagnant pools there commonly dwell a great variety of small crustaceans which have the habit of appropriating the phosphatic matter from the animals and plants on which they feed. This material they deposit in the outer coat of their body, or, as it is commonly called, the "shell." When these creatures die, their remains are doubtless in part dissolved and reappropriated by other organic forms, but in part they find their way to the bottom, and there along with other mineral materials form a layer rich in fertilizing matter. If the water which enters a morass is charged with iron, this layer generally appears as a bog ore; but in most swamps the amount of the oxides of this metal is so small that the deposit is not of that nature, and the phosphatic material is thus the more ready to serve the needs of the plants which call for it. The solubility of lime phosphate is much less than that of other compounds of lime, so that it is not borne away in solution as readily as ordinary limestone would be; in consequence of this limited solubility the bottoms of the swamps often come to contain a remarkable amount of grain-producing material. (See Fig. 22.)

The phosphatic matter which finds its way into swamps and is there stored in the deposits accumulated on their bottoms is doubtless in all cases derived from the rocks lying in the region whence the streams

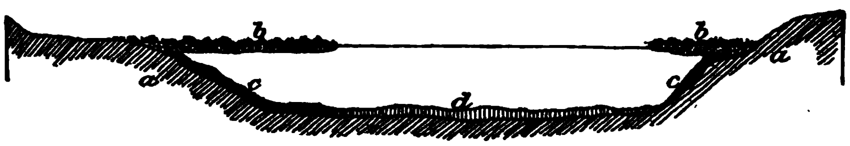


FIG. 22.—Diagramatic section through lake basin showing formation of infusorial earth. *a*, bed rock; *b b*, floating peat; *c c*, decayed peat; *d*, infusorial earth.

which flow into the morass drain. Almost all strata except the purer sandstones and flinty rocks contain a notable quantity of this substance, which was built into their masses at the time when they were accumulated on the ancient sea floors, the material coming to its position in the bodies of fossil animals and plants, which in turn obtained it from the sea water. Entering the swamp through the rivers the lime phosphate is first appropriated by certain water plants; these are eaten by fishes and crustaceans, and when these animals die their skeletons convey the phosphatic material to the floor of the bog, where it is slowly built into a layer.

It is through the local accumulation of phosphatic matter in something like the manner above described that the swamp soils accumulated on the sand of eastern Virginia and North Carolina have been made exceedingly fertile. In that region, through the enrichment which the organic forms of the swamp waters have contributed to the deposit on the bottoms of the morasses, the drained ground affords extremely fertile fields. Thus, while the sandy region about the Dismal Swamp is essentially worthless for grain crops, the dewatered swamp land yields even to a rude tillage exceedingly large returns. These fields often afford rich harvests for many successive years without any fertilizing whatever. (See Fig. 23.)

VEGETATION IN THE FRESH WATER SWAMPS OF CENTRAL FLORIDA.

The swamp lands of the United States, which are the most redeemable and which when won to the uses of agriculture afford fertile fields, lie mainly on that portion of the Atlantic slope between New York City and the mouth of the Mississippi River. Almost without exception these morasses lie at such height above the sea that by the use of simple engineering contrivances they may be effectively dewatered. In general these fresh-water swamps are covered with a dense growth of timber, which, owing to the fertility of the soil, is intermingled with a very thick growth of underwood, climbing vines, reeds, and other water-loving plants, so that the cost of clearing away the luxuriant vegetation must be added to the considerable expense which is afterwards required in draining the land by ditches. Nevertheless the quality of the soil is so good and its endurance under cultivation so continuous that the next great step in the economic development of the eastern portion of the United States will probably consist in the redemption of these inundated lands. In the general accounts of the swamp districts of the United States contained in a memoir published in the

FIG. 23.—Diagramatic section from seashore to interior of district recently elevated above the sea level. *a a*, bed rocks; *b*, beach deposits and dunes; *c c*, marine sands with gently rolling surface.

Sixth Annual Report of the Director I have given a somewhat special account of these redeemable swamp lands. It may be here noted that some of the largest fields for the enterprise of the engineer lies in the State of Florida, where there exists about 28,000 square miles of country more or less adapted to such improvement.

Although, as before remarked, the larger part of these coastal swamps of the United States are covered by dense forests, certain fields which are destitute of arboreal growth invite improvement. Thus a large part of the Everglades in southern Florida is open land, but is almost covered by a growth of reeds and other relatively slight vegetation. There are also considerable areas, generally lying in the central portion ot timbered swamps, which are so far covered with water that they appear as tolerably permanent lakes, such as Lake Drummond, of the Dismal Swamp, of Virginia. In most regions these lacustrine areas will, when drained, afford fertile ground, but in some instances their bottoms have not received a coating of vegetation and remain as bare sands, scarcely more fitted for the uses of agriculture, even when thoroughly drained, than the general surface of the plains which lie without the limits of the morass.

MARINE MARSHES.

The last class of humid soils which we have to notice is that which includes the varied forms of tidal marshes which are formed along the seashore. These marine morasses are produced wherever there is a tidal movement of more than 1 or 2 feet in altitude. They accumulate in the indentations of the shore which are sheltered from the action of the greater waves, for the reason that in more exposed places these surges break up and scatter the frail accumulations as rapidly as they are formed. Like the lacustrine swamps, marine marshes begin with the growth of a fringe of vegetation next the shore; but while the mosses play the principal part in forming the peat deposits of fresh water, the grasses, certain species of which have the capacity of enduring salt water, do the work of constructing these marine deposits. The shelf they build is at such a height that its upper level falls just below the plane of high tide, so that with each oscillation of the waters a depth of a few inches is for an hour or two laid over the surface of the marsh. Each recurring tide not only refreshes the plants but it also brings in among them more or less floating débris, which catches in the tangle of the stems and gradually adds to the mass of the deposit. Beginning to grow, with water of considerable depth, the shelf in this manner gradually attains to near the level of high tide. This sheet of dense fibrous peat, composed mainly of plant remains, is mingled not only with the materials washed in by the tide, but is in part composed of the waste

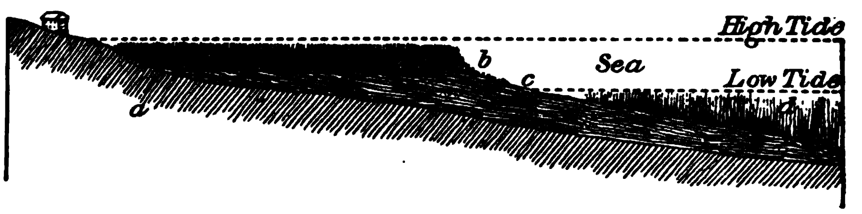


FIG. 24.—Diagrammatic section showing the origin and general structure of marine marshes. *a*, original surface at shore line; *b*, grassy marsh; *c*, mud flats; *d*, eel grass; *e*, mud accumulated in eel grass growth.

derived from the numerous small animals, such as shellfish and crustaceans, which dwell in the interstices between the plants. Unlike the lake swamps, this sheet of organic matter, formed as above described, never floats on the water; it lies upon the bottom and firmly adheres thereto. At the margin of this sheet of vegetation the waves from time to time break up the structure of the mass and distribute the waste over the bottom of deeper water, thus shallowing it and making it easier for the organic shelf to advance farther into the bay (see Fig. 24).

The construction of this tidal peat is still further favored by the growth of the interesting plant commonly known as the eel grass (*Zostera maritima*) a species of true flowering plants that has acquired the habit of living with nearly all parts of its body permanently below the level of water. Even a portion of its flowers are permanently covered by the sea. Growing in a densely crowded manner, this singular plant, by its remains and by the quantity of detritus which it gathers in its entangled foliage, shallows the areas of the bays in which it grows and so makes a foothold over which the higher lying turf gradually extends. Favored by these conditions, the tidal marshes gradually spread over the shoals of our bays, finally closing all the sheltered inlets of the coast except where the depth and width of the indentations is such as to permit the waves to beat against their shores with great violence. Thus along the coast between New York City and Portland, Maine, the growth of these peculiar marine marshes has diminished by more than one-half the area of the harbors which were occupied by tolerably deep water at the close of the last glacial period. The total area of these accumulations which are now bared at half tide along the part of the shore above referred to exceeds 350,000 acres.

Along the shore-line between New York and St. Augustine, Florida, these tidal marshes are very extensive and widely distributed; they contain an area many times as great as that presented by the shore of New England. The total surface which they occupy has not yet been well ascertained, but it probably amounts to some thousands of square miles. It is a noticeable fact, however, that the character of these marine marshes gradually alters as we go southward; with the change of species of the plants which compose them and the alteration in the energy of tidal currents due to the diminished height of oscillation they exhibit a marked change in their character, the plants grow less thickly, and the deposits often assume the character of muddy flats. South of St. Augustine and around the shore-line of Florida these marine marshes are generally covered with a growth of mangroves, a tree of curious structure and habits which by its peculiarities is able to grow in salt water. It is probable that within the limits of the United States the total area of marine marshes, including only the deposits which are bared at half tide and which owe their formation mainly to the growth of grass-like plants, is nearly 10,000 square miles.

