A SKETCH

OF THE

NATURAL HISTORY

OF THE

DIATOMACEÆ.

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CHAPTER XIV.

NATURAL HISTORY OF THE DIATOMACEÆ.

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PREFACE.

It is desirable that the reader of the present brief sketch should, at the outset, understand that it is intended to be of an essentially popular character, and by no means a scientific treatise on the diatomaceæ. It has been prepared in such a manner that it will, it is hoped, bring to the attention of others besides strictly scientific observers one of the most beautiful groups of organisms with which the naturalist is acquainted. To that end the language employed is as untechnical as was judged consistent with clearness; and when it has been found necessary to use technical terms, their meaning has been at the same time made plain. This short preface has been intended more specially for the scientist into whose hands this volume may come, so that he may understand its aim and purpose, and, at the same time, not judge it as he would had it made pretence to a position among thoroughly scientific works. At the same time it must be understood that it has of course been made scientifically correct, so that what it teaches concerning the diatomaceæ may be as nearly as possible up to date, and consistent with the latest investigations in this field of research.

INTRODUCTION.

IT is a matter which is well understood at the present day, that if the geologist desires to carry out, in a systematic and scientific manner, his investigations into the history of the globe upon which he dwells, he must earnestly and conscientiously qualify himself for extended and searching observations in many more branches of knowledge than his predecessors of but a few years back considered necessary to the accomplishment of their labors. To properly comprehend the structure and modes of formation of strata, be they made up of solid rock or more loosely aggregated material, he must be a mathematician of no low order. To understand the how, the why, and the where of the great stone book laid open to his eye, to read aright the record of the rocks, he must call in to his assistance at least the learning of the physicist, the chemist, and the biologist, if he be not—which, in our present and ever growing state of knowledge is practically impossible—a physicist, a chemist, and a biologist himself. But as it would be evidently impossible for any one man to be thoroughly skilled in all these branches and their various ramifications at one and the same time, the advanced and advancing geologist of to-day carries out the following special plan, when engaged in the study of any tract of country. He secures the coöperation of a number of specialists, persons who have devoted their time and attention more particularly to the study of distinct sections of science, so that the highest skill shall investigate for him the several parts of the work, and thus individual bricks will be contributed to the edifice which the geologist desires to erect. To this end he is aided by at least a chemist, who analyzes for him his rocks, his metallic ores, his marls, or his soils; a zoölogist, who studies the animals found in the section of country gone over; and a botanist, who turns his attention to the plants discovered in the district traversed. If he desires to carry his investigations still further, or if the particular section of country over which his labors extend requires that he should do so, he calls in to his assistance individuals who have turned their attention to particular branches of chemistry, of zoölogy, or of botany. Thus, insects may abound in his field of work, and the farmers will like to know something about the ravages they commit upon the crops; or, vegetable diseases may afflict those crops; or, the rocks may be of a kind made use of in building; or, remarkable kinds of deposits, of great interest to science or of value in the arts, may occur. In all of these, or any similar cases, it will be necessary that the subjects should be investigated by competent observers, and they must be found, and their coöperation secured. Where the geology alone, as restricted by the boundaries which limited it a few years back, is considered, but few of these specialists will be required to assist. But, at the present day, and, more particularly, as is the case with our state surveys, where the gentleman who accepts the position of state geologist is expected to make his investigations practically applicable and at an early date, the field of labor is very much more extended, and the assistants required much larger in number. Hence it has come to pass that the modern geologist recognizes the necessity of attaching to his staff of assistants one who is specially skilled in the use of the microscope, an instrument, the proper employment of which necessitates a long and severe schooling of the hand and mind, but more particularly the eye in a peculiar manner and direction. For microscopy has become a science in itself, so that, though the naturalist, the chemist, or the physician may possess and look through microscopes, yet it requires one who has mastered its secrets, and has skilled himself in its most advantageous workings, to apply it so as to obtain the best results. But, even in microscopy as a branch of science, there are specialists. Thus, we find one who devotes himself almost exclusively to perfecting the optical portions of the instrument; another will study its application to chemistry and toxicology alone; another, its use in medicine, pathology, and physiology; another, its employment as an adjunct to geology, and so on, as can be readily understood; for science and knowledge are growing so rapidly nowadays that division of labor becomes as necessary therein as it has been found to be in the mechanic arts.

