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The Rural Science Series

EDITED BY L. H. BAILEY

THE SOIL

•The  Co. •

THE SOIL

ITS NATURE, RELATIONS, AND FUNDAMENTAL
PRINCIPLES OF MANAGEMENT

BY

F. H. KING

PROFESSOR OF AGRICULTURAL PHYSICS IN THE
UNIVERSITY OF WISCONSIN

New York

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EDITOR'S PREFACE TO THE RURAL SCIENCE SERIES.



THE rural industries have taken on a new and quickened life in consequence of the recent teachings and applications of science. Agriculture is no longer a mere empiricism, not a congeries of detached experiences, but it rests upon an irrevocable foundation of laws. These fundamental laws or principles are numerous and often abstruse, and they are interwoven into a most complex fabric; but we are now able to understand their general purport, and we can often trace precisely the course of certain minor principles in problems which, a few years ago, seemed to be hopelessly obscure, and which, perhaps, were considered to lie outside the sphere of investigation. Agriculture has developed into a system of clear and correct thinking; and inasmuch as every man's habit of thought is determined greatly by the accuracy of his knowledge, it follows that the successful prosecution of rural pursuits is largely a subjective matter. It is therefore fundamentally important that every rural occupation should be contemplated from the point of view of its underlying reasons. It should be approached in a philosophic spirit. There was an attempt in the older

agricultural literature to discuss rural matters fundamentally; but the knowledge of the time was insufficient, and such writings fell into disrepute as being unpractical and theoretical. The revolt from this type of writing has given us the present rural literature, which deals mostly with the object, and which is too often wooden in its style. The time must certainly be at hand when the new teaching of agriculture can be put into books.

For many years the writer has conceived of an authoritative series of readable monographs, which shall treat every rural problem in the light of the undying principles and concepts upon which it rests. It is fit that such a series should be introduced by a discussion of the soil, from which everything ultimately derives its being. This initial volume is also an admirable illustration of the method of science, for the soil is no longer conceived to be an inert mixture, presenting only chemical and simple physical problems, but it is a scene of life, and its physical attributes are so complex that no amount of mere empirical or objective treatment can ever elucidate them. If the venture should prove that the opening century is ready for the unrestrained application of science to rural life, then it is hoped that the Rural Science Series, under the present direction or another's, may ultimately cover the whole field of agriculture.

L. H. BAILEY.

CORNELL UNIVERSITY,
ITHACA, N.Y., June 1, 1895.

PREFACE.

IN the preparation of the pages which follow, the writer has endeavored to have them bear to the reader a rational presentation of the fundamental principles of the soil as they relate to the immediately practical aspects of agriculture. The technicalities of the subject matter, and the lines of experimentation which have contributed the facts used, have been largely avoided, not because they are deemed unimportant, but in the hope that by so doing there might result a thirst for wider reading which would lead to a search for these matters in places where they are better presented than they could be here.

No effort has been made to treat subjects in an exhaustive manner, the aim being simply to use so much of recorded facts as shall sufficiently enforce those principles underlying the management of soils which it is needful to understand in order that a rational practice may follow. The soil has been considered as a scene of life, where altered sunshine maintains an endless cycle of changes, rather than as a mere chemical and

mechanical mixture, and so far as possible the problems have been given definiteness by treating them quantitatively.

A free use has been made of all available literature, and credit is usually given by author's name in the text where the reference is made.

Special acknowledgment is due to the United States Geological Survey for the use of cuts in Chapter I., and also to the National Geographic Society for Fig. 11.

F. H. KING.

UNIVERSITY OF WISCONSIN,
MADISON, WIS., May, 1895.

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THE SOIL.



INTRODUCTION.

It was early one morning late in October after there had been several very severe frosts that a fox squirrel, either by chance or in deliberate search, passed under a large tree and found the ground thickly strewn with butternuts. All night these nuts had been falling by ones and by twos until now the ground was nearly covered with them. As some other squirrel had done, one, or maybe, two hundred years before, so did this one take a nut, and hurrying off to a secluded spot, bury it in the soil beneath the forest mold. Why this was done, whether with the intention of recovering it for a future meal, or whether, like a deliberate forester, he planted it that another tree might grow, only that squirrel knew. It lay there in the ground undisturbed the winter through; but in the spring, as with a thousand seeds of other kinds, its obstinate shell opened without a jar or sound. Water crept in, and the rich oil stored all winter in the thick meat rapidly changed into sugar, so that out of this and other materials borne along in streams of water which now were setting in from the soil, the tiniest cells began to form, some building a stem upward

into the sunshine and air, and others building rootlets downward and outward into the darkness and dampness of the soil. As the building, or growth, went rapidly on, it was not long before the materials stored in the nut and which induced the squirrel to carry it away, had all been used; but not, however, until, as a result of this use, there stood in the rich, dark mold a perfect little butternut tree with its roots brought into contact with the water among the soil grains and its green leaves spread where the throbbing pulses from the rising sun shall be made to pump the water and do the work of building a great forest tree.

The processes of sprouting, budding, growing, and fruiting are marvelous ones, and the farmers, gardeners, and florists whose lots are cast among them have the grandest of opportunities for enjoyment and for intellectual and moral uplifting, as well as for pecuniary profit, if only they will train themselves to take advantage of them and then allow themselves the opportunity of doing so.

Believing fully in the soundness of these words, the writer, in preparing this treatise, has aimed to present the most practical and fundamental facts and principles concerning the soil as largely as possible from the standpoint of the How? and the Why? and at the same time to pause now and then to view some of the wonderful adaptations of structure to physical environment which the long processes of evolution have finally produced. We can well afford to do this because the future development of agriculture can be made most rapid and most sure, not more by giving to the farmer new facts than by making him able to observe, interpret, and correlate the facts which each and every year's planting, hoeing,

and harvesting must inevitably bring under his own eyes. The business of farming has now become so complex, the sciences to which it must look for direction are so numerous, and the needs of the world for great quantities of materials for cheap, wholesome food and clothing are growing so rapidly more urgent that the farmer of Nineteen Hundred must rise upon a plane of better directed efforts and more economic methods. He can no longer do as most of us say the squirrel did, — plant without thought of adaptation or fitness, but simply as and because his father, grandfather, and great-grandfather did.

SUNSHINE AND ITS WORK.

Let us not drop at once into the soil and lose ourselves in the darkness of its details, but first let us look about and see how our field is related to the world at large and to the powers that energize in it. Let us begin with sunshine and the work it does.

While we are yet a long way from fully comprehending the nature of sunshine, we have learned enough to know that it is a sort of motion which comes to us from the sun, traveling through interplanetary space at the rate of 186,000 miles in a second of time, and on reaching us and being transformed into one or another form of energy, it does almost the entire work of the world. When the skillful man strikes a ball with a bat, he does it in such a manner that almost the entire motion of the bat passes into the ball, sending it far into the field, while the bat is brought as completely to rest at his side as if it had struck a bank of plastic clay. Now the sunshine, coming to us from the sun, is as definitely a source

of power and is as capable of doing work, of setting something in motion, as is the bat when actuated by the powerful arms of the man. When the solar energy, or sunshine, falls upon the soil, the soil grains take up or absorb a portion of it as definitely as does the ball absorb the motion of the bat, the molecules making up the grains of soil have their velocities increased just as the ball had its motion as a whole augmented, and this increase of molecular motion in the soil grains is what raises its temperature.

When the motion in the surface grains becomes so great that the soil is warm or hot, some of that motion is transmitted to the molecules of air coming in contact with the earth, and these, traveling faster than they did before, push one another farther apart, thus causing the air to expand and so become lighter, bulk for bulk, than the air which has not been so heated. Once in this condition, the lighter air is forced upward by that which is heavier, and wind is the result. In this wind we unfurl the sails of a vessel or set a windmill, when the motion of the wind becomes transformed into a motion of the mill. This mill attached to a pump drives the piston, and water is raised from the well. Thus it is the sunshine warms the soil, the soil expands the air, the air drives the mill, and the mill lifts the water.

Take another case: When sunshine falls upon water, its surface molecules are set into such violent motion that the force of cohesion is overcome and the water changes to a gas, or evaporates. These rapidly moving molecules of water vapor rise quickly into the upper regions of the air where, as their motion slows down, the force of cohesion gains the ascendancy again and they coalesce, forming clouds and finally large drops of

rain, or flakes of snow, and fall back to the ocean again or upon the land, giving rise to soil moisture, to springs, rivulets, and rivers, or, where the temperature is permanently low enough, to ice-fields and glaciers, all of which, as we shall see, have had their part to play in the production of soil.

But not all the sunshine goes directly back after being transformed at the surface. Some of it, in its altered guise, spreads downward in the soil, and after the snow is gone and while spring is advancing into summer and summer into autumn, a large amount of sunshine is being stored. It is stored by increasing the rate of motion in the soil, and in the lower atmosphere by increasing its temperature. Now, in the temperate and polar zones, when the days become shorter than the nights, the rate of molecular motion so much slows down, because more altered sunshine is lost during the night than is received during the day, from both the surface air and surface soil in which plants live, that finally the intensity of molecular swing becomes too feeble to maintain longer the processes of growth, and plants begin to ripen, to shed their leaves, and finally, as the motion in the medium in which they live becomes too feeble, they fall asleep and winter has come. Conversely, too, when the days become longer than the nights, when more blows of sunshine reach the soil during the light than can escape during the darkness, there finally becomes an amount of molecular hustle and bustle in which sleep is no longer possible, and spring, with all its fresh verdure and joyous music, bursts upon us.

It is very essential that we fully grasp the important part which both direct and altered sunshine play in plant growth; for while we have no control over the

amount which may come to a given field, we can and do control the amount stored in the soil, and we also determine the number of plants which shall stand upon the field to utilize the sunshine which does come to it.

In constructing a house, it is not sufficient to have upon the ground stone, sand, lime, lumber, and nails, enough and to spare, together with the master builder who knows how these should be put together. In addition there must be a moving power, a source of energy, which is capable of raising these inert materials and bearing them to their places. So in building the butternut tree, it was not enough that the squirrel should plant the nut in a fertile soil with abundant moisture; nor yet that there lived in the midst of that oily meat a master butternut builder capable of directing how the carbon, oxygen, hydrogen, nitrogen, phosphorus, and other materials should be compounded and brought together so that by no possible slip an acorn could drop from the boughs of the spreading tree; but, in addition, there must be a moving power, a source of energy, and this is the ether waves, born in the limitless ether ocean at the fiery surface of the sun so rapidly that more than 400 million millions of them arrive at each leaf every second, having come across 93 millions of miles in about eight minutes of time. It is under such hurried strokes as these that starch and sugar are made in the cells of plants and that cellulose is set in the framework of the tree.

So powerful is the work of the sun against the cold ether of space that Lord Kelvin estimates it at 133 thousand horse power for each square meter at the sun's surface, and the working capacity of a cubic mile of sunshine near the surface of the earth he places at nearly twenty-two horse power. Now, since the cubic miles of

sunshine are arriving at the earth at the rate of 186,680 per second, one section of land and the air resting upon it must receive

$$186,680 \times 12,050 = 2,249,494,000 \text{ ft. lbs.,}$$

and this is equivalent to about one-seventh of a horse power for each square foot of surface. Not all of this power reaches the earth's surface, nor is all which strikes the surface converted into work. It is not the chemical work in the cells simply which is actuated by the sunshine, but, as we shall see in another place, both the circulation of sap and the capillary flow of water in the soil are dependent upon it, in part, at least.