The quality of the soil which may be won from these organic accumulations of the shore land is excellent. Owing to the abundant remains of animals, they are remarkably rich in those materials which are most necessary for vegetation and which are rarest in ordinary upland soil; lime, potash, soda, and phosphate are commonly present in relatively large quantities; in fact, these marine marshes in their excess of soluble materials in many ways resemble those which are found in arid districts. In both cases the excess of such matter is mainly due to the imperfect circulation of water through the soil; in the case of the arid land from the lack of water; in that of the marine marshes, from the fact that the fluid does not, during the brief time when the mass is exposed to the air, have a chance to discharge the water it contains.

When these marine marsh lands are won from the sea they afford soils of remarkable fertility and endurance to the tax of culture. It requires, however, a certain time after the surface has been barred from the sea before the soil of the marsh is fit for tillage; the tough layer of fibrous roots must first be destroyed by decay or by fire and the excess of saline materials removed by solution in rain water before the earth is adapted to the growth of plants which yield valuable crops. These changes will spontaneously take place in the course of from 3 to 5 years after the sea is excluded from the marsh, but by breaking up the surface with a plow and cutting frequent ditches through the plane a single year will often suffice to bring the soil into the state where any of our domesticated plants will grow upon it. At first, in just the manner of the arid fields of the desert region, and for the same reason, this marine marsh soil will in times of drought form a crust of saline materials on the surface. As the drainage becomes more complete this crust ceases to appear, as it does on the alkaline plain after a thorough irrigation. As the excess of organic matter decays the surface of the reclaimed marsh settles down until it comes to rest at a point of from a foot to 18 inches below its original level.

Some of the richest fields of this country are yet to be won from these salt marshes of the ocean shore. So far but little has been done to reclaim them. A few small areas in Massachusetts, New Jersey, and Delaware, probably not amounting in the aggregate to more than 5,000 acres, have been diked from the sea and reduced to subjugation more or less complete. Of these reclaimed areas the largest lies in Marshfield, Massachusetts. Here a district of about 1,500 acres has been separated from the ocean by means of a small dike. There are many other places along the shore between New York City and Portland, Maine, where areas of from 50 acres to 16,000 acres can, in a similar way, be reclaimed at a relatively small expense. By the use of proper machinery the cost of diking, ditching, and breaking up this class of soils will probably not on the average exceed $100 per acre. Considering the exceeding fertility of fields thus won from the sea and their remarkable endurance to agriculture, which permits them to be cropped for a generation without the use of fertilizing materials, they may fairly be regarded as remunerative investments even at this considerable cost of preparation. The experience of the seaboard states of northern Europe clearly shows that these marine marshes afford a most valuable resource for the future of American agriculture.

TULE LANDS.

Among the many local varieties of soil which have attracted attention and received special names we may note one of the most interesting varieties, known in California as tule lands. These deposits are to be ranked in the group of swamps. They mostly occur in the valleys of the San Joaquin and Sacramento and especially in the lower portion thereof. They consist of very extensive marshy districts which are subjected to inundations and which occupy in general the position of alluvial plains in other parts of the country. Near the level of the sea these marshes are mostly occupied by species of the round rushes; at higher points in the valleys is a greater variety of grass and rush-like vegetation.

It has been found that when these lands are subjugated by drainage or by burning the peaty matter in the dry season the ground is admirably adapted to grain crops. Even without plowing, after treatment by fire, the ashy soil yields remarkable returns of wheat.

It seems likely that the relatively very great fertility of these tule lands as compared with the reclaimed swamps of the eastern part of the United States may be explained by the comparative dryness of the country in which they are found. There are many reasons for believing that the climate of the California district is prevailingly drier at the present time than it was in the immediate geological past. It seems, therefore, likely that, although at many places still quite wet, these swamps have somewhat dried away; a good deal of their vegetable matter has decayed and the ashy waste thereof is commingled with the peat which remains, adding much to its fertility. Moreover, the quantity of dust transported through the air in this part of the country is great, and in the course of time the contribution of enriching sediment from this source has probably been considerable.

There appears to be more variation in the character of these tule lands than in swamp deposits in other parts of the country. Thus it has been noted that those which lie near Tulare Lake afford a heavier soil than similar deposits found elsewhere in California. A detailed discussion of these variations here would be out of place; moreover, the present writer has not had the opportunity personally to observe them.

ANCIENT SOILS.

Although the soil-coating of the earth is in a certain way an ephemeral structure and is commonly subjected to immediate destruction where it is affected by the action of the waves, by glacial wearing, or by other violent accidents, some parts of this detrital coating in certain times and places have by chance been preserved to us from a remote geologic past. The first clearly recognizable deposits of this nature are found in the rocks of the Carboniferous age, where, indeed, they plentifully occur; beneath each bed of coal we commonly discover a layer of material which was the soil in which began to grow the plants from whose remains the coal bed was formed. So as far as these coal-producing plants were rooted forms they generally drew their sustenance from these ancient soils. We can still in many instances trace their roots, and occasionally we find the tree fern or other plant to which they belong standing erect amid the swamp deposits which accumulated about it, and which now appears as coal. These soils of the Coal Measures differ from those now existing on the upland parts of the earth in certain important ways; they are generally of less thickness than are those of to-day which have been formed under similar conditions, and contain a rather smaller proportion of organic matter. These peculiarities are probably due to the fact that in the olden time there were few kinds of plants which had strong roots, and thus there was less opportunity for vegetable matter to become commingled with the earth (see Fig. 25).

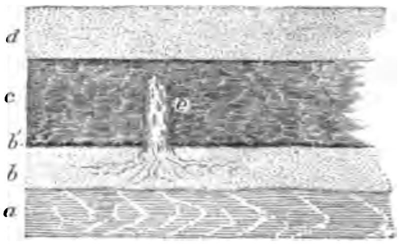


Fig. 25.—Section through coal bed. *a*, bed rock; *b*, under-clay or ancient soil; *b'*, position in which iron oxides often occur; *c*, layer of coal; *d*, sandstone or other bedded rock; *e*, fossil tree, with roots in under-clay.

The most peculiar feature of these ancient soils consists in the fact that they usually lack those materials, such as potash and soda, which are a conspicuous and necessary element in the greater part of the soils of the present time. The general absence of such material has led to the occasional use of these ancient deposits as fire clay, i. e., materials which will endure without melting the high temperature to which they are exposed in furnaces. In any ordinary soil a white heat will cause the siliceous element of the deposit to melt, for the reason that the lime, potash, or soda which it contains will combine with the silica when the mass is greatly heated, thus forming a glass or cinder. It is not likely that the present condition of the Carboniferous soils is that which they exhibited when plants first began to grow upon them; at that time they may have had the usual share of alkaline substances; but the very conditions which made these soils the seat of swamps secured the surface on which they lay from wearing downward in the manner common in ordinary districts, and so prevented the constant renewal from the underlying rock of the materials removed by vegetation. The result was that in time the earth below the swamp accumulation was deprived of the matter which could be removed through the action of plant roots. So far as these plants by their conditions of growth could take up soluble minerals of the soil, they removed them, storing the matter in their stems and leaves. When the plants decayed their waste fell into the peaty accumulation and gradually the mineral matter became leached out and conveyed away to the sea. As there was no means of restoring plant food, the soil gradually lost the power of contributing to the growth of plants. Thus while in the case of ordinary upland soils the process of decay in the underlying rock continually adds to their fertility, while the waste of vegetation is constantly returned to the earth, in most of these swamps of the Carboniferous time, on the contrary, all the conditions serve to pauperize the layer. Owing to various causes, however, some of which are to be noted hereafter, the soils beneath our modern swamps do not in the same complete manner undergo the process of exhaustion.

It is probable that the progressive removal of the soil matter from beneath the swamps of the Carboniferous period had much influence on the development of the peaty material which in time became converted into coal. The larger part of their carbonaceous material was formed from the waste of plants which required a certain amount of mineral matter for their support. This the plants had to obtain through their roots. After the swamp attained a certain thickness, the continual leaching away of these substances would gradually limit the growth of the plants which tenanted the morass, and finally the growth might be entirely arrested by lack of such material to support the vegetation.

PRAIRIE SOILS.