These few words, by way of an introduction, have been deemed necessary, so that the general reader, into whose hands these volumes may come, might understand that the geological survey of New Hampshire has been the first of our state surveys which has possessed a special microscopist, a person who has turned his attention particularly to the study of the application of that instrument, aided by other means of research, to the investigation of geology. It is true that similar investigations have been made to some extent, by others as well as himself, for other surveys; but in no case hitherto have special collections been made systematically, and in such a manner that any very valuable results have been arrived at, for, in this branch of science as well as in others, a definite end should be had in view, and the specimens collected and the examinations made be for that end. It has remained for the state of New Hampshire to be the first to inaugurate a thorough microscopical survey of its geology and assistant branches of science,—paleontology, petrology, and biology; and it is to be hoped that the results will be, therefore, proportionally valuable and interesting to science at large, and conducive to the welfare more particularly of the citizens of that state. It has been considered desirable, and, in fact, necessary to the proper understanding of the subject, that that portion of the work of the survey which comes within the province of the microscopist should be treated of under more than one head. Thus, at the present time, that part of his investigations which has a particular bearing upon paleontology, or the study of the remains of organized beings found stored up in the form of what are known as fossils in the various strata of the earth, will be treated of, while micro-petrology, or the examination of the minute structure of rock-masses by means of the microscope, will be considered at another time and by another hand, as the bearings of the two branches are so very different. The minor applications of the microscope to the subjects coming under the consideration of the survey will be gone into as opportunity offers and desirability requires. As it is to the study of the remains of the minute forms of extinct beings that micro-paleontology is at the present time particularly devoted, the structure of more highly organized beings not having been investigated in this connection to any very great extent, those smaller organisms, their life, history, habits, and relations to geology and the useful arts, will be herein considered; and we shall begin with a group of organisms whose remains constitute, in some parts of the world, strata of many feet in thickness, underlying cities, and, at other points, make up the greater part of vast mountain chains, and which have in former times played a very important part in the history of our globe. These are the Diatomaceæ.

PART FIRST.

A Sketch of the Natural History of the Diatomaceæ.

As a large majority of the persons into whose hands the present volume will come are ignorant of the characteristics of the group of organisms which it is intended to consider, that is to say, the Diatomaceæ, and as they occupy an important position in the scheme of the geologist, before going into their bearings on paleontology it has been thought best, at the outset, to devote a few pages to a sketch of their natural history, presenting familiar and readily understood descriptions of their forms illustrated by figures, their habits, modes of growth and reproduction, and manner of occurrence in nature, so that the value of a knowledge of them may be comprehended, and the reader be able, if he desire so to do, to follow up their study and learn where they are to be found, and how they may be collected, prepared, and examined.

It is a remarkable fact that these beautiful and wonderful atomies, the diatomaceæ, are so little known to biologists in general, who, we find, have neglected in a remarkable manner to make themselves acquainted with the so-called lower forms of life, confining to a great extent their investigations to a study of the larger groups. This doubtless has arisen mainly from the fact that they cannot generally be seen and much less studied by the unassisted eye, but require, for the full elucidation of their anatomy and physiology, the most perfect appliances of modern skill, as epitomized in the achromatic compound microscope. Now, however, that the microscope is coming into more general use among scientific observers, it is to be hoped that some obscure points relating to this group of organisms, more particularly connected with their mode of reproduction, as well as the subjects of evolution, abiogenesis, and classification, which, it is considered, may be more thoroughly studied in these apparently simple forms than in the more complexly organized forms of existence, will be elucidated, or, at all events, have considerable light thrown upon them. Unfortunately, perhaps, the forms of the diatomaceæ are so beautiful and attractive, that, as they have been in the manner mentioned neglected by accomplished biologists, they have been collected, observed, figured, and described by totally incompetent persons, who, in very few cases, have possessed the training which would qualify them for undertaking the investigation of organisms of which so little is known, and whose position in the plan of being even is not thoroughly established. Hence, a great deal of that which has been published on this subject is totally useless, if it be not in many cases absolutely harmful, tending to confuse rather than simplify matters, and render the little that is known concerning their life-history obscure. The natural consequence has been that students of the diatomaceæ have fallen somewhat into disrepute, and, in some cases, observers have been frightened away from a field of inquiry which was beset with so many difficulties at the outset. Under these circumstances it is hoped that the present sketch will recommend itself for perusal to every one interested in natural history, and at the same time introduce to many unacquainted with them an extremely attractive group of wonderfully constituted and beautifully sculptured beings. Those wishing to follow the subject up more thoroughly will find, in the works of Kützing, Smith, Rabenborst, Ralfs, and others,—a list of which will be given hereafter,—ample opportunities for making themselves acquainted with what is known concerning the diatomaceæ.

