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BY

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Concerning Soils, Germs and Worms.*

By Dr. Persifor Frazer.

In Part III of the Report of the Geology of New Jersey, of 1868, under the head of "Economic Geology," the Director, Prof. Geo. H. Cook, says: "In the detailed geology and under the proper heads, will be found chemical analyses of gneiss, limestone, slate, shale, trap rock, clay, green sand, etc. The soils are mostly derived from these; sometimes from one, and sometimes from a mixture of two or more of them. And this geological classification is the best that can be made. A more common classification is into sandy, loamy and clayey soils. The latter, however, is not capable of general use. The meaning of the terms always depends on the experience of the person who uses them. What in one part of the State is called a clayey soil, in another part is called a loamy soil, and in still other places it would be called sandy," etc., etc. This statement will furnish an appropriate introduction to the observations on soils which are here proposed, since it shows how vague is the average conception of the character of that storehouse whence we draw our life. But the farmer's division into sandy, loamy, and clayey is not more crude than was that of the average geologist. To him soils were but the comminuted rocks of the earth's crust mixed with more or less adventitious organic matter, and moistened by the rain, the dew, and the capillary flow of the ground waters. Professor Cook, as he says, "to show how light or sandy a soil will produce vegetation," instances in the same chapter the following analysis of beach sand from Old Beach, Atlantic City:

* Substance of a lecture delivered before the Pennsylvania Horticultural Society, Tuesday, April 18, 1899, by Dr. Persifor Frazer, Professor of Horticultural Chemistry, Penna. Hort. Soc. Subsequently revised to January 1, 1904, and in part rewritten.

Silicic acid and quartz	95·44
Alumina Peroxide of iron	3·00
Lime	0·45
Magnesia	0·22
Water	0·30
Total	99·41

In the report of the geological survey of New Jersey for 1879, glass sand and sandy clays are noted as producing oak-land and pine-land soils.

How very different is the idea of a soil in the minds of the agricultural chemists of the present day may be judged by Wiley's definition ("Principles and Practice of Agricultural Analysis." Chemical Pub. Co., Easton, Pa., 1894): "The term soil, in its broadest sense, is used to designate that portion of the surface of the earth which has resulted from the disintegration of rocks and the decay of plants and animals, and which is suited, under proper conditions of moisture and temperature, to the growth of plants. It consists, therefore, chiefly of mineral substances, together with some products of organic life, and of certain living organisms, whose activity may influence vegetable growth either favorably or otherwise. The soil holds various quantities of gaseous matter and of water, which are important factors in its functions." Yet it is possible to make plants grow without the intervention of any soil in the sense of the last definition (Storer, "Agriculture in Some of Its Relations with Chemistry"); for not only does the mistletoe grow in the air, but hyacinths, cuttings of rose bushes, *tradescantia*, and Indian corn, or almost any of the ordinary grains, may be made to grow and bear seeds in glasses of water, provided the latter contain some ash-producing material and some nitrates, which are ordinarily derived from the soil. However small the amount, some potash, lime, magnesia, iron, phosphoric, sulphuric and nitric acid (or, in the place of the last, ammonia) must be present in order to develop the plants of the higher orders (id. I).

Soil is necessary as a prop for the plant in nature, as well as a sponge from which to extract the food which is to sustain it; and for certain plants, such as tubers, the light, easily-displaced covering of pure silica sand, when once well manured, produces more perfectly formed plants than the less yielding natural mold.

The passage of water and its saline constituents through a plant, and the evaporation of the former (or, more properly, its exhalation, since the process is connected with the life of the plant and may take place, unlike ordinary evaporation, when the surrounding atmosphere is saturated with moisture), results in an enormous circulation, estimated by Watson at 30 hogsheads of water on every acre of grass land per day. About 300 parts, by weight, of water pass through a plant to one part fixed and assimilated in its tissues.