There is another important group of soils which owe their peculiarities not to any excess or insufficiency in their water supply, but to the circumstances of their geographic situation and organic history. These are the prairie lands of the Mississippi Valley, and the similar soils which are found in various parts of the world. The origin of the prairies of this country has been a matter of much discussion, and many theories have been advanced to account for their existence. In the state of nature from which they are now rapidly passing, these wide fields were generally unforested rolling plains with scanty woodland growth, which was mainly limited to the neighborhood of the streams, while their surface was covered by a dense and rank herbage of annual plants, mainly grasses springing each season from perennial roots. Along the banks of the permanent streams and in swales of their surface there were strips and patches of woodland, but it was often possible to journey for a day without seeing a tree. This untimbered country was in marked contrast with much of the neighboring land. Thus a large part of Michigan and Ohio and portions of Indiana were densely wooded, and these districts lie on three sides of the extensive prairie district which existed west of the Mississippi River. The soil of these prairie lands generally afforded a combination of mineral and organic matter exceedingly well suited to grain crops, so that when subjugated it yielded ample returns to tillage.

Among the several explanations by which it was sought to account for the treeless yet fertile nature of the prairies we may note the two which seem most important. It has been held that the prairies owe their unforested condition to the exceeding fineness of division which characterizes their mineral material, it being supposed that such comminuted matter was unfavorable to the growth of trees. This does not seem to be a reasonable supposition, for we find that when occupied by civilized man the prairie soil will nurture a great variety of trees quite as well as any other soil. There is therefore no reason to suppose that the condition of the soil can in any way account for the failure of the forest growth to take or keep possession of these districts. It has been supposed by some that these prairie districts have recently been occupied, in large part at least, by great lakes, the extension of the freshwater seas such as Michigan and Erie, or perhaps other basins of the northwest. While it is probably true that a considerable portion of the prairie districts have been thus recently submerged, it seems certain that this fact can not in any way account for the absence of forests, for the reason that a large part of the area in northern New York, Ohio, and Pennsylvania was also recently occupied by extensions of the great lakes which lie in the vicinity, yet these regions are abundantly timbered. It seems therefore certain that the forest trees have had time to return to the prairie district, especially as there are scant patches of varied wood along the streams and other wet places in prairie districts.

The most essential peculiarity of prairies consists, as is well known, in their treeless nature. This feature may be well explained in the following simple way: The region they occupy is characterized by periods of enduring drought, which reduces even the forest-clad portions of the country to conditions of extreme dryness. At such times forest fires will spread with great celerity and extend to vast distances; even in the relatively humid districts of Michigan such conflagrations, though opposed by all the arts to which the settlers can resort, often extend for scores of miles. The native Indians of this part of the country were in the habit, through carelessness or design, of firing the prairie grasses every spring. Such fires swept like a whirlwind over the plains and were rarely interrupted in their ravages by broad rivers or by swamps. They would extend into the margins of the forest, and if the vegetable mold was not very retentive of moisture would result in the destruction of all young trees in the wood. In pine woods such fires would destroy all the vegetation with which they came in contact.

It is likely that in the far West, near the foot of the Rocky Mountains, where the climate after the close of the glacial period became excessively dry, the soil may have ceased to bear forests because of its arid nature. The process of burning may then have extended the prairie country to the eastward until the condition of open ground was brought into districts where the amount of rainfall was sufficient to maintain forest trees.

Evidence that this timberless character of the plains east of the Mississippi river has been brought about by the spread of fires is afforded by the conditions which existed in Kentucky during the latter part of the last century. While the Indians used this region as a hunting ground, the district between Louisville and the Tennessee line, extending thence westerly along the southern border of Kentucky to the Cumberland river, was mostly in the condition of prairies. Except near the streams and on the margin of this so-called "barren district," the forests were scarred by fire. There were no young trees springing up to take the place of the old and thick-barked veterans of the wood, which from the hardness of their outer coating could resist flame. When these mature trees died they had no succession, and so the prairie ground became gradually extended over the area originally occupied by forest. After the Indians were driven away about 50 years elapsed before the country was generally settled, and in this period the woods to a considerable extent recovered possession of the areas of open ground. The periodic firing of the grass having ceased, seeds were disseminated from the scattered clumps of wood, and soon made them the centers of swiftly spreading plantations. It was the opinion of the late Senator Underwood, of Kentucky, who had seen this country in the first years of the present century and who was a most intelligent observer, that the timberless character of this district was entirely due to the habit which the aborigines had of firing the grasses in the open ground.

It is an interesting historical fact that the first settlers of the country deemed the untimbered limestone lands of western Kentucky infertile, and therefore gave to them the name of "barrens." They were led to the conclusion that these lands were sterile by the fact that in their previous experience the only untimbered lands with which they had come in contact were unsuited to agriculture. It is not likely that the Americans or their British forefathers had ever seen any soil which was, before it was subjugated, in anything like the condition of the prairie lands, unless it may have been inhospitable fields near the seashore or certain small areas of a fertile nature in the Shenandoah Valley, which had been deforested by Indians, probably also by means of fire. Several years passed after the settlement of Kentucky before the true character of the so-called "barren" lands was ascertained and they were found to be generally of a very fertile nature. Meantime young forests rapidly extended and much of the country which was in a state of prairie had to be stripped of this woodland growth before it was ready for the plow.

The extremely fertile nature of prairie soil when it is first tilled is easily explained. Owing to the generally level character of the district occupied by these open lands the soils were deep, for the reason that they did not have the chance to slide down to the streams in the manner which we have seen to be common in hilly districts. The frequent burning of the rank growth of vegetation constantly returned to the soil large amounts of potash, lime, soda, and phosphatic matter in the soluble form which is suited to the needs of grain-giving plants. As the deposit lay on nearly flat surfaces and the rainfall was moderate in quantity, the ground water did not bear the soluble materials away to the stream as rapidly as they were formed. The result was that when these prairie regions were submitted to the plow they yielded in a few years the store of plant food which had been garnered during many centuries of preparation. Unfortunately, their primal fertility has not proved very enduring; the layer of fruitful earth is generally of only moderate depth, and with the reckless agriculture which commonly characterizes this country they have been in most cases within 30 years brought to a state where they afford only a moderate return for the labor bestowed upon them. The crops of wheat which originally were 30 or 40 bushels to the acre are, after a generation of culture without artificial replacement of fertilizing materials, reduced to an average of about 16 bushels. It should be noted, however, that even where the original fertility of these prairie soils has been materially diminished they are readily restored to something like their pristine condition by a proper system of tillage, in which deep plowing and a reasonable use of fertilizers alike find a place.

The effect of the vegetation which occupied the prairies for many centuries before the coming of white men was to draw the soluble portion of the fertilizing substances to the upper part of the soil, and to leave the subsoil unaffected by any of that peculiar work which is accomplished by the strong roots of forest trees. These, as we have seen, tend to draw mineral substances from the deeper portions of the subsoil and from the bed rocks, accumulating the material in the growing vegetation, whence its return to the upper part of the soil by process of decay. Much can be done to help these soils by deep plowing and by the the process known as subsoiling, whereby deeper layers are opened to the access of air. In a word, we need to imitate in the prairies the peculiar task which has been performed in most districts by the roots of trees.

WIND-BLOWN SOILS.

Last among the soils of peculiar history we may consider those where the mineral materials have been brought to their position by the action of wind. In most countries this group of soils is of small importance, and in North America the blown-sand areas do not occupy in the aggregate more than two or three thousand square miles of surface. The most easily recognized accumulations of this class are those which form along the seashore, where winds blowing inwardly to the coast carry the dry sands from the beach and deposit it in the form of hill-like masses, termed "dunes." These heaps of blown sand often march slowly and with a variable movement far inland. The blast of the wind drives the grains up the more exposed side and over the summit, where they drop in the lee of the mass of the hill. These "dunes" sometimes rise to the height of one or two hundred feet above the base. Wherever they are formed on open ground they have a ridge-like character, the long crest lying transverse to the direction of the prevailing winds. Where the dry sand enters the forest lands the accumulation is often in a more sheet-like form, and this because the close-set trees destroy the movement of air currents. (See Fig. 13.)

When they first start from the shore the dunes are usually composed of very clean sand, the grains of which are of about the same size in each layer of the deposit. The material is of a finely divided nature, but occasionally the stronger winds convey to the mass pebbles as large as ordinary peas. As the dune advances farther from the shore they come into a region where the energy of the storms is rapidly diminished by the friction of the air upon the surface; the pebbles are then left behind in the path of the dune and only the finer materials are conveyed onward. As this motion of the marching sands is usually at the rate of a few feet each year, the matter is partly decomposed by the action of air and rain, so that vegetation finds a chance to take root upon it. As the living mantle grows thicker it gradually restrains the action of wind, until finally the mass is brought to rest.