The Diatomaceæ, or, as they have come to be familiarly termed by those more or less acquainted with them, the Diatoms, have been so named from a genus called *Diatoma*, which received its name at a time when it was considered to be an animal, and was placed in a group to which a celebrated German naturalist, named Ehrenberg, gave the distinctive title of Polygastrica, or, polygastric animalcules, or, minute animals possessing many stomachs. The name *Diatoma* had been bestowed upon the organism in question from two Greek words, *dia*, through, and *temno*, to cut asunder, on account of its appearing as a number of minute, oblong boxes, attached, corner to corner, in such a manner as to form a zig-zag chain, and looking as if the chain had been formed from a ribbon-like band, partially broken across at intervals. After a while, when it came to be known that the group to which the name of polygastrica had been given was made up of many totally distinct groups,—some animals, some plants, and some neither one nor the other, but merely broken pieces of animals, plants, or minerals,—different forms were, one after the other, or, in some cases, many together, removed from this heterogeneous assemblage. Some, it was found, could be placed in divisions already known, but others had to be made into classes by themselves, and these newly constituted groups had to have bestowed upon them, as a natural consequence, appellations by means of which they might be distinguished and known. The *Diatomaceæ* was one of these apparently natural groups, and as all the forms, it was found, grew after a manner the same as the organism upon which the name of *Diatoma* had been bestowed, that is to say, by a partial or total splitting across, the distinctive name of *Diatomaceæ* was given to them, and they were erected into a family by themselves, and provisionally placed in the animal kingdom. Very soon, however, it was observed that they possessed characters inconsistent with animals as then known, but more nearly allied to plants. For this reason they were soon removed to the vegetable kingdom, and, after a time, ranked as algæ, or water-plants which do not produce evident flowers. Yet there have been, and in fact still are, observers who think that these organisms were improperly removed from amongst the animals, and the consequence has been that, for a few years, they vacillated between these two kingdoms. By far the greater number of naturalists, however, have come to consider them as plants, and so they have rested up to a very late date. It has been within the last six or eight years that their true position has apparently been determined by a German naturalist named Haeckel, who considers that they possess characteristics which qualify them for a position, along with a few other minute forms of life, in a group separated alike from animals and vegetables, and to which he has given the name of Protista. Without, at the present time (for it would be out of place in a publication of the character of the present), going into the consideration of the reasons which have influenced the eminent German naturalist in his conclusions, suffice it that the author of this sketch coincides with him in his opinion, and considers the diatomaceæ to be neither animals nor plants, but Protista.

The diatomaceæ are inhabitants of both fresh and salt water, as well as that which is brackish by reason of its being subjected to the periodical influx of the water of the ocean, or that from springs and streams. They live in many cases attached to submerged objects, such as plants, rocks, or wood-work; but some species appear to be free, and unattached to anything. It is, however, likely, as has been shown by the present writer, that all of them spend a portion of their lives attached to substances below the surface of the water, whilst they have periods of freedom when they swim about, and in this way disseminate the species. Although we find them inhabiting both fresh and salt water, yet it would seem that there are certain forms which will not thrive in both of them. Thus, we find certain well marked species which would seem to be confined to the ocean, whilst others are only to be seen in running fresh water, and still others exist solely in quiet lakes. However, so little has been done towards studying the local peculiarities influencing the distribution of these organisms, that we will dismiss the subject with this brief mention, merely pointing out that therein lies a field for investigation which will yield abundant fruit to the patient and conscientious student.