There is another fact regarding sunshine which we need to understand. It is this: The waves which come to us from the sun are very complex in their character; indeed, it appears as if there were a very large number of them differing from one another chiefly in their length or, what amounts to the same thing, in the number which arrive in a given interval of time, much as we know to be the fact with musical tones differing in pitch. In the case of light there is a long series of wave lengths which are characterized by being able, when they fall upon the retina of the human eye, to produce the physiological effect which we designate as color of one sort or another. But associated with these color waves, there are many others to which the human eye is not sensitive, and these are designated as dark waves. Some of these are much shorter than the color waves, and are specially powerful in breaking down the molecular structure of many substances; that is, in producing chemical changes. Then again, on the other side of the light waves, there are dark ones of much longer periods of vibration, and these

long waves, to which we are insensible through the sense of sight, have a wonderful power of heating many substances when they fall upon them, and one of these substances in which we are specially interested in this study of soils, is water. When you take a large lens and let the bright sunshine pass through it, the glass is very little warmed by the passage, but if you hold paper at the light focus, it is quickly set on fire by the strong heating power of the dark or invisible rays. This has been proved by allowing the light to pass first through a solution of iodine in bisulphide of carbon, which is very transparent to the dark waves, but opaque to the light ones. When such waves are brought to a focus, they produce intense heating effects, and water is made to boil quickly under their influence. If, on the other hand, the light from the sun is first passed through a solution of alum in water, which is largely opaque to the dark waves, these are sifted out, and when the light waves by themselves are focused upon the water or paper, very slight heating effects are observed.

The fact that water is opaque to the dark rays from the sun,—that is, absorbs them instead of transmitting or reflecting them unaltered,—lies at the foundation of the evaporation of it from ocean, lakes, and streams, and also from the soil and the leaves of vegetation in some degree. When these waves fall upon the water, they set its surface molecules in rapid vibration, that is, they heat them, and this increased speed of to-and-fro movement overcomes the force of cohesion and the molecules fly off, or evaporate, as we say. Were the water not opaque to these dark waves from the sun, neither snow nor ice would be rapidly melted in the spring, nor would there be as much evaporation from the ocean as we now

have, and hence rains would be less frequent and the lands less productive.

THE ATMOSPHERE AND ITS WORK.

We have dwelt very briefly upon the nature of sunshine and the part it plays in the work of the world. Let us next look at the atmosphere, for this, both in a broad way and in many details, has to do with our subject, the soil.

In the first place let us note that, light and imponderable as the air seems to be, it nevertheless presses very heavily upon all surfaces at or near sea level — so heavily, indeed, that the pressure is nearly 15 pounds on each square inch of surface and more than a ton to the square foot. Each square rod of land lying near sea level sustains a load amounting to 289 tons, and each acre 46,200 tons of air. Does it seem to you strange that, while the extended palm of one hand is pressed downward by a load of air equal in weight to that of the body, we are yet unconscious of it? If this puzzles you, place your hand beneath the surface of a pail of water. The water does not seem to bear it down. Carry your hand to the bottom of the pail. Still you do not realize that it presses any harder, and yet the bottom of the pail is carrying a load of some 20 pounds, and this is evident enough to you when you hold the pail upon the hand. When the hand is immersed in the water, it is buoyed up with a pressure equal to that which bears it down, and the pressure which crowds it to the left equals that which would move it to the right and, so long as the pressures are equal in all directions, we are unconscious of them. As fish move through the waters of the stream,

the lake, or the ocean, unconscious of and unimpeded by the pressure of it, so do we travel along the bottom of an ocean of air; for such in reality the atmosphere is.

In breathing, in drinking, and also in eating, we regularly, but unconsciously, utilize atmospheric pressure. Raising the ribs and lowering the diaphragm lifts off the outside air-pressure in part, and at once the air crowds in until the lungs are stretched and filled by it. To drink, we project the lips under water, shut off communication with the nostrils, using for this purpose the curtain called the soft palate, and then draw down the floor of the mouth, thus making the cavity larger; this removes part of the pressure from the water inside the lips, and at once the greater outside push upon the water fills the mouth and we are ready to swallow. Then, too, in eating, we place the morsel to be chewed between the teeth with the tongue; but how is it removed when the work is finished? If you will watch yourself, you will observe that with both the lips and the passage to the nostrils closed, the lower jaw is dropped, which destroys the balance of pressure on the flexible cheeks, when the air on the outside immediately tucks them in between the teeth, and this crowds the morsel out, all so easily, so unconsciously, and in so brief a time that it is not without difficulty that we can convince ourselves of the real means used to do the work.

It is the unbalancing of this same atmospheric pressure that produces the gentle breeze, and the terrible tornado; that lifts the water in the pump and in the siphon; that produces the draft in the chimney and the in-going and out-going currents of air which constitute soil-breathing or soil-ventilation, so essential to plant life.

I have said that we are living at the bottom of an aërial ocean, and this ocean has a depth of 200 or possibly of 500 miles, but, unlike the one of water, it grows so rapidly less and less dense as its upper surface is approached, that in rising upward from the ground through it one would leave behind him in the first 15 miles all but 4.8 per cent of the entire mass; and yet this thin upper portion offers resistance enough to those stone-like bodies called meteors, traversing space, so that when they plunge beneath its surface, moving at their fearful rate, they quickly become intensely hot or are even converted entirely into gas by the great heat produced during the fall, long before the lower depths of the atmosphere are reached.

Were we to separate the molecules of different kinds which together make up the atmosphere, we should find a large variety of them, but if, after doing so, we were to compare them, volume by volume, we should find, under average conditions, in every 100 cubic feet of air not far from 20.61 cubic feet of oxygen, 77.18 of nitrogen, 1.4 of water vapor, .04 of carbon dioxide, and .78 cubic feet of a recently discovered gas, named argon, reported at the last meeting of the British Association by Lord Rayleigh and Professor Ramsey, as composing about one per cent of the nitrogen of the air. Professor Morley found at Hudson, Ohio, in his very critical analyses, made in duplicate daily and continued for six months, that the oxygen composed 20.949 per cent of the oxygen and nitrogen taken together, which would make the per cent of nitrogen 79.051.

Besides the substances mentioned above as being found in the air, there should also be named, on account of their important relations to agriculture, ammonia and

nitric acid, together with a modified and extremely active form of oxygen, named ozone; and when it is stated that water, carbon dioxide, nitrogen, ammonia, and nitric acid, taken directly or indirectly from the atmosphere, contribute more than 97 per cent of all the materials which are built into the tissues of plants, we can begin to understand how great a part is played by the aërial ocean in the bottom of which we live.

There is another extremely important office which the atmosphere performs, and that is to keep the earth warm. When the sunshine reaches the upper limits of our air, it enters it almost wholly unimpeded, and only as the last few miles of the lower depths are reached is there an appreciable number of its waves turned back into space or absorbed by the air in their passage through it. But when these ether waves break against the land and water surface of our planet, their force is very largely spent in setting the molecules of soil and of water swinging to and fro more rapidly than before, and this means to make them warmer. But to make it clear just how the air is able to save this warmth for us, another fact must be mentioned. It has been said that the ether waves coming to us from the sun set the soil and water molecules swinging when they strike against them. Now the opposite of this is the case at the surface of the sun. There the swinging molecules strike the ether of space, and by that very act lose so much of their power as speeds away to the earth in the waves produced. The rate of vibration of the molecules at the solar surface is, however, very rapid, so that the waves which are sent down through our atmosphere to the earth are very short, so short, indeed, that they seem to make their way among the molecules of our air without

disturbing them; but the to-and-fro motion which these waves engender in the earth molecules is very much slower, and hence when these in their turn start waves back through the ether toward the sun, as they do, these waves are much longer and are unable to make their way past the air molecules without setting them swinging; but this means to make the air warmer, it means to hold the sunshine imprisoned for the time being, but in the altered guise of terrestrial heat.

How great this accumulation of heat is will be appreciated when it is stated that Professor Langley, after making a long and very careful experimental study of this property of our atmosphere, at the base and summit of Mt. Whitney, in California, reached the conclusion that, had our earth no atmosphere, its surface temperature, even under the equator at noon, would be 200° C. below freezing, and this means a temperature of -328° F.

With this fact before us, and remembering how slowing down the molecular motion in the tissues of plants, even to the rate of our winter temperatures, stops all plant growth, there is no difficulty in realizing how important this property of the atmosphere is to the life of both plants and animals.

The transformed solar energy does not accumulate at the earth's surface indefinitely, but only until a certain degree of intensity is reached, and then the mean yearly out-go exactly balances the mean yearly in-come. Just how this balance is attained, one will readily understand if we use an illustration from another field. Suppose we have a tall vessel with a hole in one side near the bottom, and that into this vessel a stream of water is flowing over the top. Evidently the in-going stream

may be so large that, at first, more water enters over the top than escapes through the opening at the bottom; but there will come a time, if the vessel is deep enough, when the pressure forcing the water out becomes so great as to cause the quantity of water escaping to exactly equal that which enters, and under these conditions a balance is established. So it is with the out-going heat of our earth; its intensity increases under the resistance to its escape by the atmosphere until the jostle of the air molecules among themselves becomes so great that enough waves of the long sort escape into empty space to exactly compensate for those which are being transformed at and near the surface of the earth.

Not all portions or constituents of our atmosphere exert the same screening power over the long dark waves radiated back into space by the earth. It is the lower layers of the air, and especially those portions which are heavily dust and moisture laden which exert this power in a pre-eminent degree. And it is because of this fact that soil temperatures decrease as the altitudes on mountain sides increase until, even under the equator, permanently frozen ground and eternal snow-fields and glaciers may be met only four or five miles above sea level. So, too, when the sky clears after a winter storm and the air has been swept exceptionally clean of its moisture and particles of dust by the forming crystals of snow, each of which has its beginning about a particle of dust, that the radiations escape rapidly through the clear air, giving rise to the cold waves which traverse the country in the rear of winter storms. This is also the reason, in part, why killing frosts in fall and spring usually occur only on clear nights; and why it is that the temperature of arid regions falls so rapidly as soon as the sun has set.

Looking at the atmosphere once more in its relation to life, we find that it performs a very large and very important work as a distributing agent or means of transporting the food and waste of every living being. Taking up the carbon dioxide as it is thrown off in the soil by the germs which consume dead organic matter there, from the lungs and tissues of animals living both upon the land and in the water, from the craters of active volcanoes, and from the fires kindled by man, it is borne by the winds into contact with the green parts of plants, where its carbon is appropriated in the processes of growth. Taking up the oxygen, too, as it is set free from the carbon dioxide in the tissues of plants, the winds bear it back to the soil, to the tissues of animals, and to the fires of the home and the workshop. Taking up the water, too, of which the plant must use from 200 to 300 pounds for every pound of dry matter produced, it is borne fresh and sweet from the salt sea and deposited upon the land, into which it sinks, to be drunk by the roots of plants or brought back by gravity, in the form of springs, to quench the thirst of animals.

WATER AND ITS WORK.

Water is another agent which plays an extremely important part in the processes going on in the soil, and it will be helpful to us if, before entering upon details, we can get a broad view of the work it has done and is now doing.

Studies, both in astronomy and in geology, point to a stage early in the history of the earth when the temperature of the solid land was very far above even a red heat. This being true, there must have been a time

when the great ocean sheets which now cover three-fourths of our globe to a mean depth of 16,000 feet did not exist as such, their waters then floating in the form of vapor, shrouding the whole earth in an atmosphere of great density. At this stage water began its great work which to-day is still in progress. Let us see what it has been.

If the small amount of water vapor and dust particles existing to-day in our atmosphere play so important a part in holding back the dark radiations from the earth's surface and thus keeping it warm, as we have seen, how extremely opaque in those early days the atmosphere must have been to these long waves, and how slowly must the surplus heat have passed away by this method! And yet the first great work that water did was to greatly hasten the cooling of the earth down to the temperature at which it might become the abode of life. The manner in which it did its work was this: The water in the upper, clearer portions of the atmosphere lost its heat by radiation and, condensing into drops, fell as rain to a lower and much warmer level, where, at the expense of the heat of the region into which it had fallen, it was quickly evaporated, but only to rise once more into the upper regions to send off into space the large amount of heat which had been imparted to it. The vapor of water, being much lighter than air, rose more quickly than heated air currents could have done, and then, on being condensed into liquid drops, returned again far swifter than it had risen, so that the number of journeys made by these water molecules in their mission of cooling the earth far outnumbered those made by the molecules of oxygen, nitrogen, or carbon dioxide during equal intervals of time. Nor is this all, for each pound of water carried

with it on every journey many times the amount of heat which an equivalent amount of air was able to bear.