Migrating sands are formed not only along the seashore and along the shores of the greater lakes, but also beside the banks of rivers, which cut through deposits of glacial drift, where the sands have been separated from the clay. Thus some of the most extensive, or at least the most widespread, dune deposits occur along the eastern sides of the greater New England rivers, as for instance in the district bordering the Merrimac, between Nashua and Concord, New Hampshire. They are less conspicuous and characteristic beside the rivers in these districts, for the reason that the areas are generally forest-clad, and so the deposit appears in the form of a broad sheet accumulated between the trees.

As compared with Europe, deposits of blown sand in the form of dunes are relatively rare on this continent, because on the eastern coast, where alone sandy shores abound, the prevailing winds are from the west and air currents thus serve to prevent the extension of the blown deposits for any distance into the interior. A narrow strip of dune sands borders the Atlantic coast from Cape Florida to the eastern end of Long Island. They are tolerably abundant on Cape Cod and the islands which lie south of that cape. The northernmost point at which any considerable deposit of this nature occurs is in Massachusetts, immediately west of Cape Ann. At no point, however, do these dunes extend for more than about 3 miles inland from the sea, though there are some lying at points farther inland, accumulated when the seashore lay somewhat farther westward than it does at present. The slight incursion of these dunes is due to the great violence of wind during easterly gales. The rate of movement of the storms, however, does not persist for any distance from shore, and the material thus imported is subjected to the constant attack of the less violent but more prevalent westerly breezes.

The most important interior deposits of dune sand are found along the borders of the great lakes in the Laurentian system of waters. Of these the largest and most interesting area lies at the south end of Lake Michigan.

Although a portion of the sand included in these dunes has been derived from the existing beach of the lake, it is probable that the greater portion came from the ancient shore of that water which, during the last or Pleistocene geologic epoch, lay at a higher level than at present.

Similar deposits of blown sand, essentially like dunes in origin, though commonly of a more sheet-like nature, are apt to be formed in regions where the surface is covered with fine débris, but where there is not enough rain to support a vegetation sufficiently luxuriant to protect the detritus from the action of wind. This is the case in the Sahara and other deserts, where a large part of the detritus was formed on ancient sea floors or accumulated when the climate permitted the construction of soils, but where the arid conditions now prevent the growth of plants.

In such desert regions the winds are continually bearing away large amounts of sand and other finely divided rocky matter which accumulate in marching dunes within the desert region and often invade the better watered countries on its margins. Thus the sands from the Sahara, marching before the west winds, have already entered and devastated considerable portions of the valley watered by the Nile. The general effect of these movements of air-driven detritus is to impoverish the surfaces which they cover. The deposits themselves, owing to their very siliceous nature and their extreme permeability to water, are of little service to plants, and therefore are worthless for the uses of man.

It should be noted that the dunes formed by the disruption of soils which, though once well watered, have through climatic changes become extremely arid are less infertile than are those which are formed from the coast detritus. The reason for this is readily seen. While the coastal sands have by washing been deprived of all their clayey matter and are thus generally of a nearly pure siliceous nature, the detritus of the desert contains a large part of the finely divided and fertilizing materials which belonged to the soil before it was broken up. Owing, however, to the action of the wind, this finer material is commonly driven to a much greater distance than the coarser débris. The result is that in many of the desert areas in the Cordilleras the pulverized rock matter has blown away from the surface leaving a sheet of pebbles and other rock fragments where there was once a distinct soil. In the eastern portion of Asia, about the head waters of the great rivers of China, there are vast accumulations, sometimes a thousand feet or more in thickness, composed of fine dust which has blown from the desert area of that continent into the more humid region of the eastern part of the continent. The masses accummulate in the form of a table-land, sometimes filling deep valleys which were excavated in a time before the dust invasions began. Deposits of less extent and thickness essentially like those in China have been formed by the migrations of dust in several other parts of the world. In the western Mississippi Valley, especially in the northern portions of that area, are considerable accumulations of fine-grained detritus evidently brought from a great distance. This material is commonly known as loess; its origin has been a matter of much debate, but it seems likely that it is in part at least due to the action of the wind blowing the fine detritus from the region about the eastern face of the Cordilleras into the central portion of the continental valley.

In larger part, however, the loess of the Mississippi Valley probably owes its origin to conditions which existed during the last glacial period, when the region in which it lies received the fine flour-like sediments ground up beneath the ice and borne forth to the margin of the glacier by streams of fluid water which flow beneath such ice masses. This fine-grained and therefore easily transported detritus appears to have been distributed over wide areas adjacent to the main stream in the northern part of the great valley. As these soils, which owe their origin to drifting dust, are generally formed by the descent of the particles into interspaces between the growing vegetation much in the manner in which it accumulates in alluvial terraces, the mass commonly takes on a horizontal distribution well suited to the uses of agriculture. The mineral substances of which it is composed are usually much oxidized before they enter on their journey, and owing to the way in which they are laid down amid the growing vegetation they become thoroughly mingled with decayed vegetable matter. Thus while the march of the wind-driven soils is in an immediate way devastating, the movement of the lighter part of the débris may be advantageous to the soil of the districts in which it comes to rest.

None of the dune deposits in this or other countries have any value for tillage purposes. In fact their only human interest consists in the dangers which they may bring to fields and habitations. In Europe this is often serious. In the region at the head of the Bay of Biscay an extensive territory has been covered by these sands and reduced to a state of sterility. It has required a large amount of official care to restrain the march of these blown sands in that part of France. In eastern England a considerable village known as Eccles was, more than a century ago, overwhelmed by the vast marching dune. So thick was the accumulation that not only were all the houses deeply covered, but the parish church was buried beneath the mass. After more than a century of inhumation, the subsequent march of the wandering hill has begun to disclose the houses of the village, and it seems not improbable that in the course of another century the heap may pass by the site of the town.

We have now completed our general survey as to the effect of the varied conditions which operate in the formation and preservation of soils. This account is incomplete as regards details, but it is to be hoped that it may give the reader a general idea as to the balance of the organic and inorganic actions which affect this admirable life-giving coating of the earth, the zone from which all the higher life springs forth, and to which, after the appointed term of existence, it quickly returns. We have seen that the adjustment of these conditions permits the soil to form and do its appointed work in varied states of the earth's surface. We have now to consider some of the effects of human culture on the soils, and also in a measure the reactive effect of this envelope upon the estate of man. In this field of inquiry we shall find a large and varied set of problems which can be considered only in a very general way.

ACTION AND REACTION OF MAN AND THE SOIL.

The primitive men, at least in their savage state, had very little influence on the soil—much less, indeed, than many species of lower animals. As long as men trusted to the chase, to fishing, or to the resources afforded by wild fruits and grains for their subsistence, and to chance stones picked up along the stream for their weapons, they were practically without influence upon the soil. When, however, our kind took the first long step upward in the arts and began to till the earth, a new and momentous influence was introduced into the assemblage of soil conditions. Even in its simplest form tillage requires that the natural coating of vegetation shall be stripped away in order that the plants which have been selected for culture shall have entire control over the nutriment which the earth affords. Agriculture, moreover, requires that the soil shall be overturned in order that plants may in the open textured earth have a better chance of pushing their roots easily and swiftly through the mass in search of food. Both these processes are exceedingly subversive of the original conditions of the soil. They manifestly tend to break up the adjustments by which the deposit is created and preserved. While in the wild or natural state the surface is generally covered by an assortment of trees of varied species, as well as of lesser undergrowth, the roots of which are always deepening the detrital layer and winning new and lower-lying stores of nutriment. Moreover, in this condition the earth is well protected from the detrimental action of the rain by a coating of decayed organic matter which is constantly working down into the true soil.

In its primitive state the soil is each year losing a portion of its nutrient material, but the rate at which the substances go away is generally not more rapid than the downward movement of the layer into the bed rock. Thus from age to age the detrital mass, save by unusual accidents, is neither thinned nor impoverished. But when tillage is introduced, the inevitable tendency of the process is to increase the rate at which the soil is removed until the destruction begins to trench upon its depth and fertility. When mantled with its coating of vegetation, which in its natural state is never violently disturbed, the earth yields to streams only that part of dissolved matter not seized upon by the dense tangle of roots, which in most cases occupies the whole of the detrital layer. Except for the undissolved sediments worn away along the banks of the stream or the shores of lakes and seas, no part of the soil, while it remains in its normal condition, goes away in the state of mechanical suspension.

If the reader would acquire a distinct eye impression of the difference between the conservative conditions which prevailed in the soil before man's interference and the destructive state which exists afterward, he should during a time of continued rain resort to some of the numerous valleys of the Appalachians where the country is but partly subjugated by man. He will there observe that the streams which drain the district where tillage prevails are charged with a burden of detritus won from the soils. This is shown by the reddish yellow hue it has imparted to the water flowing from the valleys where tilled lands lie. While most of the tributary brooks send out such turbid waters to the main stream,

FORM OF SURFACE IN AN ELEVATED REGION SOUTH OF THE GLACIATED BELT.