Ordinary soils contain large quantities of nitrogen; in fact, by a series of experiments on Scotch soils and manures made by Anderson, the average proportion of organic matter in the soils was 7·02, and of nitrogen in this organic matter 0·206; or a relative proportion of nitrogen to organic matter in the natural soil of somewhere near 1 : 35; whereas in the manures applied to the eight farms from which these various soils were taken, the average proportion of organic matter was 13·94, and of nitrogen 0·382. The proportion of the nitrogen to the organic matter in the manures was as 1 : 36·49. Consequently, the relative proportion of this invaluable plant food element was higher in the natural soil than in the manure laid on to enrich it.* Professor Storer con-

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*It is interesting in this connection to note the "fertilizing ingredients" and their cost, enumerated by Mr. MacFarlane in his admirable report on "Fertilizers." The quantity of each ingredient in a given fertilizer must, according to Dominion law, be stated by the dealer. (Published by the Inland Revenue Department of Canada, Bulletin 86, Ottawa, 1903.)

Nitrogen in salts of ammonia or nitrates as well as in compound fertilizers	$0 13
Organic nitrogen in ground bone, fish, blood or tankage	12
Phosphoric acid—soluble in water	6
" " " 1 per cent. citric acid	5½
" " insoluble in Thomas' phosphate powder	3½
" " " ground rock phosphate and fertilizers generally	1½
Potash contained in wood ashes	6
" from high-grade salts	5¼

siders the utilization of these natural and almost inexhaustible supplies of nitrogen among the most important of the problems of to-day, and adds that from remote time the improvement of the soil-nitrogen has been deemed, by wise cultivators, more advantageous than employing fertilizers, or keeping additional cattle to produce more manure. These stores of nitrogen are found in arable loam, leaf mold, peat, swamp and marsh mud, etc., and here is where an agent often neglected renders valuable service, as will be seen further on.

The effect of "symbiosis," as Storer calls it, or blended life of various kinds, is well illustrated by the little knobs and warts on the roots of clover and leguminous plants. The most generally received explanation of this phenomenon now is that bacteria enter the roots from the soil, and form colonies within the roots, thus giving rise, by the mutual growth of bacteria and plant-cells, to those excrescences. The lower organisms thrive on the juices of the plant, and in turn render some service in supplying these roots with nitrogen. Hellriegel has shown that nitrogen from the air is stored up for the benefit of such plants, even when the latter are grown in sand free from organic or nitrogenous matter. Nodules form upon the roots at the time that nitrogen is being taken from the air; but material akin to the ash-residue of the normal plant must be strewn with the sand. When growth ceased, in such experiments, occasionally germs from the air fell upon the sand and started the growth anew; but on supplying water, which had been in contact with garden loam and was charged with bacteria, the full and healthy growth was recommenced, and the plants assumed their normal dark-green color. The plants feed upon the substance of the bacteria after the latter have died.

These plants, which get nitrogen from the bacteria, charge the soil with nitrogen to the benefit of succeeding crops of other plants; and this is the modern explanation of the utility of rotation in crops, which has been recognized probably ever since husbandry began. A continuous succession of peas, for example, not only gives rise to nematode worms, instead of bacteria nodules on the pea roots, but these worms are transferred to the next crop which is put in, and impair or ruin it.

Great lichens, such as reindeer moss, or Iceland moss, grow freely on bare rocks and sterile soils. Fungoid growths are noticed, even covering in a few days surfaces of iron. These fungi produce large quantities of nitrogenous organic matter.

Berthelot showed that certain nitro-organisms living in soil feed on the nitrogen of the air, and produce nitrogen compounds, at first insoluble in water, but later converted into soluble nitrates, to the amount of 75 to 100 pounds per acre per annum.

But the fixation of nitrogen by nitro-organisms in the soil is less important than that by bacteria on the roots of leguminous plants.

The general conclusions as to nitrogen and micro-organisms in their relations to plants, reached through the work of Atwater, Wagner, Heiden, Hellriegel and Wood (of the Storrs Agricultural School in Connecticut), may be thus summarized:

Pease, alfalfa, serradella, lupine, probably clover, and in general all leguminous plants acquire large quantities of nitrogen from the *free nitrogen* of the air during growth.