The next great work that water did was to slow down the rate of rotation of the earth upon its axis until, according to the investigations of G. H. Darwin, our day was changed from one perhaps not longer than three hours to its present twenty-four. It is through the instrumentality of the tides, which, acting as a friction brake upon the earth, have steadily slowed its motion down, but much more rapidly in the early days than at the present time; for then, on account of the moon being nearer to the earth, the tides had perhaps thirty-six times their present magnitude.

As soon as large land areas emerged from the sea, then the third great work of water began; a work which, through all this long time, has consisted in dissolving out, in altering, in breaking into smaller fragments, in grinding, and finally in transporting from higher to lower levels the soil, the minerals, and the rocks of all lands.

This third work of water has been a vast one indeed, but just how great our present knowledge does not make it possible to form even an approximate estimate; that it has been very large, every considerable land area bears ample and indisputable evidence. Take the state of Wisconsin as an illustration: Leaving out of the count the vast depth of deposits which together have been grouped as Laurentian, in this state we have, lying above them, a measured thickness of rock fragments exceeding 30,000 feet, built from materials taken from the soils, the coast lines, the banks of streams, and the subterranean waterways of earlier land areas by this never-ceasing action of water. But great as has been the work of water here in sweeping the dust and litter of land

sculpturing into the sea, the strata referred to are the accumulations of less than half the years since the work began.

Finally, with the advent of living forms upon our planet, water took up still another very important work; for to both plants and animals it is indispensable. Making up the larger part of their weight, it is the medium in which the chemical transformations essential to the processes of growth take place, if, indeed, it does not play the part of an active and indispensable agent in bringing these changes about. Then, too, water not only takes up and holds in the liquid form those substances in the soil which may become the food of plants, but it is the medium of transportation by which all materials are moved from root to leaf and from the leaf back to the various places where the processes of growth are taking place. In the physiological processes of the animal body, it has a similar and equally important rôle to play; for here, too, it becomes first a solvent and then a medium of transportation by which all food is taken to, and the wastes removed from, the various organs of the body. Finally, both in plants and animals, water acts as a temperature regulator, tending, by its evaporation from the surface, to prevent the tissues becoming too warm, and among many animals this action is very marked; for they have the power, when the body is getting too warm, of sweating or pouring water upon the surface, where it may evaporate quickly and thus cool the body.

LIVING FORMS AND THEIR WORK.

Not only are the various forms of terrestrial life greatly dependent upon the soil for their well-being, but the soil

itself throughout geologic time has been wrought upon in many and very important ways, so that a general statement of the work living forms have accomplished and are now doing will be a helpful preliminary to our study of the soil.

All are familiar with the very rapid washing away of soil by the heavy rains which fall upon steep and naked hillsides, and also with the equally marked protecting influence exerted in the prevention of such washing by the roots and close-lying herbage of plants of almost all kinds. By this action land plants hold in check, in an extremely important manner, the destructive power of water and of wind, giving much deeper and far more fertile soils than would otherwise be possible.

On the other hand, however, these same roots hasten the destruction of rocks by growing into their fissures and wedging them apart, and also by corroding and dissolving away the surfaces both of rocks and of soil grains wherever they may come in contact with them. Nor is this all, for living in the soil, chiefly in the surface 14 inches, are great numbers of microscopic forms, which, feeding upon the dead tissues of plants and animals, evolve large quantities of carbon dioxide, nitric and other acids, which in their turn become corrosive agents, bearing off in the water which runs to the sea vast quantities of soil in solution. Mr. T. M. Read has estimated that the Mississippi alone carries annually to the sea 150,000,000 tons of dissolved rock materials, while other streams bear away proportionately large amounts.

But in this world of never-ending change life has done more than to protect the steep hillsides and to hasten the solution of soil and the crumbling of rocks. In addition

it has been a great rock-builder and gatherer of mineral wealth. Taking out of the sea-water the lime which the carbonic acid has dissolved and floated to the ocean, the great army of shell bearers and coral builders have, in all the geologic ages, laid down their mantles and frameworks to become the limestones of the world. In favored situations, too, the decay of the organic tissues of plants and of animals has resulted in the formation of gases, which, rising through the water, have precipitated from it iron and possibly lead, zinc, and copper as it was being borne along in the slow coastal currents, thus bringing into rich deposits in a few places these metals so indispensable to the civilization of to-day. Then there are our great beds of coal and peat, our deposits of asphalt and bitumen, and our reservoirs of mineral oil and natural gas, all of which are believed to have resulted chiefly from the decomposition of the tissues of living forms.

Truly, life, working in the laboratories of the lowermost layers of the atmosphere, in the surface few inches of the dark soil and more widely spread in the transparent ocean waters, using direct and altered sunshine as its moving power, has done and is still doing a very great work. And let the farmer never forget that his life work is thrown among not a few cultivated plants and domestic animals, but rather that every farm is inhabited literally by thousands of kinds and millions of individuals, most of them microscopic, it is true, but powerful in their great numbers. Nor can we for a moment think that only those forms which we consciously aim to raise hold vital relations with us; for year by year, as the horizon of our knowledge of the life histories of the living forms about us is made broader, it

is only yet again and again that we learn of new and important relations existing between them and us.

OVER AND OVER AGAIN.

The tide comes and goes and comes again. The morning dawns, the sun sets, the stars come out, and once more the sun is in the east. The cold winds cease to blow, the birds come and then are gone, the snows drift high along the fences, but spring is sure to follow. This method of cycles in the ongoings of nature is so general and so fundamental to the constancy of results, especially in agriculture, that we may well pause for a brief general consideration of it.

The critical and quantitative methods of investigation which so strongly characterize the nineteenth century have led us to know that neither the material of things nor the power which does work can be destroyed. No discovery of modern science is more fundamental and far-reaching than that of the indestructibility of both matter and energy, and equally fundamental is the other fact that, do what we will, we can create neither the one nor the other.

We may, if we choose, conspire to have the energy of burning straw, in the fire box of the engine, converted into the energy of steam and transmit this through the piston and driving belt to the thresher where the work is done; but while this is going on, through the friction of belts and bearings, and that of the agitation of the straw, grain, and air, there reappears ultimately, in the form of heat, an amount of energy equal to that given to the steam which drove the piston while doing the work, and this too is a measure of the direct and altered sunshine

required to perform the labor of building the straw used for fuel. Over and over again is energy used to do the work of the world, but in altered form and in divers places, nowhere destroyed and nowhere created.

The few bushels of ashes left after burning the winter's supply of wood seem to point to a destruction of matter, but their weight, added to that of the products which escape through the chimney, is actually much greater than the original weight of the fuel; for much oxygen from the air has united with it. So it is with our domestic animals; what we realize in their increase of live weight, and in the weight of the dung and urine, falls so far short of that of the food consumed that here is a seeming destruction of matter, but when the materials which are thrown off in the invisible form from the lungs and from the skin are taken into the count, the wastes exceed the food consumed by the amount of oxygen which the animal has taken from the air. Now, in both of these cases, the oxygen which the sunshine released from the carbon in the tissues of the growing plant finally returns to reclaim its carbon again and bear it back as carbon dioxide to the atmosphere from which it was taken.

The water, too, falling as rain upon the soil, and rising in the sap to contribute its constituents to the building of the woody fibre of the fuel, or the starch and sugar of the food, is again returned to the atmosphere to make the rounds once more. It is the same way with the nitrogen and with the ash ingredients, — each and all are used over and over again, but nowhere in the round is there any loss of matter or any gain.

Take our atmosphere as a whole: In the equatorial zone of strongest heat the air is steadily rising to a con-

siderable height, where two currents part and move toward the poles, but only to return as under currents and to make the trip over again. Then, besides this world-wide circulation in the atmosphere, there is a tendency, most of the time, for the air to travel from the land to the sea and from the sea back to the land again, the currents being along the land surface from the sea during the warm portions of the year, but back again toward the sea overhead; then when the seasons are cold and the sea is warmest, the air from the land areas slides along their surfaces, out upon the sea, while, as an upper current, it travels back again to return once more; and by these two great systems of winds the land is watered by the moisture brought from the sea, and the general composition of the whole atmosphere is maintained remarkably constant.

In addition to these larger systems of circulation, the greater absorption and transformation of sunshine at the surface of the earth than takes place higher up in the atmosphere, maintains everywhere and at all times local ascending and descending currents, so that, no matter how rapidly vegetation may consume the carbon dioxide of the air, and put in its place free oxygen, or how rapidly animal life in the air, or microbe life in the soil, may use the free oxygen and put in its place carbon dioxide, these local ascending and descending currents keep the air so thoroughly stirred that the most careful chemical analyses reveal only exceedingly small variations in the relative proportions of the oxygen, nitrogen, and carbon dioxide in the air; and since both plants and animals tend constantly to disturb this relative proportion of gases, it is plain that by this over and over again process, a healthful atmosphere, so

essential to the well-being of both plants and animals, is maintained.

Let us now try to gain an idea of the magnitude of the movement in the endless round which water makes as it journeys from the sea to the land, and back from the land to the sea again. Observe the face of your watch just one minute, and then reflect that, on the average, during each such interval of time, the Mississippi River empties into the Gulf of Mexico 40 acres of water more than 21 feet deep; while in South America, its great Amazon unloads a burden nearly five times as large, or more than 103 40-acre-feet per minute. But large as this work really is, it does not measure the volume of water which, on the average, is steadily rising from the earth's surface into the atmosphere under the impulse of altered sunshine; for a large part of the water which falls upon the land is evaporated there, to return as rain in another place instead of being carried away by the rivers. On an area equal to the state of Wisconsin, for example, where the mean annual precipitation measures about 3 feet, the total fall must exceed an average of 40 acres of water 5 feet deep, for each minute of the year. But there are large areas of land where the mean annual precipitation is 60 inches, and others still where 8 feet of water fall: In these cases, for an area equal to the state of Wisconsin, or 56,040 square miles, the aggregate precipitation must exceed 8.5 40-acre-feet of water per minute in the first case, and 13.6 in the second. Now, on only a moderately fertile soil, the writer has grown maize, supplying it with water just as rapidly as it could use it to the best advantage, and found, as an average of two trials, that it did take, during its growing season, or one-third of a year, the

equivalent of a rainfall of 34.3 inches, and produced a yield, when calculated for an acre, of more than four times a very large field crop grown under the best natural conditions of rainfall in Wisconsin; so that to grow a field of corn, of such quality, and the size of this state, would require the delivery of water upon it at the rate of 40 acres more than 14 feet deep every minute during the growing season, or a rainfall greater than the largest considered above. Large then as this movement of water is, it is seldom great enough during the growing season to enable a moderately fertile soil to produce its largest crops.

But it is neither to the gaseous nor to the liquid portions of our earth that this process of over and over again is limited; for even the solid land is profoundly involved in it. Careful measurement has shown that there goes to the sea annually, dissolved in the waters of the Mississippi River, 150 million tons of rock; and of these, 70 millions are the chief constituents of limestone—carbonates of lime, and magnesia; so that the selfsame materials which journeyed to the sea, dissolved in the rivers of unnumbered centuries ago and laid down there by the action of marine life, have since become a part of the dry land, certainly once, if not many times, and are now journeying back to be rebuilt into the coral reef on the ocean's bottom yet once more.

Nor is it rock and soil held in solution simply which water in its ceaseless rounds is bearing back to the sea; for with the dissolved materials there is borne along as suspended sediment in the waters of the Mississippi alone, in the space of a single year, 362 million tons, making 513 million tons of rock and soil carried to the sea by one river, besides 750 million cubic feet of matter which are shoved along the bottom to form its delta.