The fourth ridge from the foreground lies in a field which has been for some time untilled, and which is beginning to be gullied by the rain.

Near Natural Bridge Va. Looking North.

House Mtn in background.

we here and there find one which, though swollen by the rain, lacks all such coloring matter. The stream is either pellucid, or, if stained, has the brown hue which decayed vegetation may impart. On investigation it will always be found that streams which flow clear water drain from valleys in which the primitive forest is unbroken, while those charged with a load of detritus are from districts where there are extensive tilled fields. After a little practice in observation it is possible from the share of mud in the waters of a brook to tell how far the clearing away of the forests has extended in the valleys whence it flows. Where, as in the valley of the upper Missouri, the vegetable coating is extremely incomplete, owing to the present arid state of the country, the torrents which form in times of rain may, from the ease with which they wear the unprotected surface, convey large amounts of detritus in their waters. This, however, is an exceptional condition of the natural soil (see Pl. XXX).

In this country, where the lands have been tilled for a relatively short time, the evils arising from the waste of soil when it is bared of vegetation are not so pronounced as in many parts of the Old World, where extensive districts have to a great extent been devastated by this action. Thus in many parts of the Mediterranean region, particularly in Italy, the soil upon the slopes of steep hillsides, which once bore luxuriant forests, and which might with due care have been made the site of rich pastures and orchards, are now reduced to the state of bare rock. In the region immediately north of Florence there are upland districts where it is possible to walk for miles without setting foot on anything in the way of soil which has any arable value whatsoever; yet in this section but a few centuries ago there was a thick layer of fertile forest mold, which, when the woods were swept away, was quickly washed down upon the plains or into the sea.

The effect of the extensive culture of European soils is shown in the proportionately large amount of waste carried out in the form of mud by streams which drain that country. The Rhone and the Po, which flow from two of the most completely tilled districts of the world, discharge with their waters enough detritus to lower the surface of the country which they drain to the amount of about 1 foot in each thousand years, while the Mississippi, which drains from a valley as yet imperfectly tilled, carries to the sea only about enough detritus to lower the surface by one foot in 7,000 years. Although the evils arising from the washing away of the soil in America have not as yet been very serious, a close reckoning of the loss would probably show that it already amounts to the practical destruction of that coating over an area some thousands of square miles in extent. These depauperated districts lie almost altogether in the region to the south of the glacial belt, and mainly in the hilly portions of the so-called Southern States, especially in Virginia, the Carolinas, Kentucky, Tennessee, and Mississippi. There is scarcely a county in these States where it is not possible to find a number of areas aggregating from 300 to 500 acres where the true soil has been allowed to wash away, leaving exposed to the air either bare rock or infertile subsoil. Where subsoil as well as the truly fertile layer has been swept away the field may be regarded as lost to the uses of man, as much so, indeed, as if it had been sunk beneath the sea, for it will in most instances require thousands of years before the surface can be restored to its original estate.

Where tillage, without due care for the needs of the soil, has led to the destruction of the superficial layer, while the subsoil is retained, the damage is remediable, provided pains be taken to smooth over the ridges and furrows with which the earth is seared, and to clothe the surface in grass. Those who find themselves charged with such care will do well to observe what happens when any steep slope is deprived of its forest covering and is left unprotected by such a coating as is formed by grass roots. As soon as a surface of this nature is laid bare, the rain, gathered into rills, begins to cut in the manner of mountain torrents, the separate channels often being separated from each other by intervals of only a few feet. As long as the beds of these rivulets are in the friable earth they wear rapidly downward, and thus keep

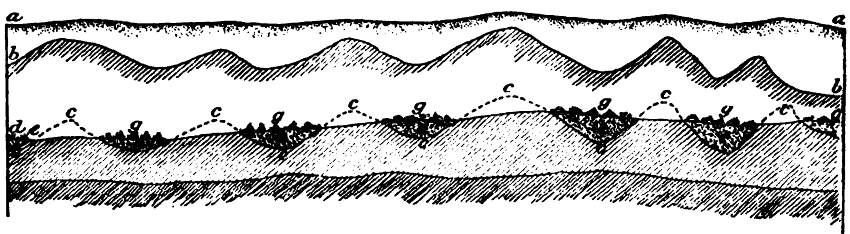


FIG. 26.—Diagrammatic section showing process of formation and closing of gullies on hillsides. *a a*, original surface; *b b*, gullied surface; *c c*, original outline of gullies; *d d*, outline of healed surface; *e e*, detritus washed into gullies; *g g*, vegetation serving to retain detritus.

the sides of their little valleys very steep; they often, indeed, form an angle of 30° or more in inclination. The earth when moistened slips down these declivities with such speed that no vegetation has a chance to take root upon them, and so the process of degradation may go forward at the rate of several inches a year. Where certain species of trees or bushes, such as willows, are naturally or artificially planted in the furrows in so close-set an order that they may check the rapid currents, and by their roots prevent the down-cutting of the streamlets, the erosion may be checked and in a few years the surface will again become smooth. The mode of this action is indicated in the accompanying diagram, which represents successive stages which have taken place in a rain-furrowed field in the limestone district of northern Kentucky in a term of 10 years (see Fig. 26 and Pl. XXX).

It is most important that the conditions of this rapid erosion, which is likely to take place on a large part of the lands of the earth, should be clearly understood and its consequences distinctly apprehended. The prime cause of this danger is due to the reckless effort to win for

VIEW SHOWING THE GRADUAL PASSAGE FROM ROCK TO SOIL.
In the right foreground is a small recent talus formed since the excavation was made.

plow-tillage land which is fit only for other and less unnatural forms of culture. Wherever the inclination of the slope exceeds about 5° of declivity (or one in twelve), except where the soils are remarkably permeable to water, it may in general be said that justice to mankind demands that the field be as far as possible exempted from the influence of the plow. Such land should be retained in grass or in orchards, or used as a nursery for timber.

Although our land is still almost of virgin fertility, a heedless neglect of our duty toward it has led to the destruction of the soil over an aggregate area of probably not less than 4,000 square miles. This means the loss of food-giving resources which would be sufficient, with proper care, to support a population of about one million people. Besides this annihilation of the earth resources in the area where the soils have been allowed to wash completely away, a vastly more important though less visible damage has been done by the partial destruction of the nutritive layer, in the course of which it has been thinned and worn to a point where it will no longer pay the cost of tillage. When brought into this impoverished condition it is, in the common phrase "turned out," or, in other words, committed to the slow process of redemption which the natural agents of soil-making may bring to bear. It is fortunate that over the most of this country, perhaps over three-quarters or three-fifths of its tillable land, the surface has such a gentle inclination, and the native grasses form so firm a sod, even on exhausted land, that these abandoned fields do not wash away, but are allowed slowly to recover from the brutal ill usage to which they have been subjected.

The total area of these abandoned fields which lie in the States of Virginia, Tennessee, and Kentucky alone amount, according to the estimate I have made with some care, to between five and six thousand square miles, or about one-thirteenth of the total tillable surface of these States. Taking the lands of the United States as a whole and basing the estimates on numerous local inspections of the conditions of diverse areas, I am satisfied that at least five per cent of the soils which have in their time proved fertile under tillage are now unfit to produce anything more valuable than scanty pasturage. The average impoverishment of the area which has been subjected to the plow is not to be computed; but from the statistics of grain production, as shown by the successive censuses of the country, it seems not unlikely that it amounts to 10 per cent or more for the whole country. It is greater in the South and in the new States of the Mississippi Valley than in the eastern portions of the Union, because careful tillage has long been made possible in the last-named section by the high price of farm products.

A portion of this waste of our soils has been inevitable and not blameworthy, for it has been due to the rapid extension of the population over districts so remote from markets that it was only by methods of tillage which taxed the earth to the utmost, that any profit could be had from farming. We have, indeed, thus paid away much of our birthright in the fertility of our soils as the price for a swift expansion of our population. Although there may be a certain justification, as above noted, for a portion of our soil-wasting, a larger part of it has been brought about by an ignorant neglect of certain simple but inexpensive precautions which to a great extent would have saved the progressive decline in the productive value of the earth. Although these precautions are almost self-evident, it may be worth while to set them clearly and briefly before the reader.