It is clear that there is a connection between the root tubercles and this acquisition of nitrogen, but what the connection is remains to be discovered.

Cereals which have been experimented with have not shown this power of taking nitrogen, nor had they such tubercles as are found on the roots of legumes.

In the experiments undertaken soil infusions did not seem necessary for the production of root tubercles. It is considered probable that the micro-organisms or spores were floating in the air and thence found their way to the pots in which the plants were growing.

As a rule in the experiments, the greater the abundance of root tubercles, the larger and more vigorous the plants, and the greater the gain of nitrogen from the air.

Where loss of nitrogen occurred there were no root tubercles. It was largest with oat plants and largest where they had most nitrogen at their disposal in the form of nitrates. The gain of nitrogen in legumes helps explain why they act as renovating crops, and the loss in the case of oats suggests why they should be an exhausting crop.

(MacFarlane, Bulletin 86. Canadian Report I. R. D.)

On barren ledges of rocks the frost and other causes produce disintegration, and the spores of fungi resting on this talus produce nitrogenous matters from the air. The soil is then ready for the next step, which is the making of mold.

Humus, according to Storer, is the organic portion of all the earth-like products which results from the decay of vegetable or animal matters. In temperate climates the tender parts of vegetable matter are converted by the oxygen present into carbon dioxide and water (through micro-organisms chiefly), and the residue is humus, which resists further decay.

The acids of various constitution, together known as humic acid, though not very soluble in water, are chemically active.

Agricultural plants, in general, cannot feed directly upon humus, but, through the micro-organisms which feed on it, are supplied with nitrogen.

Three ferments in all are needed: one to set free ammonia; one to produce nitrites from it; and one to produce nitrates from nitrites. Nitrification is most active in hot summer weather. No nitrates are produced by putrefying processes. On the contrary, nitrates, if present, are converted into ammonia.

In an experiment made by Leone with nitrates and hen-dung in loam, placed in a box so that air could freely pass between the particles, first nitrates were partially reduced to nitrites. In a fortnight both nitrates and nitrites disappeared, and only ammonia was detected. In little over a month, nitrates again began to appear, and in three months there were only nitrates. Lorgna defines nitrification as the last term of putrefaction.

The above experiment shows how easily an injudicious treatment of a valuable manure may entirely destroy its efficiency. A few words on the value of farm manure and the best methods of securing, preserving, increasing its efficacy, and applying it, seem here appropriate. Hellriegel, in 1897, proposed a simple plan easily applicable everywhere and every year, by means of which a practical agriculturist may see differences between adjacent crops treated differently, and thus decide what should be the substance applied to the soil to insure the best harvest. It is to pass over a few square rods of the field, at various places properly selected, without applying dung or fertilizer. In accordance with this principle other plots of like dimensions may be treated respectively with lime, marl, dung, or fertilizers. The heights and densities of the resulting crops, the fulness of the ears and the development of the grains, etc., may easily be compared, and a correct conclusion drawn as to what is best for that particular soil.

J. Koenig, in his prize essay, "How Can the Farmer Preserve and Increase the Stock of Nitrogen on His Property?" (Berlin, 1887), gives the results of his investigations and experience as follows:

(1) In the decomposition of nitrogenous substances of every nature a loss of free nitrogen, more or less considerable, takes place.

(2) This loss is the greater the more the atmosphere has access to the decomposing mass.

(3) Too much moisture is as hurtful as too little. Stable manure requires such a degree of humidity as permits its components to lie close together.

(4) The addition of substances which fix ammonia (such as gypsum, kainite, and kieserite) prevents or reduces the loss of nitrogen. *These substances are, however, of little or no value if care be not taken at the same time to prevent as much as possible the access of air.*

In storing stable manure, it should be kept in a watertight receptacle, roofed in, and it is desirable that it be trodden down by the farm animals. It is perfectly clear that the use of gypsum or ordinary ground land plaster prevents any loss of nitrogen in the stable, and, according to Holdefleiss, Vogel, and others, the same substance, or gypsum produced in the manufacture of the acid phosphate, prevents the loss of ammonia from the liquid part of the manure. Another suggestion by Dr. C. A. Goessmann, Chemist for the Massachusetts Agricultural College (Bulletin 45, March, 1897), is that there should be added to the manurial refuse materials of the farm such single manurial substances as will enrich the former in the directions desirable for any particular crop.