The continual transfer of these large amounts of material from the land to the margin of the sea bottom, perpetually destroys the balance in the figure of the earth, so that the land areas rise to compensate in large measure for the materials borne away, while the marginal sea bottom subsides in like proportion to readjust the balance; but as the sea sediments continue to subside, they become plastic under the great pressure to which they are subjected, and flow toward and under the rising land areas where denudation has been going on, so that in a very powerful but extremely slow manner there is a real movement of the solid land toward the sea above and from the sea back again to the land beneath. And if such profound and long-enduring systems of rotation as these are maintained as essential to the life of the world as a whole, we may practice with great confidence a rational rotation of crops in our systems of agriculture.

“ We cannot measure the need
Of even the tiniest flower,
Nor check the flow of the golden sands
That run through a single hour ;
But the morning dews must fall,
And the sun and the summer rain
Must do their part and perform it all
Over and over again.

“ Over and over again
The brook through the meadow flows,
And over and over again
The ponderous mill-wheel goes.
Once doing will not suffice,
Though doing be not in vain.”

CHAPTER I.

THE NATURE, FUNCTIONS, ORIGIN, AND WASTING OF SOILS.

OF all commonplace things, it would be difficult to find one more uninteresting to most people than soil. Walking over it all our lives, it has come to be, in our unreflective moods, simply dirt, something essentially unclean and to be shunned. So deeply ingrained is this feeling that it comes to many almost as an inheritance, and people of culture, as well as the ignorant, find themselves stoutly inclined to shun everything and everybody directly associated with it.

But the spirit and results of investigation, which have grown so rapidly during our century, have already so widened our horizon of knowledge, and so changed the attitude of mind toward the phenomena of nature about us, that we are coming to study, in the spirit of science, many of those things which lie nearest to us, and with great moral, intellectual, and pecuniary profit; and since soil, air, and water are indispensable to all forms of life, we must know more and more of them as the demands for food and homes increase.

Taking samples of soil from where we will, whether from the fertile prairies of central North America, from the tundras of Siberia, from the barren wastes of the Sahara, or the rich river bottoms of the Amazon, everywhere we shall find them composed of mingled fragments

of materials of various kinds. Usually the soil is composed chiefly of small fragments of rock of many varieties, which may be regarded as the basis of them all. Associated with these fine rock remnants there is almost always a varying amount of organic matter derived from the breaking-down of vegetable and animal remains. Then, too, adhering to the surface of these fragments, or scattered among them in the form of crystals, there are various substances which have been deposited from over-saturated solutions of soil moisture.

In clayey soil there is present among its fine silt-like particles a small quantity of silicate of aluminum having water combined with it, and which gives to it its sticky, plastic, or putty-like quality. This adhesive clay, however, forms only a small part of the whole weight of such soils, amounting to not more than 1.5 per cent, according to Schlösing. Then, too, the soils in many parts of the world have scattered through them larger or smaller blocks of stone, varying in size from great masses sometimes weighing tons, down through those which a man can barely move, to pebbles and coarse grains of sand. These fragments form no part of the soil proper, but instead are the materials out of which soils are made. It is true that the roots of plants may place themselves alongside of these coarse pieces of rock, and by their action derive some nourishment from them, but the amount thus obtained is insignificant when compared with that which an equal volume of soil might contribute if placed in their stead; so that such rock fragments, while they will contribute their volume of soil to the agriculture of the future, are a positive hindrance to that of the present.

SURFACE SOIL AND SUBSOIL.

In humid climates, where the rainfall is sufficient to insure remunerative crops, it is common to speak of the surface, 6 to 12 inches of the fine rock fragments, as constituting the soil, while the deeper portions are spoken of as the subsoil, and this distinction grows out of the fact that oftentimes when the deeper soil is brought to the surface, it is found to be unproductive for a time, and, besides, there is generally a sharp line of demarkation in the color of the two portions. In arid regions, however, where crops can only be raised by irrigation, both of these distinctions largely or wholly disappear; so much so that, in leveling fields to fit them for an easier distribution of water over the surface, little or no care is taken to avoid exposing the subsoil or covering even deeply the surface layer, experience having proved that earth from the bottom of cellars, and even that from depths of 30 feet, may be quite as productive, if not more so, than that which has been long exposed to the air.

This difference in the nature of the deep soils of arid and humid regions appears to result from a variation either in the abundance or arrangement of the finest of the soil particles which exist in the deeper layers, the deeper soils of humid regions being usually more close in texture, and less easily penetrated by water.

This difference in the texture of the soils of humid and arid regions is not confined to the subsoil, but involves the surface portions as well, so much so that when most soils of humid climates become dry, the surface is very hard and difficult to move, while those of the arid regions of the world are so incoherent that the

slightest puff of wind is sufficient to raise a dust, and a wind storm at any time is quite certain to raise great clouds of sand so characteristic of desert regions.

Just why the soils of dry climates should lack in the amount of adhesive materials is not readily explained by unquestioned facts, but the condition appears to be in some way related to the larger amount of lime which Hilgard has shown these soils to contain. It has been abundantly proved by different experimenters that when the salts of lime are added to muddy water, it has the effect of enabling the silt particles to be gathered together or to become flocculated, settling to the bottom and leaving the water clear, while without the addition of lime it would have remained turbid for an indefinite period.

Hilgard has also shown by experiment that while any clay or tough clay soil, after being worked into a plastic mass and allowed to dry, acquires a texture of almost stony hardness, if to another portion of the same mass only half a per cent of caustic lime be added, a difference in the degree of plasticity is at once observable, and on drying the whole falls into a pile of crumbs at a mere touch; and this change is assumed to result from the expulsion of the water of combination, from the grains of colloid clay, and the gathering of them together into compound particles of larger size, which then lose their cementing power.

We do have, however, many clays very impervious to water, becoming, when worked, quite plastic and adhesive, but which cannot be used for brick or pottery on account of the large amount of lime they contain, which slacks after firing and by its expansion fractures the ware into which it has been shaped. Chemical analysis shows

such clays to contain in some cases as high as 5 per cent of lime and yet for some reason the clay has not lost its plastic character; the lime has not produced the flocculation it sometimes does.

Schlösing found, when he was trying to wash a soil with which he was working, until water would pass away from it clear, that, by passing a stream of carbon dioxide through the soil, it had the desired effect, and he attributed the clearing of the filtered water to the formation of more soluble lime carbonate, which, by coagulating the fine clay passing the filter, causes it to be formed into compound clusters too large to escape. In view of this fact it may perhaps be urged that the lime once in the impervious clay could not be acted upon by the carbonic acid sufficiently to dissolve enough to do the work of flocculation, and also that soils more open, as those of arid regions must be when very dry, give easier and more complete access to both the carbonic acid and to what water does fall, so that with the usually relatively larger amount of lime present, owing to the less leaching in dry regions, enough would be dissolved to make a more complete coagulation than generally takes place in the soils of the more humid regions.

RELATION OF THE SOIL TO ORGANIC EVOLUTION.

But soil is very much more than a mass of broken and weathered fragments of inert rock, among which are strewn a small amount of the fast-decaying remnants of plant and animal life. To appreciate the mechanism of that great locomotive which in six days places the fruits of California on the tables of Boston, one must look at it, not cold and still, as so many nicely fitting pieces of

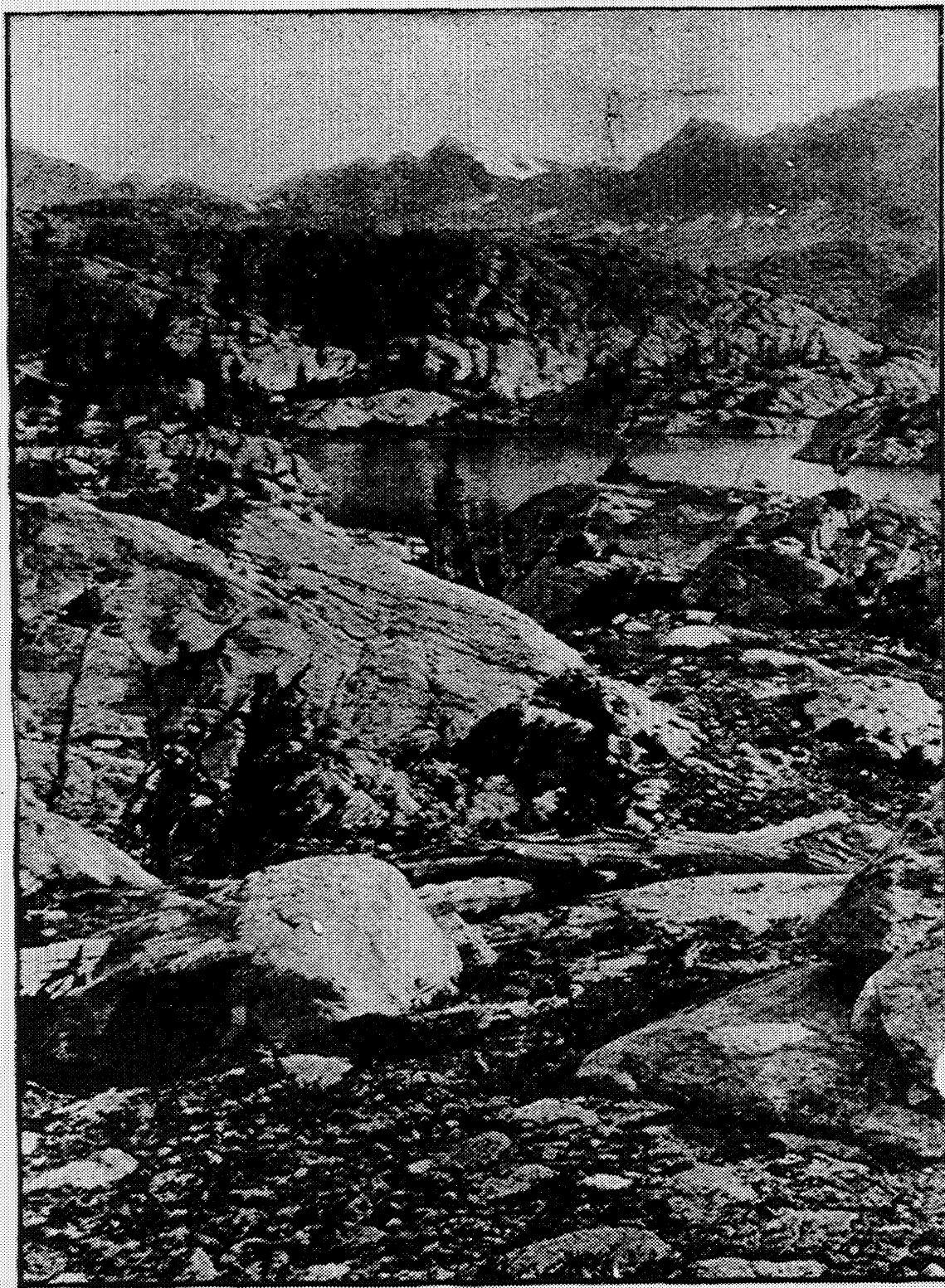


FIG. 1.—Showing surface denuded of its soil by glacial action and not yet re-covered.

polished brass and steel, but alive, the great heart throbbing, the strong arms at the wheels, and the monster starting, hurrying, halting, with its tons and tons of burden, always responding with the utmost promptness and the greatest exactitude to every beck and nod of the intelligence at the throttle. He must realize how, in its furnace open to the free air at both ends, the strength of forty horses is brought out of lifeless coal and placed in a chamber without an entrance doorway and only a chance to escape by doing work against the great piston heads. So if we will understand the soil, as farmers should, we must see it in action, helping on the work of the whole world as well as in producing the basket of apples, the bushel of wheat, or the pound of pork.