First of all, every husbandman should clearly understand that the process which he follows in obtaining crops from the soil is essentially unnatural. In the state of nature all that the vegetation takes from the earth is promptly returned to it by the processes of decay. Therefore it is evidently necessary to limit as far as possible the tax laid upon the earth in our artificial treatment of it, and to provide in every practicable way for the replacement of the substances removed by the harvests. The details of methods by which the pauperizing of the soil may be avoided belong in the main to the science and art of agriculture; there are, however, certain questions in relation to these matters on which the geologist may be allowed a word of comment. The natural method of preventing the progressive thinning of the soil due to the material removed by crops and to the washing away of its substance in the state of mechanical suspension is by deepening the layer of detritus and making it as open-textured as possible. This end can best be attained by thorough tillage, especially by the process known as subsoiling, whereby the compact lower layers of the soil or even the decayed portions of the bed-rock, if they be near the surface, may be disrupted and the matter put in a condition to become dissolved and made available to plants. In this way, while the surface may still wear down at a rate much more rapid than when it is forest-clad, the lowering of the base of the soil may be made to keep pace with it. Moreover, by keeping the detritus near its original thickness and also open-textured, a larger portion of the rainwater will enter the earth and, moving slowly toward the open drainage channels, may not scour away the débris. By this downward extension of the soil the mass of detritus within a given area which can yield plant food is likely to be increased, and so the earth becomes better fitted to the peculiar drain which tillage imposes on its mineral stores (see Pl. XXXI).

Our common method of shallow plowing continued year after year to the same depth tends to create a few inches below the surface an artificial hardpan formed by the pressure of the base of the plow. At best this instrument of tillage is a rather clumsy contrivance for the end it seeks to accomplish: its action is that of a wedge driven through the earth, which divides and overturns the soil above the share while it compacts and smears the lower portion over which it slides into a mass which, if the material be at all clayey, as is the case with all good soils, becomes in a few years almost as impervious to water as a roof. The result of this action of the plow is to limit the penetration of the rain-water to the upper part of the detritus, which is loosened by tillage, and also to prevent the penetration of roots and increase the danger of the materials washing away.

These evils may be in a great measure avoided by a few simple expedients. When only the common plow can be used, the depth of the furrow should be varied from year to year so that the compressed level where the heel has trod may often be broken up. Where possible some subsoil-breaking implement should frequently be used to open the lower portion of the detrital layer to the entrance of water and of roots. Among the many means by which these ends may be attained we note the familiar device of sowing certain crops, such as red clover, the plants of which have strong tap roots; these, save in very compact earth, will penetrate to a greater depth than that to which the plow is ordinarly driven and thus serve to make water ways and paths for the roots of weaker species into the subsoil.

Although a certain amount of gain may be had by varying from season to season the depth to which the plow is set and a yet greater advantage from subsoiling, every description of plow is more or less injurious to the soil through the smearing and compacting action which it inflicts upon it. It is a most unfortunate limitation of agriculture that spade tillage is so much more costly than that accomplished by the plow. One of the greatest desiderata in connection with our farming is an instrument which will overturn the earth in the manner of a spade—that is, without compacting the lower portions of the deposit in order to overturn the upper parts. No one who has carefully compared the condition and product of fields which have been long tilled by these two instruments, the plow and the spade, can doubt the destructive effect of the first-named tool. There seems to be no essential mechanical difficulty in the way of the inventor who would seek to produce an instrument which would delve the earth as does a spade. The amount of power requisite to effect the overturning should certainly be much less than that expended in the rude rending work which the plow effects.

It is a common practice to remove all or nearly all the woody matter of our crops from the soil on which it has been produced. The result of this process is that in a few years the earth comes to lack that share of decaying organic substance which its normal functions require. It should be remembered that in the state of nature soils have commonly from 5 per cent to 20 per cent of their mass composed of such organic débris; any considerable decrease in the amount of this material will more or less completely arrest the processes by which mineral substances are gradually brought into a state in which the plants can make use of them. The introduction of this organic débris is partly accomplished in tilled fields by allowing the weeds and other wild plants to occupy the surface during a period of fallow. The waste from this growth when turned in with the plow serves in a certain but generally insufficient measure to secure by its decay the conditions necessary for the solution of rocky matter in the earth. When, as is often the case, this vegetable waste is burned before the ground is plowed, although the mineral materials are returned to the soil in the form of ash, the principal end is not attained. The only really effective way of maintaining the due share of organic matter in soils is to plow in well chosen green crops. Even where, as on a small portion of our American fields, barnyard manure is occasionally used, the quantity of vegetable waste thus introduced into the soil is likely to be inadequate.

Wherever there is a considerable exportation of crops from any district it is impossible, save with extraordinary care, to avoid a diminution in the fertility of the soil. The sale of each bushel of grain or other product of the fields permanently removes a part of the resources of the earth. However carefully the barnyard and other manures may be gathered and returned to the field, this progressive waste is inevitable. If the soil retains its fertility it is because of its speedy descent into the underlying rocks. The rate at which the exhaustion proceeds is generally in proportion to the immediate success of the agriculture. Farming is, in general, a process of selling the birthright of those who own the land.

A century ago it would have seemed to a considerate observer aware of the principles above laid down that the progressive decadence of our soils was something which could not be contended against, and that the process was sure in the end to bring every land to the state in which its food-producing resources would be exhausted; but within the last 50 years we have learned to seek in the mineral kingdom for various chemical substances which are removed from the soil by crops, and which may thereby be returned to it in quantities required to maintain its fertility. This use of mineral fertilizers, at least on an extended scale, began with the introduction of guano, the dried waste of bird life which had accumulated on the islands of a nearly rainless district off the west coast of South America. Guano appears to have been extensively used by the Peruvians long before the conquest of the continent by the Spaniards. It was first brought to Europe and introduced to the attention of agriculturists about the year 1840. Shortly after that time a very extensive trade in the substance was established, and in the course of twenty years it led to the substantial exhaustion of the principal fields of supply. Owing to the increase in the price of this substance the attention of chemists was called to the possibility of making similar fertilizing materials, using as a basis the geologic deposits of lime phosphate, soda, and potash. At first this new art was practiced for the purpose of adulterating the natural guano; but, unlike a majority of such sophistications, it has led to a new and most important industry—that of manufacturing mineral manures.

The greater part of these artificially produced fertilizers consist of a mixture of natural earths containing lime phosphates, etc., along with fish-waste, blood, and other materials which afford ammoniacal materials. It is now, however, becoming clear that excellent manures, though they act less quickly upon the soil, may be produced altogether from the mineral kingdom. Even the ammonia required to make compounds the most speedily effective may be obtained from materials formed in the process of making gas or coke. It seems likely that the principal ingredient of these fertilizing combinations most required in ordinary crops and most deficient in soils, viz, the lime phosphate, may soon be afforded in such quantity that it will be an easy matter each year to restore to the earth all the substance which is withdrawn by cropping. So rapid is the present advance in the arts whereby avail is made of the mineral manures, that we may confidently anticipate the time when from the rocks of the deeper earth we shall obtain the means for restoring fertility to all soils where a reckless neglect of the fields has not allowed the framework of débris to be utterly destroyed.

The amount of these mineral manures now known to exist is great enough to meet the demand which would arise if the fertility of our soils were to be perfectly maintained by their use for centuries to come, and it seems likely that we have but begun to discover deposits of this nature which exist in different parts of the world. Within five years, in Florida alone, areas underlaid by lime phosphate have been brought to the knowledge of the world which contain a sufficient quantity of that material to restore the fields of North America for generations to come. Soda may be had in limitless quantities from common salt, and potash abounds in a number of minerals, such as feldspar, from which the extraction is difficult, and in glauconite or green sand, whence it may readily be separated. It seems likely that in the progress of art the methods of preparing this last-named substance from common varieties of rocks will become cheaper, and so the last of the more indispensable and most easily exhausted of the fertilizing materials of the soil may be supplied to the needs of the husbandman. When these mineral manures come into general and skillful use agriculture will enter on a new stage of existence; it will no longer be an art so gross in its methods as to lead as now to a general destruction of the soil, but a science by whose well devised means the fruitfulness of the earth will be constantly maintained and enhanced.

The influence of soil products won by tillage on commercial and other lines of development deserves a more extended notice than can be given here. More than any other creature, civilized man has come to depend upon the earth for a variety of needs, of which the primal and most important are served by the soil. Although climate, geographic position, and the resources of the deeper earth have much to do with the prosperity of our kind, the character of the soil as regards endurance of tillage and the crops which it nurtures is of the first importance. It is impossible for us to consider this matter broadly, but a few instances may be given which will serve to show the reader how on this continent the characteristics of soil have affected the history of its population in various regions.

One of the first of the peculiar effects on the history of civilized man in America brought about by the nature of the earth is found in the circumstances attending the culture of the tobacco plant. This vegetable proved peculiarly well suited to the soil of Virginia and Maryland, and therefore, even in the first century of the history of the colony, it became the principal staple in their trade with the Old World. On the returns given by this industry the political and social culture of the central colonies of the Atlantic coast chiefly rested. To it also in the main was due the profitable and rapid extension of African slavery. In a similar manner the soils of the more southern States proved in the present century well adapted to the culture of cotton, a crop which led to the establishment of large and numerous plantations, and thus to the further diffusion and firmer establishment of the slaveholding system. Though in part due to climatic features, this system by which the descendants of Africans were held as slaves is principally to be accounted for by the characteristics of the earth in southern States. If that part of the country had been provided with soils like those in New England it would have had a very different economic and political history.