They are to be found in all permanent collections of water, but have never been observed in pools formed by the rain and liable to be dried up, and they may be looked for at all seasons, although, as might have been supposed, they appear in greatest numbers in spring and during the autumn. The hottest days of summer, at least in such localities as the present writer has examined, seem to be unfavorable to their growth (that is to say, in fresh water), but they have been gathered in midwinter from beneath the ice in the Hudson river, New York. In the ocean we find that season affects the diatomaceæ, as it does most organisms which, like them, live near tide levels; that is, they diminish in numbers as the cold of winter approaches, only to increase again in spring.

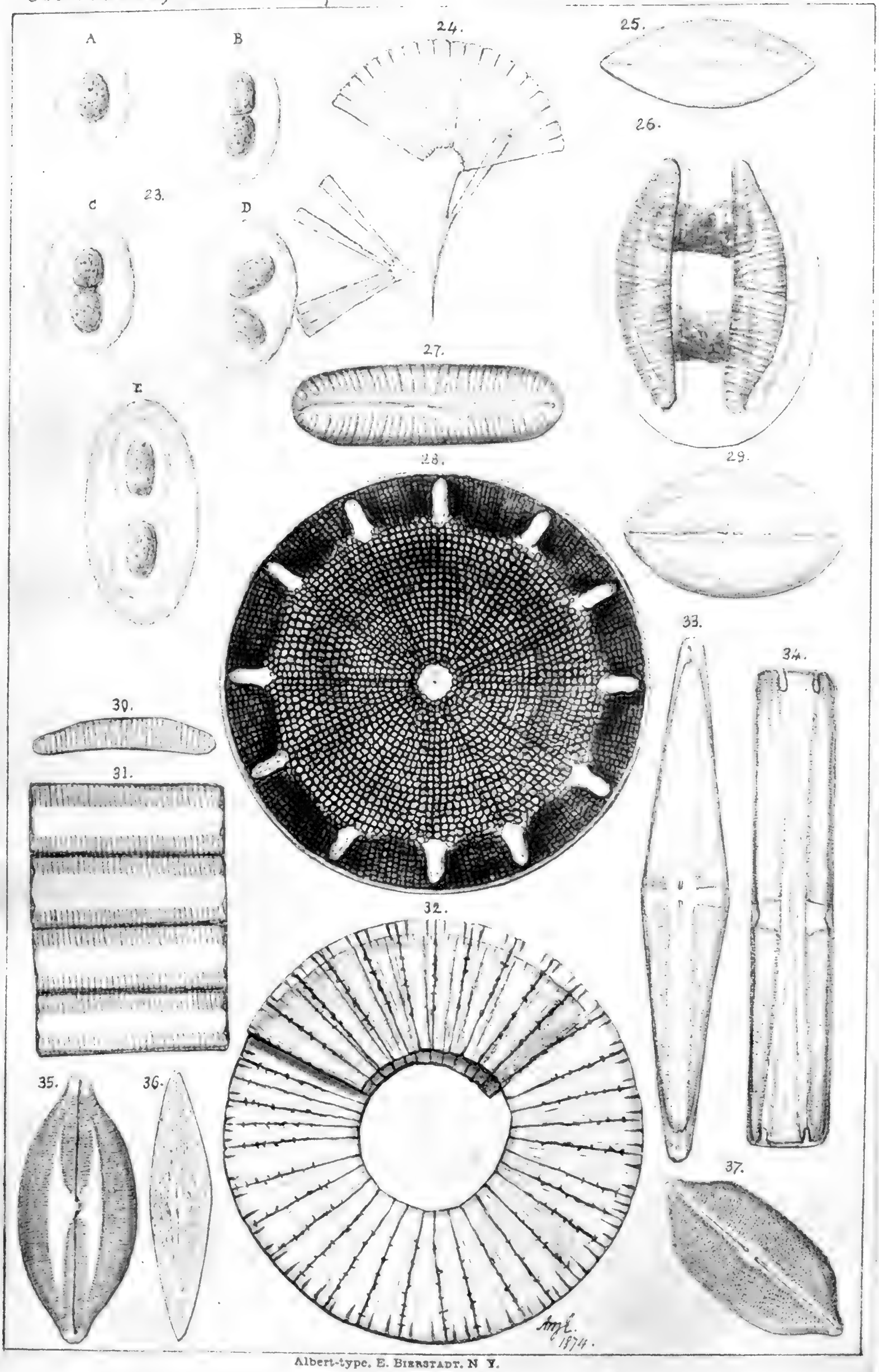
The structure of the diatomaceæ is very peculiar; and althought heir general outline can, without any very great difficulty, be made out by using a magnifying glass of moderate power, their ultimate anatomy is extremely difficult of elucidation, as will be exemplified further on. This can be readily understood when we know that the largest of them are not over eight thousandths of an inch in diameter, and that many, and those by no means the smallest, are only two ten-thousandths of an inch across. If the diatomaceæ possess an outer membrane, integument, or, we might almost say, skin, it is extremely delicate, so much so that it has not with certainty been detected as yet, although one or two observers think they have seen something that looks like such a seemingly necessary limiting portion of the individual. But we shall see hereafter that there are organisms very closely related to those we are now considering, which certainly do not possess limiting membranes, but whose whole substance is homogeneous, and made up of but one kind of substance of a semi-gelatinous consistence, and known to naturalists as protoplasm, meaning the simplest of all living matter. It is likely, then, that the diatomaceæ have for an essential base to their bodies this protoplasm; and, reasoning from what we know of allied organisms, it is within and from, in part, the substance of this protoplasm that the other portions of the individual are elaborated, constructed, and built up. What appears to be the exterior membrane of a diatom is siliceous; that is to say, it is composed of the substance known commonly as silex, but called by the chemist silica. This is the same material as that which, crystallized, we find in rock crystal or quartz, and which, variously colored, constitutes flint, agate, jasper, amethyst, and various other minerals often used for ornamental purposes. Of course, this portion of the diatom is very hard, and on this account what we may with considerable propriety call the skeletons of dead individuals are used for the purpose of polishing metals, and similar substances, under the name of tripoli,—although it by no means follows that all tripoli is made up of dead diatom skeletons.