How indispensable soil is to the life of both plants and animals as they are now constituted, will be apparent at a moment's reflection when we picture to ourselves the conditions which would exist were all the soil of the entire land area swept into the sea, leaving the surface with the appearance shown in Fig. 1. Under these conditions it is evident that all upright types of plants would be without means for maintaining that position, and there would be no provision, as these plants are now constituted, whereby they could be supplied with water except during times when the rains were actually falling; for the water would hurry swiftly from the surfaces of the naked rock into the main waterways and off to the sea.

Were the land without soil, the vegetation of these areas could only consist of a meagre growth of such forms, among living species, as now subsist upon the naked rocks of mountain sides and similarly exposed situations, where, for any reason, soil is not permitted to

accumulate; forms which, like the lichens, algæ and fungi, are not provided with true roots, and which derive almost their whole nourishment, including water, directly from the air or from dead or living organic matter.

Under such conditions as these it is plain that, for lack of food, if for no other reason, there could be no such profusion of terrestrial animals as dwell in a land of plenty among us to-day. It is true that the tundras of arctic climates produce comparatively heavy crops of lichen growths such as the "Iceland moss," which, it is said, often forms the sole food of the poor inhabitants of that lonely land, like the "reindeer moss," which in northern Europe and in Siberia is the chief food of the reindeer and, in times of scarcity, ground and mixed with flour, that of man as well, and like the "Tripe de Roche," eaten by Indians and Canadian hunters in arctic North America. And then there is the "manna lichen" growing on the arid steppes of the countries between Algiers and Tartary, which in times of drought and famine is used as food for large numbers of men and their domestic animals. But the luxuriance of growth in these cases, although small when compared with that of other vegetation, is larger than it could be did it not grow lying upon the soil which holds the water to be given to the air about them by the more gradual process of evaporation as they need it.

For not only does the soil make possible a very much greater profusion of land life than could otherwise exist, but it has also played an extremely important part in that long-continued, never-ending, and sublime process of evolution whereby, as lands have insensibly changed into sea and seas into land, as mountains have risen so slowly and silently out of level plains as to spring their broad

arches directly across wide rivers to the height of a mile and yet leave their courses unaltered, as climates have changed from cold to warm or from wet to dry, both plants and animals in this great drama of world action have been enabled to change, not simply their costumes, but if the exigencies of the new scene demanded it, legs for fins or even abandon them altogether and crawl upon their bellies through the grass.

As the soil slowly became thicker and thicker, as its water-holding power increased, as the soluble plant food became more abundant, and as the winds and the rains covered at times with soil portions of the purely superficial and aërial early plants, the days of sunshine between passing showers, and the weeks of drought intervening between periods of rain, became the occasions for utilizing the moisture which the soil had held back from the sea. These conditions, coupled with the universal tendency of life to make the most of its surroundings, appear to have induced the evolution of absorbing elongations, which by slow degrees and centuries of repetition came to be the true roots of plants as we now know them.

When plants came to have specially organized absorbing surfaces placed in a supply of moisture which periodic rains made practically permanent and bounteous and which long contact with the finely divided soil grains kept continuously supplied with plant food not obtainable before, except in the most meagre quantities, the natural consequence to follow was a much more vigorous and larger growth of the parts above ground.

But as bounteous feeding pushed the parts of plants higher above the surface of the ground, they were brought where they were obliged to withstand a much stronger wind pressure than when a precarious supply of moisture

kept them close to the surface, and hence, in order to survive and utilize the new opportunities which a fertile soil affords, it became necessary to develop a stronger and more rigid tissue than the lower types of plants possess, and woody fibre in its various forms was the result.

And then, with a deep, rich soil in regions of frequent and bounteous rains, with roots spreading wide and deep to gather and lift the percolating water, and with the woody structure of stem fixed, there began that race for sunshine which has led on and on from low to taller forms, each contestant in the battle striving always to lift and unfold its leaves in the sunshine and free air above all competitors, until there has resulted a vast array of forest trees culminating in the giant Sequoias of our Pacific coast, some of which have attained a measured height exceeding 20 rods or 352 feet.

The soil has made possible succulent, nutritious grass, great forest trees and flowers with beautiful petals, fragrant odors and sweet nectars, while, with the slow evolution of these forms, there has come into being, to use them and to contribute to their welfare in return, the cattle and horses of the plains, the birds and squirrels of the forests, and the bees and butterflies which, guided by the colors and the fragrance they have learned to know, reach the nectar the flowers have provided for them that they shall be sure to come and distribute the pollen and secure to the plants, by cross-fertilization, that renewed vigor so essential to them.

THE SOIL A SCENE OF LIFE AND ENERGY.

In the agricultural sense it should be observed that the most important use of soil is to act as a storehouse of

water for the use of plants, and that the productiveness of any soil is determined in a very large degree by the amount of water it can hold, by the manner in which that water is held, and by the facility and completeness with which the plant growing in it is able to withdraw that water for its use as it is needed. But while this statement is true in the fullest sense, it must not for a moment be thought that the composition of the soil is not an important factor in fixing land values for crop production. The great importance of the water-holding power grows out of the fact that without an adequate supply of water, neither the other food constituents which the soil contains, nor that larger part which is derived from the air, can be procured by the plant, nor transformed or assimilated by it.

Then, again, the soil is a wonderful laboratory in which a large variety of the lower microscopic forms of life are at work during those portions of the year when its temperature is above freezing, breaking down dead organic matter and converting it into those forms in which it again becomes available for plant food; and the farmer should never forget that the crop of these invisible organisms which are produced each year in his soil, determines in no small degree the magnitude of the harvest he removes from the ground and the fitness of that ground for a succeeding crop.

Finally, the soil is a means for transforming sunshine and putting it into a form available for carrying on the kinds of work which are there accomplished, and the manner in which the soil is tilled and the way it is fertilized have much to do with the quantity of altered sunshine which becomes available in carrying on this work.

*INFLUENCE OF ROCK STRUCTURE IN SOIL
FORMATION.*

There are many agencies at work in the production of soil, and the process is one which is being carried forward continuously night and day and almost incessantly the

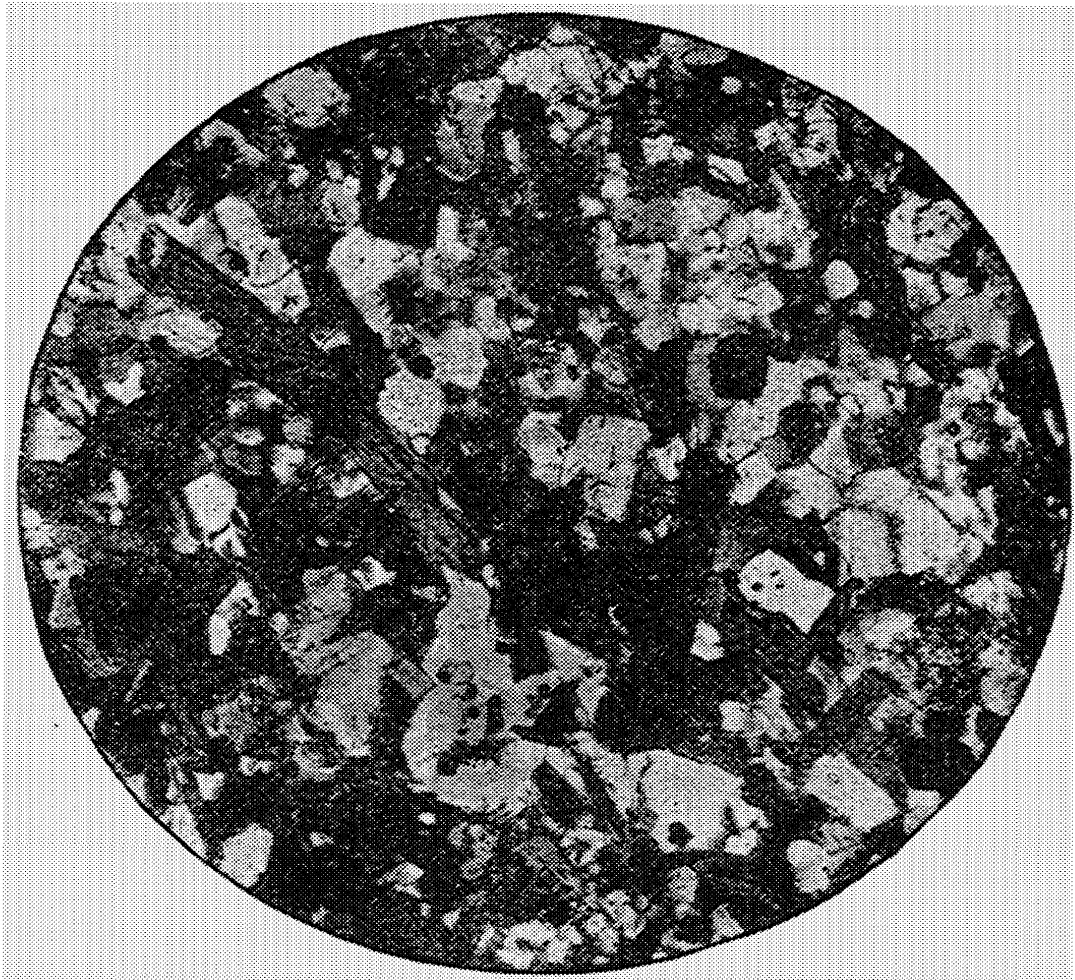


FIG. 2. — A thin section of mica schist, showing the crystalline structure which lends itself to the conversion of rock into soil.

year through. It is taking place in the tilled field and in the meadow; in the depths of the forest and on the prairie; in the driest desert regions of the world and under the tropics where rains are of daily occurrence; in the polar regions and under the equator and on the top-

most summits of mountain masses as well as along the margins of the lake and the sea, or where streams at times rise and overflow their banks.

Nearly all rocks are made up of fragments or crystals of various sizes and kinds, and these are bound together more or less firmly by some cementing material, but usually there are places which have not been completely filled with the cement, and these give to most rocks a certain degree of permeability to water. Granite, for example, has been found to absorb nearly .4 of a pound of water to each 100 pounds of rock, and the fine-textured agate is open enough to admit of coloring by capillary absorption. Fig. 2 conveys a general idea of that structure of rocks here referred to, and which lends itself so readily to their conversion into fine fragments and ultimately into soil.

When such rocks are brought to the surface, where they are exposed to wide ranges of temperature, the different rates of expansion possessed by the different minerals entering into their structure tend to loosen them and open the natural cavities wider. Into these cavities the rain water is drawn by capillarity, and on freezing tends to open the cavities still more, and to flake off from the surface minute fragments, adding so much to the soil. Then as the rocks by this action become more porous, the rain water, holding carbon dioxide in solution, enters more freely and dissolves the more soluble minerals, and, as the surface dries, these dissolved materials are brought out and washed away by the rain or blown off by the winds, thus leaving the rock more and more porous until finally it falls into fragments, illustrated so well and so frequently by what are popularly called "rotten stones."

In moist and warm climates the solvent power of water here referred to, is exerted with the greatest vigor, but in damp, cold countries the effects of freezing are most apparent, while in desert regions neither the one nor the other become soil-producing agents of any note.

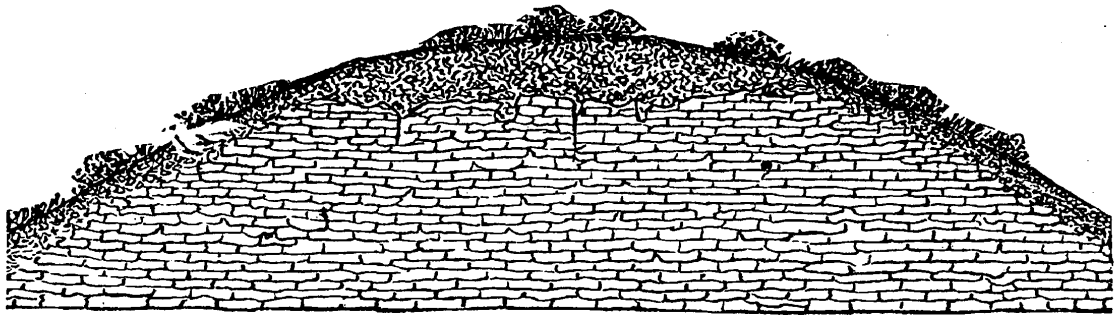


FIG. 3. — Showing the conversion of rock into soil on a limestone hill.