We perceive the effects of soil on the diffusion of slavery in a yet clearer manner when we examine into the features characteristic of the local distribution in States in which it was by law established. In the plain lands, where the soil is adapted to cotton or tobacco, slavery was dominant, indeed we may say universal; but in mountain areas, where the small fields could not be profitably tilled by slaves, the institution never found a place. In eastern Kentucky and in parts of western Virginia and North Carolina negroes have always been exceedingly rare. There are populous counties in this region where no member of that race has ever been a resident either as slave or freeman. This absence of slaveholders in the hilly and mountainous portions of the South naturally had a great effect in the issue of the civil war which that institution caused. The people of this rugged country of the Appalachians did not to any extent sympathize with, and often took up arms against, the slaveholding communities of the lowlands. As this nonslaveholding district almost cut the South in twain, its influence on the conditions of the contest were momentous. Something like the same effect was perceptible in single States. Thus in Kentucky we find that a majority of the people on the richer lands where it was profitable to keep slaves were led to cast their lot with their kindred of the same class in other parts of the South, while those dwelling on poorer soils, where they knew nothing of the institution, were overwhelmingly on the Federal side in the debate. It seems almost certain that if Kentucky had been provided with a uniformly rich soil, suited to large plantations, it would have joined the other Southern States, to the great advantage of the Confederates and to the serious injury of the Federal cause. In a struggle so nearly matched this difference might have been of decisive importance.

Not only in the doubtful issue of the war but also in the more computable triumphs of peace the character of soil in this country has greatly influenced the history of its people. A striking instance of this effect may be noted in the advance of population from the seaboard district into the Mississippi Valley. Thus, while it required nearly two centuries for the English colonies of the Atlantic coast to break their way through the rough country of the Alleghanies and then through the dense forests of the lowland region in the eastern part of the Ohio Valley to the margin of the prairie land of the West, fifty years has served to win to their uses the yet greater area of the timberless or lightly wooded country of the Far West. Although something of this speedy contest must be attributed to the rapid diffusion of railway and steamboat transportation, yet more is to be allowed to the influence of the open nature and easy subjugability of the soil in these areas. It is clearly one thing to push forward the frontiers of a civilization where each acre has to be slowly and laboriously stripped of its timber and, if it be in a glaciated district, of its bowlders also, and it is quite another undertaking to extend cultivation over a prairie district where a plowman may turn a straight furrow for miles away from his starting point. An incidental but closely related effect of this open state of the land in the central and western portions of the Mississippi Valley is seen in the rapid increase of population in this country and the great commercial prosperity which it has attained. The influence of the breadth of this region has not only been felt in the States which have sprung up like magic in the Northwest, but in the Eastern States as well. The population of the Unites States would probably at the present time be some millions less than it is if the central part of the continent had been densely wooded as far west as the one hundredth meridian.

It would be possible very much to extend the citation of these instances in which conditions of soil have determined, in a certain measure at least, the history of our people; we can, however, instance but one other example serving to show how even the system in which the land is held in ownership may be shaped by the character of surface material. The island of Nantucket, Massachusetts, owing to the fact that nearly the whole of its area is composed either of glacial moraine or of extensive sand plains which usually attend these heaps of débris, has, save in limited parts, a very thin soil not generally fit for tillage. The result is that until within a few years the greater part of the land was held in common, or jointly by the people, each owner being entitled to a share in the pasturage rights of the area. If he held, for instance, twelve such rights, he could turn out a dozen sheep to graze on the uninclosed field. Thus, owing to the nature of the soil, we had here perpetuated, in the latter half of the nineteenth century, a form of land tenure which is a survival from a remote time and represents a generally disused system of holding real property.

EFFECTS OF SOILS ON HEALTH.

The influences of the soil upon the health of man and that of his domesticated animals, though perhaps less considerable than those which directly arise from climate, are still of great importance. The cause and nature of these effects are extremely varied and deserve more attention than they have received. It is only in recent years that the nature and origin of diseases have been to any extent accurately known, and therefore the time of such studies has been brief. It will therefore not be possible to make many definite and readily comprehensible statements concerning this division of our subject.

The action of soils in producing or promoting disease in animals or man appears to be due to at least three different causes, viz:

First. The quantity of water retained in the earth immediately determines the humidity of the surface of the soil, and this may have a direct effect on the comfort and health of man and beast.

Secondly. The conditions of this soil water, as well as of the organic matter mingled with it, have a decided influence on the nourishment of many forms of bacteria which it is now well known are sources of disease. The germs of such maladies as cholera, typhoid and malarial fevers, tetanus or lockjaw, and numerous other maladies appear generally to require a residence below the surface of the earth before they can propagate their effects. In fact the larger part of the diseases which occur among human beings and probably a great number of those which afflict our domesticated animals appear to be traceable to the action of certain microscopical organisms that inhabit the soil in the regions where the maladies occur.

Thirdly. Some influence of the soil upon health is due to the quality it gives to drinking water obtained from ordinary springs or wells. Although, for convenience of presentation, we may thus separate the influence of ground water upon health into these three classes, the groups are in fact not thus distinct, but are inextricably blended.

One of the immediate effects of excessive humidity of the soil is to keep the feet of creatures which tread upon it in a condition to favor disease. Thus sheep in wet pastures are more likely to suffer from foot diseases than those in dry fields, the continual moisture of the parts making them a suitable nest for the development of certain germs. Dwellings of men are made humid by excessive ground water, which also favors the growth of certain noxious organisms. This is well shown by the coating of mold which often forms in the lower parts of houses, where the earth is soaked with water. Although the more common forms of this growth are not detrimental to health, the circumstances which favor their development appear to lead to the multiplication of disease-bringing spores. There are other direct evils connected with excessive humidity. When the air is very wet, as is the case near very humid soils, it appears to have a lowering effect on the vitality of men—at least when they are in certain states of health.

From a sanitary point of view the direct effects of excessive ground water are evidently of small consequence as compared with the secondary influences of this evil, which are due to the nurture and dissemination of the germs which it induces. It appears probable that the spores, by means of which many diseases are propagated, undergo multiplication altogether in the organic matter contained in the soil. In the opinion of trustworthy observers the development of these germs takes place most effectively, and they are most likely to be discharged into the air in those regions where the vertical range of the ground water varies greatly, especially during the warmer part of the year. The reason for this is, probably, that when the vertical oscillations of the ground water occur the air is alternately drawn down into and expelled from the interstices of the soil. As this air enters it bears with it quantities of germs which, descending along with the rainwater, plant themselves upon decaying bits of animal and vegetable matter which the earth contains. If, after these spores have multiplied, the soil water again rises to the surface, it bears the crop with it, leaving the material on the top of the ground, where it may be scattered by the wind. When the soil water rises the contained air is expelled and may also bear with it a share of the noxious materials. Where the water of the soil remains at nearly a level the germs are not only less likely to enter the earth, but those which develop there are unable to escape from their underground prison and perish where they grew.

This view of the action of oscillating ground water finds much support from the experience of men in and around extensive morasses such as the Dismal Swamp of Virginia and North Carolina. About the margin of that great area of marshes, where the ground is alternately wetted and dried to a considerable depth, the people suffer from ague, a disease which is generally believed to be caused by some species of germ developed within the earth, but in the interior of the swamp, where the ground water varies little in its height from one season to another, there seems to be a relative, or, in cases, an entire immunity from this malady. Similar evidence is found in the history of intermittent fever in regions which have recently been subjected to cultivation; thus in many parts of the Ohio Valley the early settlers suffered much from this disease, but as obstructions to streams were gradually removed and wet places drained, so that soil water was no longer brought to the surface, this disease has to a great extent disappeared. There seems to be good reason to believe that where the earth has had a chance to become charged with seeds of disease, as about dwellings and cemeteries, any overturning of the soil may lead to the propagation of maladies through the mingling of the spores and the air thus brought about. In the open fields the same effect on germs of soil are doubtless produced, but in such localities spores probably belong to species which are not so likely to be harmful to man as those which develop about habitations or in the resting places of the dead.

The health of people in Holland, in the fens of eastern England, and in similar wet districts in many other parts of the world seems clearly to show that, whatever be the way in which it acts, a variable level of underground water tends to breed disease, while its permanent position, even if it remain near the surface, is not inconsistent with the good health of the inhabitants. So long as the fens of England and the swamps of the Netherlands remained in their natural state and underwent frequent and extensive changes of water level they were generally the seats of malarial disease. Now that the drainage system retains the ground water at about a uniform height these maladies are rare.