(Canadian Inland Revenue Department Bulletin, No. 86, before cited.)

The substance of the following notes on bacteria is taken from an interesting lecture entitled "The Analysis of Water, Chemical, Microscopical and Bacteriological," before the Lowell Institute, Boston, December 5, 1889, by Dr. Thomas M. Drown, then Professor of Analytical Chemistry in the Massachusetts Institute of Technology, now President of Lehigh University, Pennsylvania. In speaking of the bacteria found in the sanitary analysis of potable waters, he says: The bacteria belong to the lowest form of life; a simple cell, with wall and contents, capable of self-nourishment and reproduction. Until within a few years their presence was unknown and unsuspected, so minute are they, and yet their importance in the economy of nature is such that higher life would come to an end if their activities were to cease. It is unfortunate that these ever-present, humble, useful organisms should be associated in our minds mainly with evil purpose and effect. True, there are malignant bacteria, to which we cannot assign any beneficial role in nature; but so there are poisonous fruits.

The bacteria, or germs, as they are also called, have many shapes; the ball or egg-like forms include the genera micrococcus and streptococcus; the rod-like forms, the genus bacillus; and spiral forms, the genus spirillum. A special form of bacteria we have all become familiar with in name —the cholera germ, called by Koch the comma bacillus.

The function of the green plant is to make organic material out of the inorganic. Trees, grass, and vegetables live entirely on the carbonic acid of the air and the water and mineral matters in the soil. Animals cannot do this, but require either vegetable or animal food. In utilizing this food, the animals do not reconvert it all into mineral matter again. The nitrogen in the proteid, or albuminoid matter which they consume, is not excreted in the oxidized form of nitrates, but as urea, a compound related to ammonia. Then the bacteria step in, find food for their support in the waste which has no more value for animal life, and complete its conversion into mineral matter that it may again serve as food for plants.

The method employed to determine the numbers of bacteria is based on the principle that by stimulating their growth and making them increase enormously within a small space, in which they cannot move, the aggregations of the newly developed bacteria will be so large that they can be seen by the naked eye. This ingenious suggestion was carried out by the famous bacteriologist, Koch, in this way: A small quantity, usually 1 cubic centimeter, of the water (that is, about one-fifth of a teaspoonful) is mixed thoroughly with, say, ten times its amount of a sterilized solution of gelatine, which contains extract of beef, peptone, etc., to make it highly nutrient, and the mixture is poured, while warm, upon a glass plate, so that it forms a thin layer when solidified. This is set aside for a few days in a warm room under a cover, and protected from the germs in the air. If bacteria are present in the water they will grow with great rapidity under these conditions, each bacterium forming a colony, as it is termed, of thousands or millions of bacteria. Then we can see and count them. It is assumed that each colony arose from a single bacterium in the water; hence, by counting the number of colonies on a plate, we arrive at a determination of the number of bacteria in the cubic centimeter of water used.

The numbers of bacteria, as determined in this way in natural waters, vary greatly. A water taken directly from the ground, at a depth of six feet or more, should contain none. In good pond waters may be found anywhere from a few score to a few hundred. In polluted streams they may run up well into the thousands or hundred thousands, and in sewage they can be sometimes counted in the millions. Organic matter is composed of carbon, hydrogen, oxygen, and nitrogen; at least, for our purpose it will suffice if we so consider it. It is only the nitrogenous organic matters which undergo those kinds of changes which we include under putrefaction, and which we regard of importance from a sanitary standpoint. Familiar examples are milk and meat, which, when exposed to the air, become offensive, but starch and sugar (which contain no nitrogen) do not.