Whoever will visit an abandoned stone quarry where the rocks have lain undisturbed for ten or twenty years, will readily observe in the stained and altered surfaces, in the softer, more easily scratched outer layer, and in the slight accumulations of soil, which the rains and the

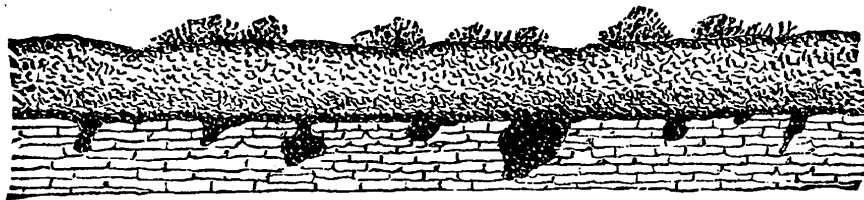


FIG. 4. — Showing the transition from rock to soil on a limestone plane.

winds have swept into the small inequalities of the rock, the initial process of soil formation as it is still taking place and has been throughout geologic ages.

Passing from the abandoned quarry to some fresh cut along the railway or roadside, where a hill has been

graded down, there may be seen at the top the finished soil, and between it and the unaltered glacial gravel or original rock below, as the case may be, every degree of progress from the one into the other, represented in Figs. 3 and 4, where the first shows the stages of transition as

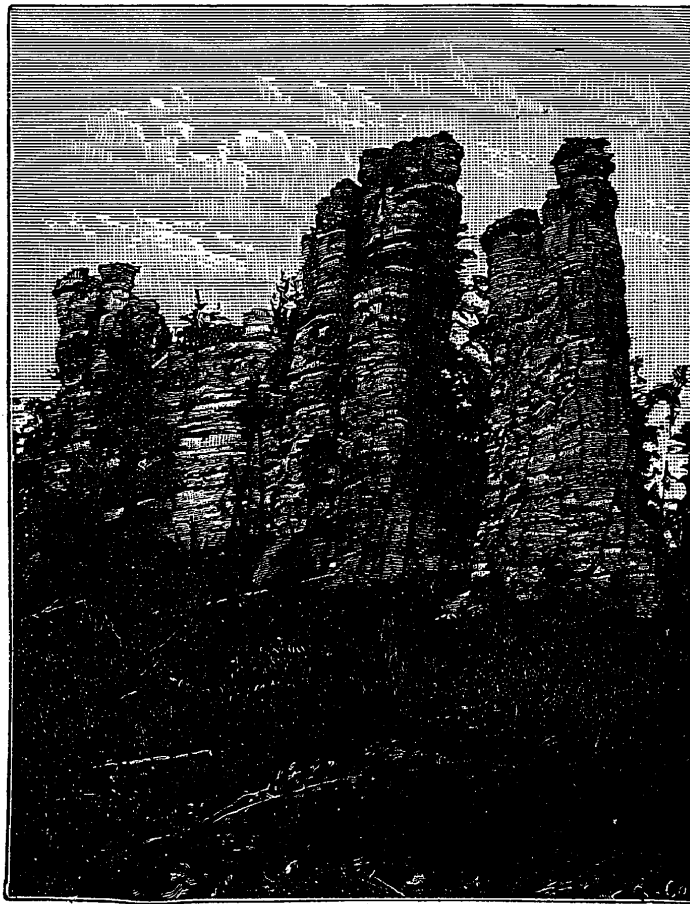


FIG. 5. — Showing advanced state of erosion. Giant's Castle near Camp Douglas, Wisconsin.

they have taken place over the summit of a limestone hill, while the second shows the same facts for a more level limestone surface.

Then, again, the rocks of almost any quarry, on examination, will be found to be divided into blocks of varying

size and form by fissures or breaks, which owe their origin to a general shrinkage of the surface layers and to small but ever-present bendings or wave-like motions of the ground. These features are well brought out in Figs. 5 and 6, and they introduce us to another process in the formation of soil.

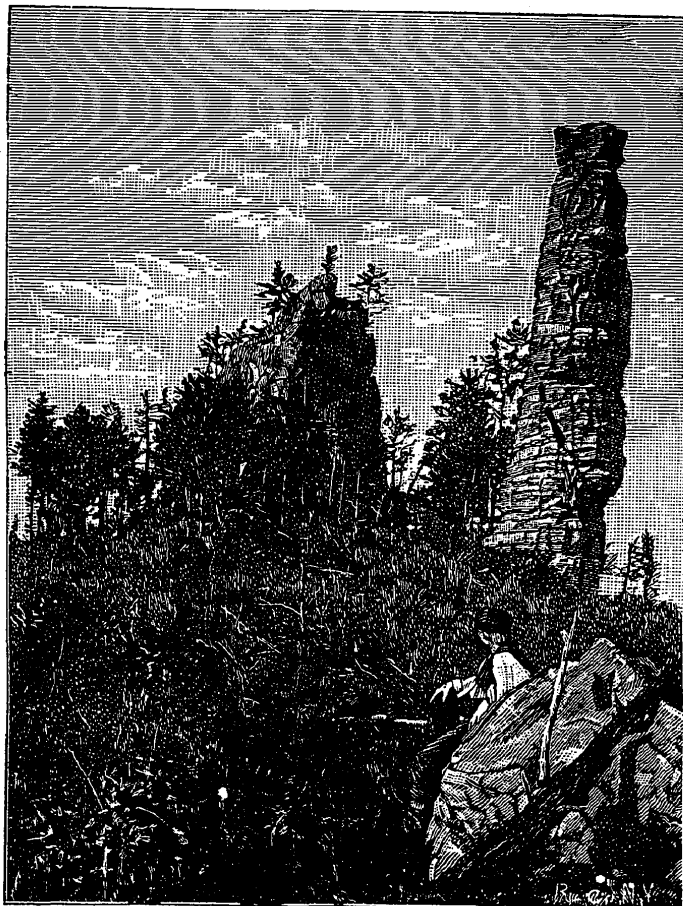


FIG. 6. — Showing the last stage of the conversion of cliffs into soil.

Such fissures as these, when not too deeply covered with soil, are often penetrated by water and by the roots of trees. Then as the water freezes and as the roots grow, both expand with an almost irresistible power and open the old crevasses wider or make new breaks where

none existed before, thus dividing the larger blocks into smaller ones, and often throwing the fragments to the foot of the cliff, where they soon become overspread with a mantle of vegetation under which they rapidly fall into soil. This process as it is carried forward in nature may be better appreciated by carefully studying Fig. 7.

Those who live near the foot of great rocky cliffs which are subject to this sort of action of ice, like the quartzite cliffs at Devil's Lake, Wisconsin, are frequently startled during cold nights in winter by loud reports followed by the sound of rolling stone as great blocks of rock, sometimes many tons in weight, snap under this action of frost and go bounding down the steep face of the pile of angular fragments which have accumulated at the foot under the same action many times repeated. Then, again, where a great tree has grown up with its roots reaching deep into some wide fissure filled with soil, on the summit of an overhanging or vertical cliff, it not unfrequently happens that a strong wind from the right direction, pressing against the wide-spreading boughs and using the tall trunk as a lever, pries off sections of the cliff, sometimes 20 feet long, as many deep, and 6 to 10 feet thick. Such a block the writer has known to fall during a wind storm.

RUNNING WATER AS A SOIL BUILDER.

Running water is another agent which, by processes peculiar to itself, has done very much in the production of soil and in giving to it certain characteristics. Standing on the bank of any small stream and watching the water as it slides over the bottom, it will be seen that there are incessantly being moved along the bed, some-

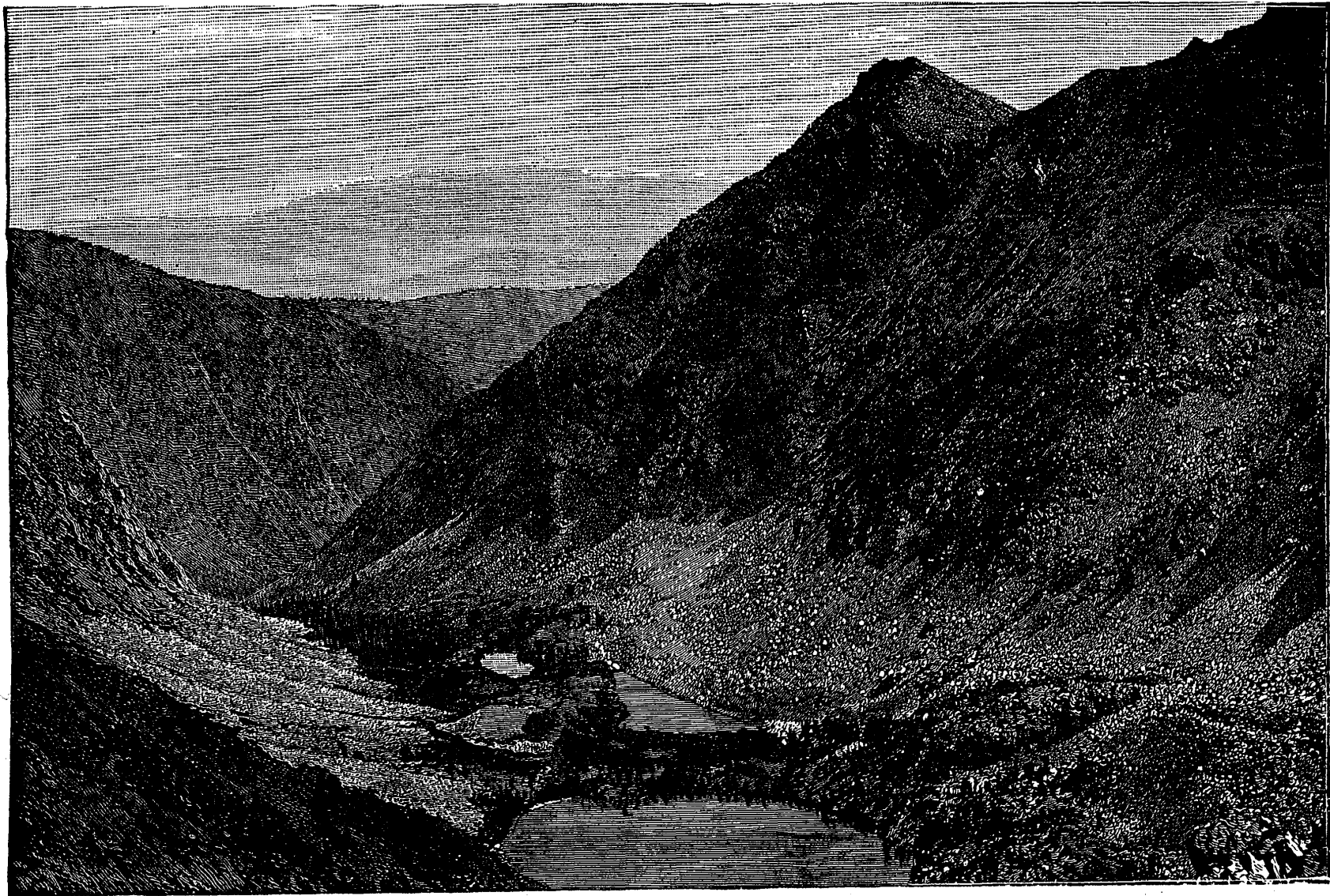


FIG. 7. — Showing the crumbled rock fragments thrown down from cliffs and passing into soil.

times rolling, sometimes sliding, grains of sand of varying sizes. One set moves on for a short distance and then stops, other grains follow after but halt at the same place until a small but appreciable ridge is formed. Similar tiny ridges are forming on its right and on its left, some above it and others below. But these are only brief resting places; for a change in the velocity of the current as the waters shift from side to side causes each ridge to move another step farther down the stream. But as the grains roll, tumble, and slide by turns in their downward course, each has its corners worn away, each is growing insensibly but surely smaller, and each is contributing something to that impalpable powder, which, rising into the body of the stream, remains suspended for almost indefinite periods except in the stillest water, where it is laid down in lakes or carried to the sea to slowly subside and become beds of clay, and when those geographical changes come which drain a lake or elevate the margin of the sea bottom into dry land, it then becomes fields of clayey soil.