In the ideal condition of a tilled district the level of the soil waters is likely to be favorable to health. The aim of the husbandman is to maintain the earth in a state where the water rarely, if ever, rises to the surface. Care as to this point is most desirable, because where water emerges from the soil or stands upon it the effect is to take away by the leaching process a much larger amount of soluble materials than ordinarily escapes by drainage which passes to the stream by way of the spring. Thus the use of underground drains, which serve to keep the soil water at a tolerably definite level, is of great advantage to the earth by restricting the leaching process, and it incidentally serves to diminish the danger which may arise from the escape of germs.

There is reason to believe that the growth of certain kinds of germs within the soil is in a way helpful to fertility; it is indeed likely that the process by which various important substances are brought into a condition to be assimilated by plants is, in certain ways, dependent on the action of these minute organisms, so that the spore-breeding work of the soil, which now and then leads to the injury of man, is only an incidental part of what may be an essential function.

There is reason to believe that, owing to the peculiarities of certain soils, they become especially suited to the development of particular kinds of germs. Thus in certain districts in and adjacent to Long Island, New York, the disease known as tetanus, or lockjaw, is of unusually common occurrence among men and animals. It is the opinion of experts in medical science that this malady is caused by some species of soil-inhabiting bacterian which invests this part of the country. It is observed that a wound which is formed by any object covered with earthy matter is particularly likely to give rise to the disease. Although this malady has been common in parts of Long Island for many years, the evil has never spread to the contiguous portions of the shore east of Point Judith. As there must have been abundant opportunities for the spread of the germs in this direction it seems reasonable to attribute their failure to extend to some peculiarities of the soil covering.

The last effects of the soil upon health which we shall notice are those arising from the use of drinking water derived from this detrital layer. Injuries from this source are commonly due to the fact that ground water is usually full of germs of various kinds developed in that part of the earth from which the spring or well drains. It may often happen that the water flows through the earth for a distance of hundreds of feet before it attains the point where it is taken for use. In the course of this journey it generally becomes abundantly charged with spores. The greater part of these germs are innocuous, but if the earth contains the organisms which produce cholera, typhoid fever, or other ferment diseases, it is quite possible that a very small portion of the soil water can convey the disease.

Besides the disease-breeding organic germs, ground water also in many cases contains various mineral substances which may be harmful to man or the animals which he associates with his life. A familiar instance of this is found in the effects arising from the large amount of limy matter which exists in the ground water of most limestone districts. This substance comes into a state of solution through the capacity which carbonic-acid gas gives to water for taking up and dissolving various minerals. This gas is derived from decaying organic matter in the soil; but for the presence of this dissolved gas the ground water would have a mere trace of lime in solution, but owing to its presence the fluid is able to take up a notable quantity which, though invisible, makes its presence evident by the hardness and flat taste which it imparts. A common effect of this excess of lime is to produce in the bodies of men, and sometimes in those of domesticated animals as well, concretions of a calcareous nature which cause disease. In certain parts of limestone districts of this and other countries maladies due to this cause are of very frequent occurrence.

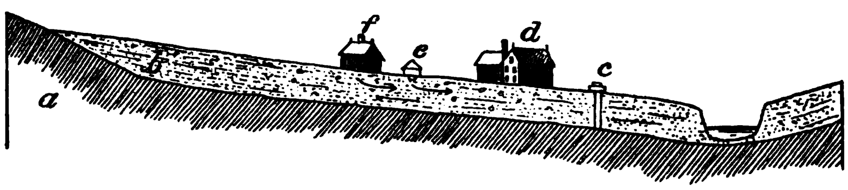


FIG. 27.—Diagram showing one of the ordinary conditions of a dangerous water supply. *a*, bed-rock; *b*, soil and other permeable detritus; *c*, well whence domestic supply is taken; *d*, dwelling house; *e*, cesspool; *f*, barn; the arrows show the direction in which the soil water moves.

Where the ground water is suspected of being the source of disease, the evils it entails may readily be avoided by the use of cisterns to which only the water draining from clean roofs has access. Except in cases where such a supply is defiled, as by a resort of pigeons to the roof or by careless construction of the reservoirs which permits the ingress of soil water, they afford absolutely safe sources for domestic use.

It seems likely that, with the advance of medical science on the lines of its present extension, many diseases of a geographical and limited nature, the causes of which are yet unexplained, will be found to be attributable to the action of the soil in the regions where they occur. Thus the peculiar malady called goitre, which is limited to certain mountain valleys, is now by some students explained as being due to the action of the water which the people drink. In the present state of the science of hygiene the only certain points of value which we have to consider concern the influence of the soil water on the development and diffusion of germs. Where the domestic supply is obtained from the earth it appears essential to the health of a household that the spring or well should be so placed that none of the waste from the dwelling, barns, or stables can contaminate it (see Fig. 27). It appears, furthermore, important that proper drainage should be so arranged that the level of the soil water is not liable to sudden alteration. Furthermore, it appears to be undesirable to have the soil near the dwelling overturned while the house is occupied. This is especially the case where the residence has been long in use.

Although the distance to which germs may be carried in the underground water is not readily determinable, it may be assumed that there is no safety in using the flow from a large spring where any part of the valley in which it lies is occupied by dwellings the sites of which are above the point of exit. The underground channels of such fountains often have a very extended and circuitous course; the water ways, so far as they are carved in the bed rock, are wide open, so that poisonous matter may in a few hours be transported through them for a distance of several miles.

If the space of this report permitted, many instances could be given in which cholera and other fatal diseases had thus been conveyed for great distances. Springs of slight creeping flow and ordinary wells where the water does not enter at one point but seeps in from the side of the excavation, do not usually drain from a distance of more than 200 or 300 feet from the point where the water escapes. It should, however, be remembered that there is sufficient evidence to prove that germs of certain diseases may remain in the soil for several years with undiminished vitality. These germs may by some chance journey go unexpected and considerable distances. Where ground water is used at all for domestic purposes, the only safe way is to take it from a level above all sources of possible contamination.

MAN'S DUTY TO THE EARTH.

The foregoing considerations concerning the origin and nature of soils, though but a brief and inadequate presentation of the subject-matter, will probably convince the reader that this part of the earth which at first sight seems to be a mere mass of ruin and abasement is really a marvelously well ordered and beautiful portion of this sphere. In it the celestial and terrestrial energies combine their work to lift the mineral elements up to the higher planes of sentient life. From it comes the sustenance of plants and animals, both of sea and land. The frame of man is the product of its forces; his form is indeed but a bit of soil uplifted for a moment to the noblest shape of life, then bidden to return to the garner of the earth. Through the ordered and harmonious interaction of the complicated forces which effect in the soil the combined decay of rocks and of organic bodies, materials which seem base and revolting to many fastidious spirits are made the unique basis of all sentient existence. When we perceive that civilization rests on the food-giving capacities of the soil, when we perceive that all the future advance of our kind depends upon the preservation and enhancement of its fertility, we are in a position to consider the duty which we owe to it. This obligation bids us nurture and care for this part of the earth with an exceeding tenderness and affection. It bids us ever remember that it is enriched with the dust of our progenitors, and is teeming with the life which is to come.

In shaping these motives to practice it seems first of all necessary to clear away those crude and indeed painful notions which lead men to look with contempt and disgust upon the soil. If there be any of the great truths of modern learning which more than any others deserve to be imprinted on the minds of youth, it is these lessons as to the nature and function of this beneficent part of the earth. Only through knowledge can we hope to bring men to a proper understanding of the value of the trust which is in their keeping. Until by education we bring people to a consciousness that the wanton neglect of their duty to their kind which an improvident use of the soil reveals is a form of treason to mankind, we can not hope to implant in them a proper sense of responsibility in the management of their great inheritance.

It is characteristic of our time that men seek to clear away evils by means of law. There is a general discontent with the results which have been obtained by the system of individual ownership of land and a growing disposition to qualify and limit the nature of that possession. In considering the questions as to the ways in which the earth's resources shall be administered, it is clearly necessary to bear in mind the needs of exceeding care in the preservation of the fertility of the earth. As long as lands are in the state of forest or prairie, the admirably adjusted forces of nature will insure their preservation. When they become tilled, it is imperative that they be peculiarly well guarded; any legislation concerning the tenure of land should be devised in view of the fact that we need to have not less but more personal interest and sense of responsibility in the management of these problems. It is not proper here to consider the probable effect of the various proposed modifications of the land laws. It seems, however, fit that any such changes as may be made should be planned with a clear understanding of the very serious nature of the needs. When in the future a proper sense of the relations of the soil to the necessities of man have been attained and diffused we may be sure that our successors will look back upon our present administration of this great trust with amazement and disgust; they will see that a state of society in which men took no care of the rights which the generations to come have in the earth lacks one of the most essential elements of a true civilization.

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