The nitrogen which we find on analysis from undecomposed animal and vegetable matter, say fresh albumen, we call "organic nitrogen," by which we mean that the nitrogen is still in its original combination before change or decay has set in. Leaving out of consideration that present in rain-water, we may say that ammonia in water is distinctly characteristic of the first stage of the decomposition of organic matter. The term "organic nitrogen" has been used, but on the tables of analyses another is substituted, namely, "albuminoid ammonia." It is an unfortunate fact that the methods of determining organic nitrogen have been, until recently, very tedious and difficult, and not always reliable, so that chemists have resorted to another process, which gives only a part of the organic nitrogen in the form of ammonia. That is called albuminoid ammonia, because albumen, when subjected to this process, gives up its nitrogen as ammonia.

From the present methods of examining water the following facts are ascertained. (1) By means of the microscope, the kind of life existing in the water, from which conclusions are drawn as to the kind and quality of the food which supports this life. (2) By means of the gelatine plate cultures, the number of the bacteria in the water, from which conclusions are drawn as to the amount and kind of decay going on. (3) The purely chemical examination reveals directly the amount of organic matter, and the conditions in which it exists. These widely different methods are merely different points of view. It is one and the same thing throughout, namely, the life processes which are going on in the water; for decay is but the manifestation of another form of life.

If it is asked why study is centered here, the answer is, simply, that experience has taught that it is the organic matter which is the cause or accompaniment of disease; it is during the decomposition of this organic matter, and in some of the changes it undergoes in the process of decay, that danger lurks. This is the chemical expression of the causation of disease. The biological expression takes another form, namely, that the bacteria which cause changes in the organic matter cause also disease. The two expressions do not contradict each other, but go hand in hand. The chemical idea implied in both expressions is that the state of change is the state of danger. From an horticultural point of view, the state of change is the state of evolution.

The vegetable mold which forms the rich top-soil of every agricultural country consists of a very uniformly fine mass of blackish color, usually only a few inches in thickness, though under exceptionally favorable circumstances it may reach a depth of nine or ten inches. Humus (of which there is a surprising lack of definition in the best works, but which is generally understood to be earth more or less charged with decaying organic matter) is well illustrated by beds of peat and so-called muck. The latter term, however, according to Storer, is misapplied, and should mean "well-rotted dung" (II, 78), though in this country, and especially in New England, it is synonymous with marsh mud. The vegetable mold, if not coincident with, at least contains the greater part of the humus in a given area, and it is in this that the germination of seeds and the growth of plants have their best development.

The humus has been investigated by our countryman, Prof. A. A. Julien ("On the Geological Action of Humus Acids." Pr. A. A. A. S., XXVIII, 1879, 311), by whose labors it is established that there are many acids of complicated constitution confounded under the name humic acid. All of them act energetically upon rocks, and perform important functions in the preparation of the material with which they come into contact to facilitate plant growth, directly through the disintegration of leaves and animal tissue, and indirectly by furnishing food to the bacteria which are so indispensable to vegetable life.

Charles Darwin, among the countless contributions of this greatest of naturalists to our understanding of nature, has observed ("The Formation of Vegetable Mold through the Action of Worms," etc.; Appleton, 1882) that the upper part of the intestines of earth worms generates the several humus acids which are produced by decaying vegetation. The calciferous glands lying below this tract produce a material which neutralizes the acids thus generated, for the digestive fluid of worms will not act unless it be alkaline. These acids, he thinks, are generated during the digestive process, and are probably of nearly the same nature as the humus acids, so that the agency of worms in producing the material out of which that of plants is assimilated is evident. The action of worms is not confined to chemical changes, but extends in many widely different directions, and, according to this accurate observer, is stupendous in its results. At the risk of repeating what is familiar to many of you, I will sketch briefly this action as epitomized in the work just cited. There are but few genera of earth worms distributed throughout the world. Their mode of life is to burrow in the ground, which they do by eating a hole through the soil, and with the mouth filled, advancing the œsophagus, thus forcing the cheeks outward in all directions, crowding the soil aside, and enlarging the burrow. ("The Soil," etc., F. H. King, Professor Agricultural Physics in University of Wisconsin; Macmillan & Co., 1896.) The material swallowed is passed through the calciferous glands lying midway in the œsophagus, where the acids are neutralized; through the crop and gizzard, where the particles are triturated by the hard stones habitually retained there; and into the intestine, where the pulp is again made acid; whence, at the mouth of the burrow, it is voided in the form of castings or worm-dung in piles of greater or less size, and more or less retaining the mold of the intestines. The castings may be seen after a rain, especially in gardens and much-frequented walks. Earth worms work preferably at night, and lie close to the mouths of their burrows by day. The mouth of a worm is situated at the anterior end of the body, and by means of a lip the animals can grasp an object and draw themselves forward. Their intestine has a deep involution of its walls, by which additional absorbent surface is gained. They breathe through the skin. They are destitute of eyes, but conscious of a bright light and sensitive to it in the anterior part of the body. They are less sensitive to radiant heat. They are very sensitive to touch or vibration, though not to sound. Their perception of odors is feeble, but enough to direct them to objects which they like to eat (cabbage leaves, onions, etc.).