But what becomes of the grains of sand which are only moving along step by step, and where was their resting place before they joined this caravan traveling toward the sea? A little observation will soon show where their journey begins. Following along the bank until a bend in the stream is reached, it will be at once observed that the concave side of the channel is deep, while the convex side is shallow. On the concave side the current is swift and plainly cutting away the bank, which now rises abruptly above the water, or perhaps has come to be so far overhanging that a portion has already broken loose and slid into the stream, where the rapid current is sorting out the grains it is able to move

along and bearing them beyond the turn. But on the convex side the ground slopes gently almost to the water's edge; the current is feeble, and hence the grains of sand advancing from above are here being laid down to fill the channel on this side as rapidly as the stream cuts away the bank on the other. The bed of a stream, then, is constantly shifting; soil is being taken from one side and borne along for a distance and then laid down upon the other, where it constitutes a new soil, and will remain as such until the stream sweeps back once more across its valley. Looking at Fig. 8, which is a map of a portion of the Mississippi below Vicksburg, it is plainly shown how the action at the bends here referred to is being carried on, the dotted areas in the channel showing where the deposits are taking place, and the clear portions where the banks are being crowded back. There is one thing about this map, however, which it is not so easy to comprehend, and that is the amazing extent to which this great river is to-day sauntering about upon its alluvial plain, some 40 miles in width, as shown by Lakes Bruin, Palmyra, and St. Joseph, which are only great ox-bow portions of its channel which it has recently abandoned. Colonel Abbot says of these shiftings of the river: "Chief among such changes is the formation of cut-offs. Two eroding bends approach each other until the water forces a passage across the narrow neck. As the channel distance between these bends may be many miles, a cascade, perhaps 5 or 6 feet in height, is formed, and the torrent rushes through it with a roar audible for miles. The banks dissolve like sugar. In a single day the course of the river is changed, and steamboats pass where a few hours before the plow had been at work." The

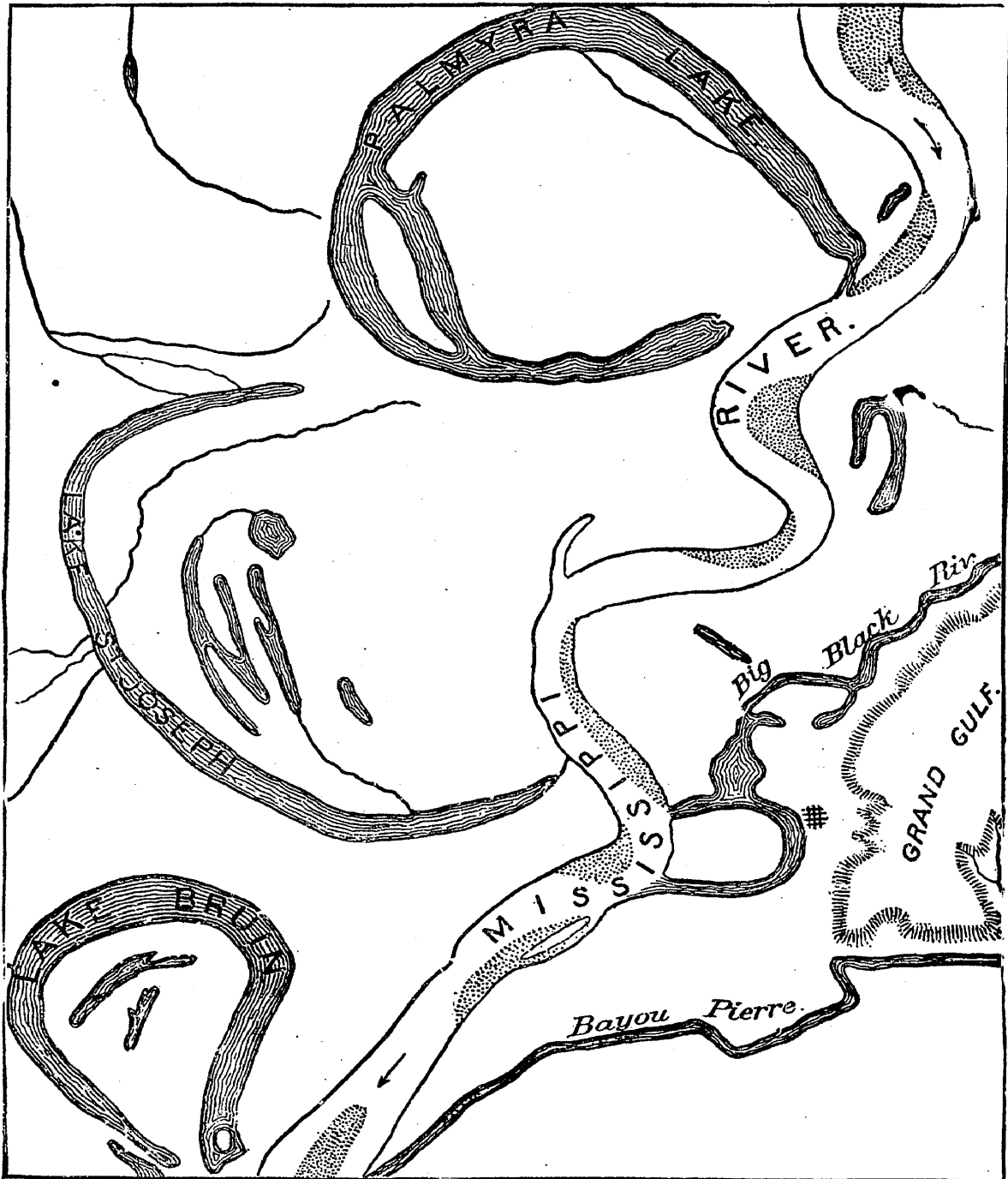


FIG. 8.— Showing the shiftings of a river channel as it forms alluvial soils.

work here is of course extraordinary, as it must be when the run-off from more than 1,200,000 square miles

is brought together into one channel on a plain which falls only one inch in 40 rods, and over which it winds some 1100 miles in making a distance south of less than half that number.

While such extreme windings as these are confined to large rivers where they traverse very flat stretches of country, this shifting of the streams, this picking up of soil from one place and laying it down in another, is nevertheless very general and very extensive; and when we speak of the Mississippi as carrying to the Gulf, suspended in its waters or shoved along its bottom, every year soil enough for 72 sections of land 4 feet deep, this work is small when compared with that which measures the shifting of sand from side to side by the same stream even after it passes the city of Memphis; and vast as this work can but be, it must constitute a standard all too small by which to measure that which in the aggregate is done throughout the broad valley of the Ohio, the Upper Mississippi, and the Missouri, with their tributaries. Glance for a moment at Fig. 9 that it may be realized, not only how many times the Madison fork of the Missouri River must have crossed and re-crossed its broad valley, but how many times over and over again it must have handled that soil before it succeeded in carrying out of its field of labor the amount which the unimpeachable testimony of those terraces show it has transported to lower levels. Think also how, again and again, a new vegetation must have taken possession of the reworked land, as the soil was being transferred now to the right bank and now to the left. Years and years, and even centuries, must have passed before a given field was entirely replowed, resoiled, and reseeded; but everywhere in the past and

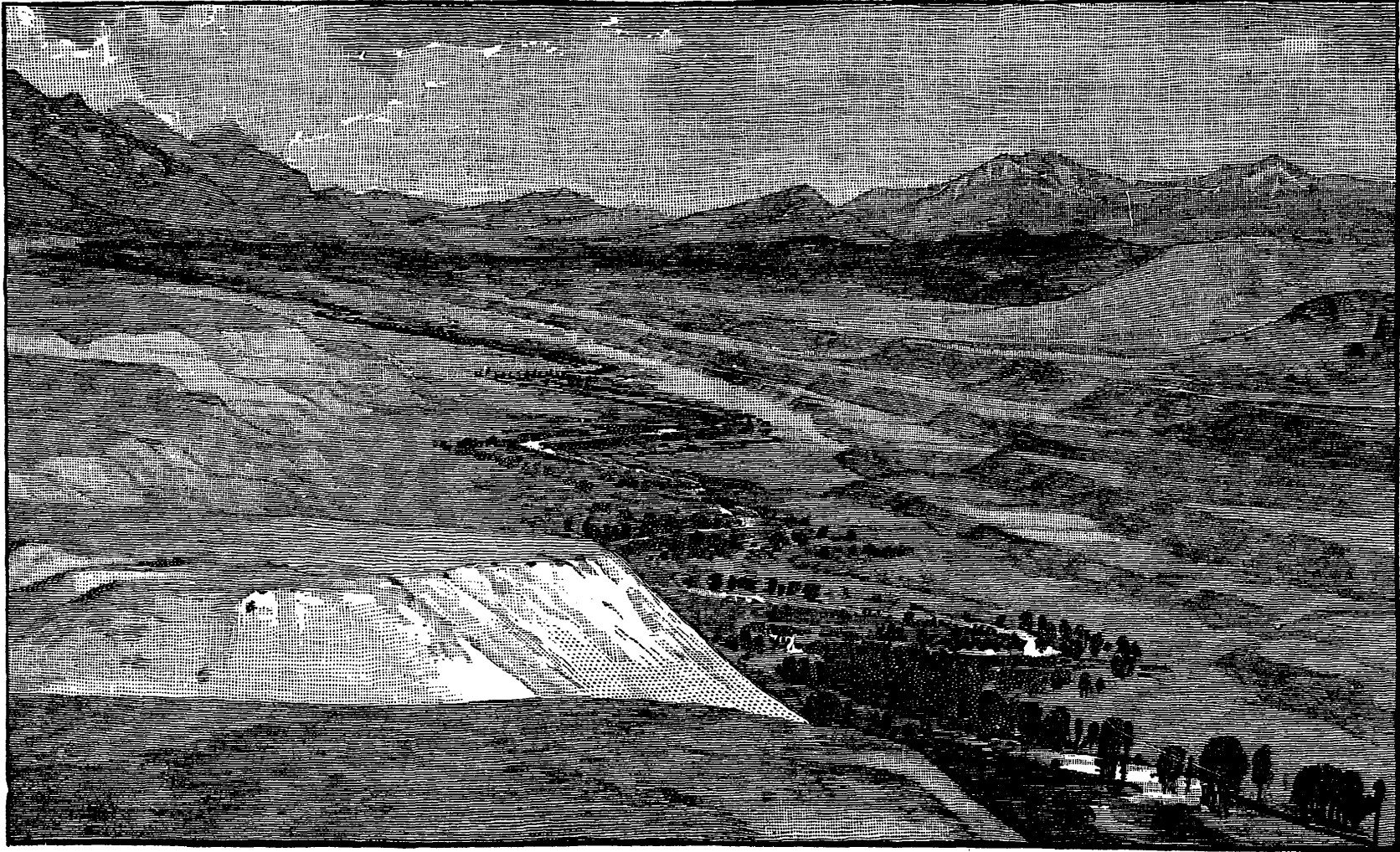


FIG. 9. — Showing the windings of a stream and the formation of river terraces. Madison River Valley, Montana.

restrict his operations. So the cultivated acres were abandoned by thousands. Then the hills, no longer protected by the forest foliage, no longer bound by the forest roots, no longer guarded by the bark and brush dam of the careful overseer, were attacked by raindrops and rain-born rivulets and gullied and channeled in all directions; each streamlet reached a hundred arms into the hills, each arm grasped with a hundred fingers a hundred shreds of soil, and as each shred was torn away, the slope was steepened and the theft of the next storm made easier.