The typical form of a mature and perfect individual diatom is constructed after the following manner: The outer wall, consisting, as has just been said, of silica, is formed of two portions so fashioned that when these are united, as they are during the life of the organism, they form a little box, within which is enclosed the softer parts which go to make up what have been called the "cell contents," under the supposition that the diatomaceæ were "unicellular" organisms. Now that the old theory of cell organization has been very materially modified, this appellation had better be discarded, as it has been used (and in fact was constructed) for the purpose of describing a condition, of the existence of which there are considerable doubts. The whole diatomaceæous individual has been called the *frustule*, and under this designation we will speak of it here. Within the siliceous wall some observers have thought that they have detected a delicate membrane surrounding the rest of the contents, but it is doubtful if such a limiting membrane really exists; and, in fact, it is much more probable that the general mass of the contents is made up of protoplasmic substance, consisting, like such protoplasm usually, of a more or less semi-fluid material, without any differentiation of its parts from the centre to the exterior. Enclosed within the mass of this clear, colorless protoplasm are seen irregularly formed masses of a substance of a greater consistence, and of a peculiar light yellowish-brown tint: this is known as the *endochrome*. Sometimes the endochrome occurs in the form of two masses, but often there are many such masses. In either case, as a common thing, the particles of endochrome are so disposed as to lie near to the two portions of the siliceous wall which constitute the top and bottom of the box. Besides this colored matter, which gives the peculiar tint to the diatoms when seen in mass at certain times, but apparently not at all periods of their existence, we find the diatom individuals to have scattered throughout their contents, but always within the layer of endochrome, one or more clear globules looking like oil. These have been called the "oil globules," and, when the diatomaceæ were ranked in the vegetable kingdom, were supposed to be the representatives of the starch found in the larger plants. Ehrenberg, who did (and, in fact, does still) rank the diatomaceæ among animals, considered these clear spaces to be stomachs, and fancied he had been able to feed these organisms on such colored matter as indigo, and see it enter these spaces. On account of their frequently being present in numbers, he constructed for the diatoms the name already spoken of,—Polygastrica, or many-stomached. There is no doubt that diatomaceæ will absorb indigo, or similar material, along with water, and thus their cell-contents may become tinted; but such taking into their interior, of matter, does not prove their animal nature, as all the Protista absorb solid nutriment, and, in fact, many undoubted plants, under certain conditions, do the same.