They are omnivorous, swallowing everything they can grasp, and extracting what nutriment the mass contains. Their preference is for half-decayed leaves, however, which they draw into their burrows partly for food and partly to close the entrances; and to this circumstance is due much of the finest soil which they produce.

They moisten the objects with a secreted alkaline fluid like pancreatic juice. The calciferous glands are probably fed with lime by the leaves in which this earth concentrates before they fall. This is excreted as carbonate of lime and aids the digestive process. The castings of worms are usually acid. Darwin concludes that they possess a low order of intelligence, in contradistinction to instinct. His experiments on this subject are very curious and instructive. With worms kept in a pot he observed the manner in which hundreds of objects of different shapes were drawn into their burrows, which are thus lined, he thinks, on account of the sensitiveness of the animals to cold, for the purpose of avoiding the contact of their bodies with cold, damp earth. The amount of work performed by worms is measured by the rapidity with which objects laid on the ground become covered by their castings. There are instances of coal ashes, strewn over a large field, which were buried in this way 7 inches in eighteen years. The tesseræ of pavements, ancient buildings, large stones (including some of the Stonehenge), ancient walls, etc., are found to be covered to a greater or less depth by the castings of earth worms, and independently of the action of other agencies. With this, of course, is to be reckoned the sinking of these objects through undermining by worms, and the subsequent colapse of the burrows. The soft mold removed from lower levels to the surface has passed repeatedly through the intestines of worms, and much of it has been finely triturated in their gizzards. Darwin estimates that, in each acre of earth which is sufficiently damp and not too sandy, gravelly, or rocky for worms to inhabit, a weight of more than 10 tons of earth annually passes through their bodies and is brought to the surface. The result for a country of the size of Great Britain in, say, a million years, is 320 million million tons of earth in land which is cultivated and well fitted for these animals. It is probable, he thinks, that all of the finest vegetable mold which we see has passed again and again through the bodies of earth worms.

There is a series, and perhaps a cycle, of changes from the partially cooled, still incandescent mass, and newly formed planet—the Earth*—to the well-cultivated hive of industry of to-day; teeming with millions of workers prosecuting countless industries, all of which depend upon the change of form of the materials which the earth furnishes, sometimes for the sake of these new forms, and sometimes for the sake of the forces which are incidentally generated; but all of which are made possible by the life which the earth gives to the workers through the products of its soil.

(1) There was the partially cooled, lava-like crust of the earth, glowing cherry-red, and surrounded by the heavy acid vapors and steam, wherein the volatilizable oxygen compounds of sulphur, phosphorus, nitrogen and the like, known as sulphuric, phosphoric, and nitric acids, pervaded and gave