“So, storm by storm and year by year, the old fields were invaded by gullies, gorges, ravines, and gulches, ever increasing in width and depth until whole hillsides were carved away, until the soil of a thousand years' growth melted into the streams, until the fair acres of ante-bellum days were converted by hundreds into bad lands, desolate and dreary, as those of the Dakotas. Over much of the upland the traveler is never out of sight of glaring sand wastes where once were fruitful fields; his way lies sometimes in, sometimes between, gullies and gorges, the ‘gulfs’ of the blacks whose superstitions they arouse, sometimes shadowed by foliage, but oftener exposed to the glare of the sun reflected from barren sands. Here the road winds through a gorge so steep that the sunshine scarcely enters; there it traverses a narrow crest of earth between the chasms, scores of feet deep, in which he might be plunged by a single misstep. When the shower comes, he may see the roadway rendered impassable, even obliterated, within a few minutes; always sees the falling waters accumulate as viscid brown or red mud torrents, while the myriad miniature pinnacles and defiles before him are transformed by the beating raindrops and rushing

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rills so completely, that when the sun shines again he may not recognize the nearer landscape.

“This destruction is not confined to a single field or a single region, but extends over much of the upland. While the actual acreage of soil thus destroyed has not been measured, the traveler through the region on horseback daily sees thousands or tens of thousands of formerly fertile acres now barren sands; and it is probably within the truth to estimate that 10 per cent of upland Mississippi has been so far converted into bad lands as to be practically ruined for agriculture under existing commercial conditions, and that the annual loss in real estate exceeds the revenues from all sources; and all this havoc has been wrought within a quarter century. The processes, too, are cumulative; each year’s rate of destruction is higher than the last.

“The transformation of the fertile hills into sand wastes is not the sole injury. The sandy soil is carried into the valleys to bury the fields, invade the roadways, and convert the formerly rich bottom lands into treacherous quicksands when wet, and blistering deserts when dry. Hundreds of thousands of acres have thus been destroyed since the gulying of hills began a quarter of a century ago. Moreover, in much of the uplands the loss is not alone that of the soil, *i.e.* the humus representing the constructive product of water work and plant work for thousands of years; but the mantle of brown loam, most excellent of soil stuffs, is cut through and carried away by corrasion and sapping, leaving in its stead the inferior soil stuff of the Lafayette formation. In such cases the destruction is irremediable by human craft—the fine loam, once removed, can never be restored. The area from which this loam is already gone is ap-

palling, and the rate of loss is increasing in geometric proportion.”

It is not necessary, however, to go to the bad lands of Mississippi or the Dakotas for examples of this work; for every careful farmer has witnessed it a hundred times on every hillside of his farm, and has studiously tried to prevent it. But this action of rain is much more general and in the aggregate much greater than has yet been indicated; for it takes place, only in a less intense and less obtrusive way, over the surface of all except swamp and the most heavily wooded lands, always moving the surface soil from the higher toward the lower grounds and ultimately to within the reach of streams.

When the soils of hillsides expand with increasing moisture or with frost, there is a small but sure movement downward, for while the push is equal in all directions, the downward thrust has the force of gravity on its side; and the same movement results when the soil comes to shrink after drying, for it is easier to draw the upper particles down than to pull the lower ones up. Blocks of stone, too, lying upon the slope, expanding in the hot sun and contracting during the night, tend to creep insensibly into the valley. When the fox, and the many burrowing animals of whatever sort, bring dirt to the surface, or when great forest trees are uprooted by the storm, the soil moved is without exception left one step nearer to the sea. It is evident that by whatever one of these methods of creeping the soil is moved, the rate of travel will, other conditions being the same, always be most rapid on the steepest slopes, so that generally this action must result in the soils of the summits or high lands crawling down and upon those of the lowlands, producing an overplacement which gives

to the soils of the invaded areas characteristics derived from the rocks whose destruction contributed the material for the overplacing soil. For the same reason, too, the resultant soils will usually be found more fertile and more enduring, as every farmer knows, than that left behind on the more sloping ground. The general facts of soil creeping and of overplacement are indicated diagrammatically in Fig. 10.

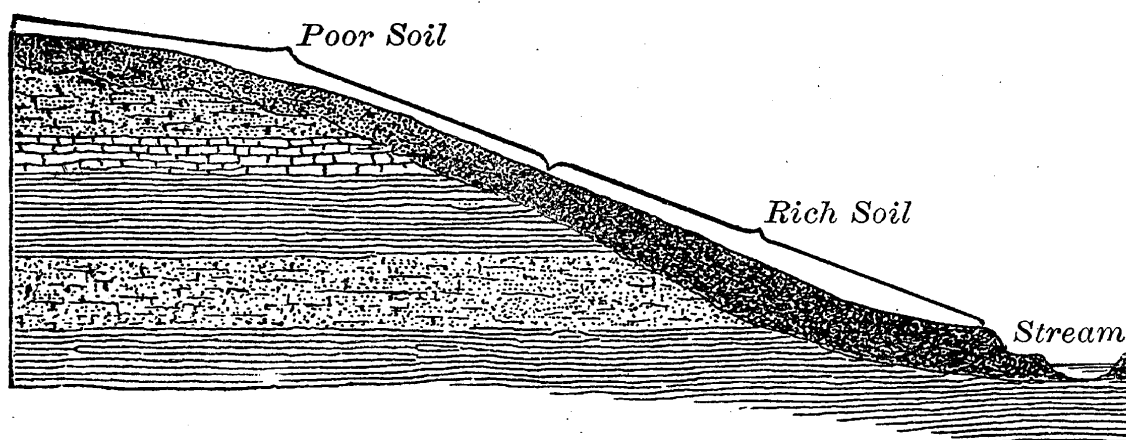


FIG. 10. — Showing movement of soils from higher to lower levels.

GLACIAL SOILS.

In those portions of the world where the temperature is so low that most of the moisture is frozen when it falls and does not all melt during the summer, the snow accumulates often to great depths and by its weight is compressed into ice. When snow in this condition has attained a considerable thickness, it begins to move along sloping surfaces much as liquid water does, converging into larger and larger streams, moving faster where the slope steepens and slackening its speed again when the descent becomes less. In Fig. 11 is shown one of these ice streams descending from the Alaskan mountains toward the Pacific Ocean, where it had its birth.

While the movements of glaciers are much less rapid than those of rivers, their far greater depth and consequent heavy pressure, together with the more rigid nature of the ice, give to these streams a grinding,

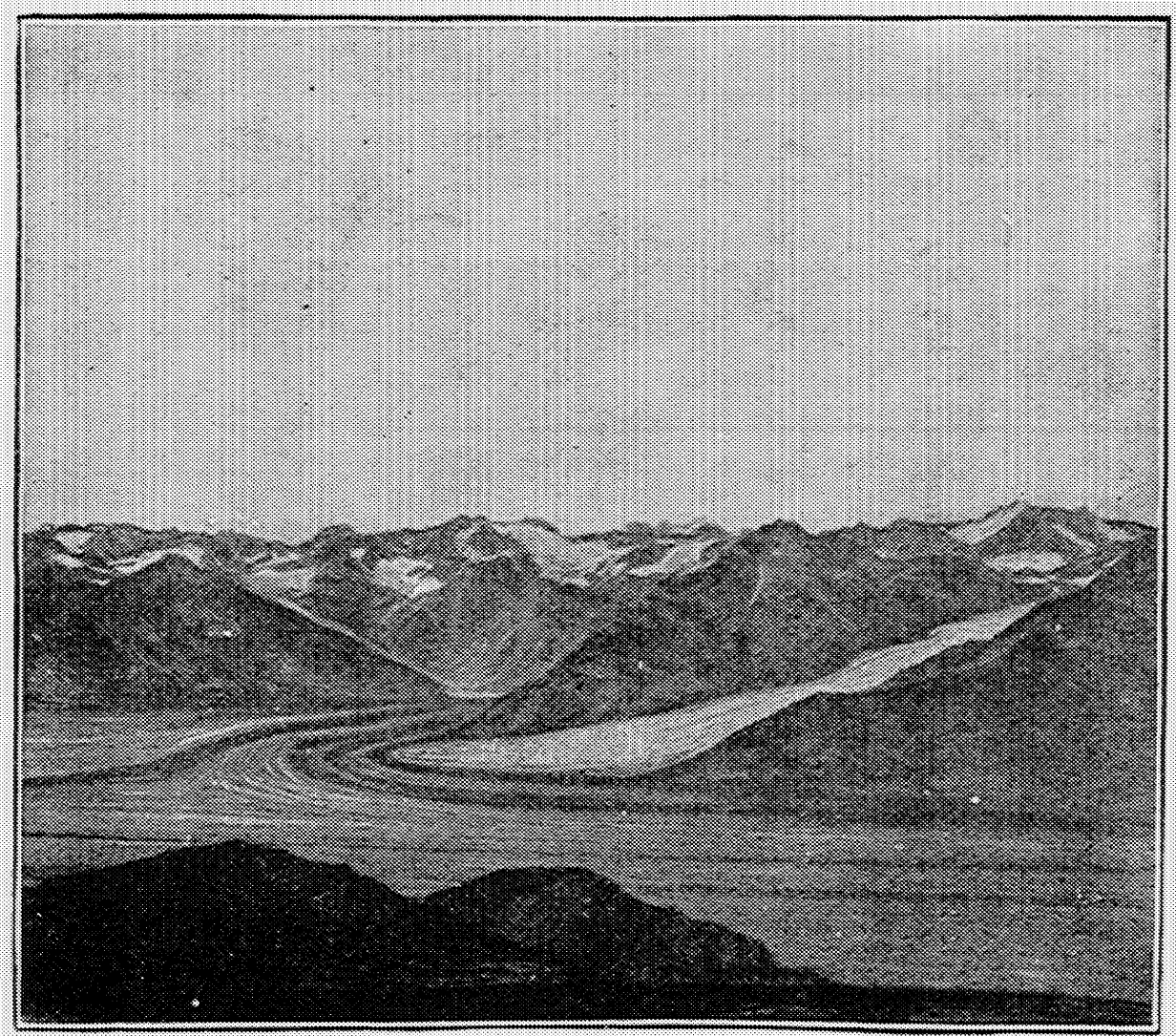


FIG. 11. — Showing an Alaskan glacier.

scoring, and transporting power which is great almost beyond measure; and hence it is that in mountain districts, which rise above the line of perpetual snow, and in the frigid zone, glaciers become soil-producing agents of great vigor.

In very recent geologic time, during the glacial epoch, a vast ice sheet gathered in the higher latitudes and spread from the direction of northern Labrador until it overran two-thirds of the North American continent, advancing so far southward as to place its front in the shape of a rude crescent, stretching from Cape Cod and Long Island through northern Pennsylvania into the Ohio valley and from thence, following the course of this stream and that of the Missouri River, to the Rocky Mountains. At the same time there appears also to have been on the Pacific slope a lesser and apparently more local sheet, which pushed itself southward through the mountain valleys until it passed the foot of Puget Sound.

What conditions conspired to induce this long geologic winter has not yet been learned, but during its prevalence the snows piled upon the land until a mantle hundreds and perhaps thousands of feet in thickness overspread the whole area outlined above, while the general level of the ocean fell as its waters were drawn upon to feed the ever-deepening snow fields as they spread over the northern continents of the Eastern and Western Hemispheres alike. As the specific gravity of ice varies between .917 and .922, the mean weight of a cubic foot will exceed 57 pounds, and an ice sheet 10 feet in depth will press upon its bed with a weight exceeding 570 pounds to the square foot, while the burden imposed by 500 and 1000 feet of ice must exceed 28 and 57 thousand pounds to the square foot, or 198 and 396 pounds to the square inch respectively. What a mill for grinding rock into soil we have here! For its nether stone one-half or two-thirds of the North American continent, and for its upper one a block of ice of corresponding size, five hundred to a thousand