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* A new view of the evolution of our planet eliminates incandescence and change from gas to liquid and from liquid to solid during the earth's history. [T. C. Chamberlin, *Journal of Geology*, vi, 609; vii, 545, 667, 752. H. Le Roy Fairchild, *Bul. Geol. Soc. Am.*, vol. xv.] According to the modern substitute hypothesis the discrete matter derived from the hot nebular ring was cooled before it aggregated to form the earth. But even if this new view should ultimately displace the assumption that the earth was a hot fluid ball, which so many distinguished geologists have considered the necessary consequence of La Place's Nebular Hypothesis, it will not in any way affect the proposition of the interdependence of various forms of life herein stated. Neither the old nor the new hypothesis of the origin of the earth pretends to account for the advent of life, and its dawn is almost universally ascribed to a time when the surface of the planet was not greatly warmer than it is now. The only difference is that the new theory gains the disposal of an immensely greater period of time during which this earliest life may have been evolved into the many forms existing to-day, and shakes itself clear of the fetters which Lord Kelvin and other physicists have put upon geological speculation. Professor Fairchild's plea is "Geology for the geologists!"

their acid character to the dense, inky clouds of steam mingled with all other but the most unvolatilizable terrestrial elements.

Finally, when additional cooling had taken place, these acid vapors condensed and descended in torrents which excoriated the vitreous mass, and sent floods of highly saturated solutions into its natural depressions—the first commencement of a sea. The waters heretofore enveloping this planet in clouds like those of Mercury and Venus, descended in great mass and deluged the basaltic crust, cracking and comminuting it, and thus offering the acids more favorable opportunities to attack and dissolve its substance; tearing away its salient prominences by crush of flood and gale; spreading out the debris as a slime, mud, or sand in the natural channels; and carrying the finest suspended particles into the sea. At last, the alkaline ingredients neutralized the acid waters, and the ocean contained only highly diluted neutral salts.

The contraction of the nucleus produced new elevations and depressions, changing the old ones; so that continuously the bottoms of the seas emerged and became dry land, and high ridges were depressed under the surface of the waters. Somewhere, either at this period or perhaps from the very beginning, appeared the force we call life because we cannot understand it; and in all probability its lowest known form—perhaps some sort of bacterium. The derivation from this simplest life-element of the lowest life-kingdom we recognize—that of plants—is not yet understood, but the advance accomplished, as always occurs in nature, the plants assisted, and were assisted by their predecessor in form, until still further progress was made; each stepping-stone being used as a support to place the next, while the old were not destroyed; just as a man flings blocks into a stream to cross dry-footed, and stands on the last he has planted to place the next.

Then plant-growths imperceptibly changed in complexity and character to the second and highest life-kingdom—that of animals; but so insensibly, and with so many interlocking characteristics among the beings which are found on the border line, that no definition has yet been found which can quite satisfactorily indicate the distinction between animal and plant, nor between plant and mineral, nor between vital and any other kind of force.

Taking the sequence of events as they are, the infinite variety of plant and animal forms, from the minutest unit capable of being seen under the microscope to the gigantic California redwood, and the elephant, the lower forms and forces act as servants to the higher. The winds and frosts still tear new mineral matter apart, and the rivers and ocean grind, sift, and spread it into gently sloping prairies. The micro-organisms and the fungi invade this material, and, reaching to the atmosphere for the organic elements which it contains, translate this carbon and nitrogen into lichens, moss, herbs and humus. But with this advance in the vegetable world an advance in the animal world has taken place *pari passu*, and, amongst other useful forms, the worms appear as husbandmen and workers of this crude mass into soil fit for the highest plants. Again and again this comminuted dust, with its bacteria, goes through the alimentary canal of the worm, and is spread over the surface, hard or soft, sterile or fertile alike, hiding the floor of our planet under the rich banquet which these humble creatures spread out for higher forms of the lower kingdom.

Upon this spring the grasses and grains, the bushes and trees, which in turn send down their roots through the soil, and, saturating the unaltered crystalline rocks with their acids, prepare new material for the steps of preparation which have been described. On the higher forms of plant life the highest forms of animals live, the highest as well as the lowest representatives supplementing their simpler diet by feeding on each other.

The processes are so various, the change of action so incessant, and in such endless rotation from purely physical or chemical to vegetable and animal, that one is unable either to specify in what resides the high and the low in nature, or wherein the forces or the forms we recognize in the three kingdoms differ from each other fundamentally, in spite of the superficial differences which appear to our senses.