The typical form of a diatomaceous individual, then, consists of a little siliceous box with its cell-contents more or less colored of an olive-brown tint. The variation in form of the top and bottom of the box, which are known as the "valves," is very great, whilst the band uniting the valves, and called the "connecting membrane," or "cingulum," remains essentially the same, being merely a ring, narrower or wider as the case may be, and conforming in contour, of course, to the valve to which it is attached, and whose outline it then typifies. In the same way, the sides of a trunk form an oblong ring, and those of a pill-box a circular or oval loop. Thus, in the genus *Pinnularia*, the connecting membrane is oblong, with rounded ends; in *Coscinodiscus*, and the many similar genera, circular; in *Triceratium*, triangular; in *Amphitetras*, quadrangular, and so on, as can readily be understood, and will be made more plain when the various forms come to be seen in their integrity. As has been said, the outline of the valves varies very greatly, but is, for the most part, constant in each genus. We occasionally find, however, that the outline of the valve is the same in two or more distinct genera, which are then separable by means of some other character. The intimate structure of the valve itself is very beautiful and characteristic, but we shall be able here to consider such structure in general terms only, leaving its more particular description until we note the peculiarities of a few typical forms, which will be described in detail, and illustrated by figures showing their outline and sculpture, as revealed by means of the microscope. The minute sculpture of the diatom valve is commonly spoken of as its "markings," and in all cases they are generally of a similar character on both valves. This, however, is not always the case, as we find in some genera which pass most, if not all, of their lives attached to objects like plants, sticks, stones, and the like, submerged in the water (fresh, brackish, or salt) which the diatomaceæ inhabit. In such cases, as they are dissimilar, and can be distinguished, it has become customary to call that valve which is next to the object upon which it grows the lower valve, and the opposite one the upper,—and if, as must often be the case when the diatom is fixed to the under side of a plant leaf as it floats upon the surface of the water, the position of the valves is reversed. In all cases the valves are convex at the edges, although they may be somewhat flattened near the middle, so that when the edges are in contact they enclose the cavity already spoken of, and which may be very shallow in proportion to its width, perfectly spherical, or several times deeper than wide.

The great point of beauty in the diatomaceæ, and what has attracted to them the attention of so many unscientific possessors of microscopes, is the symmetry and forms of these same sculpturings or markings found upon the siliceous envelope; and these vary in delicacy from comparatively coarse reticulations to such extremely minute dots that no microscope has as yet been constructed which will show us what is their true character, so that, as they lie side by side in rows, the siliceous cell-wall appears to be marked with extremely faint lines. But this is not all, for there are diatoms upon which even such faint lines have not been seen; but we know that they must be fashioned after the same manner as their brothers, and must, therefore, possess markings of yet greater fineness, and which time, it is to be hoped, with the aid of improved means of research, will reveal to the inquiring eye of the future observer. The great delicacy of some of the markings found upon diatom cell-walls, and the consequent difficulty of seeing them, has led to great rivalry in makers of lenses for microscopes, and certain species have been selected and accepted as "test objects," by means of which the power of lenses to show their structure has been made evident. But as this has become a special department of microscopy we will pass it by, at the present time, with this mere allusion. These beautiful markings are, for the most part, hexagonal, that is to say, six-sided, or, at least, they are of forms derived from the hexagon, that being the form most economical of space under the circumstances. And it can be readily understood how this has come about, if we consider the matter after the following manner: It is well known that matter, by which is meant solid or semi-solid substance of any kind whatever, if left to itself uninfluenced by any outside force, as gravity and the like, will assume the globular form. Thus we find that the drop of water, of oil, or of metallic quicksilver, is round or spherical, or nearly so. So we can understand that the silica deposited as skeleton by the diatom would assume the spherical form. Likewise, the minute markings or granulations made up by those siliceous particles would, in a like manner, be at least spheroidal, be they elevations, as it is assumed by some observers, or depressions, as is thought to be the case by the majority of students. Now, supposing them to have a circular outline when they are far apart, if they are made to approach each other closer and closer until they touch, they, at last, by mutual pressure, will present a six-sided outline. That such would be the case may be proved, experimentally, in a very simple and, at the same time, elegant manner. Let a mass of soap and water be placed in a bowl, and a pipe like a straw be thrust down into it. Then if air be blown through the tube, keeping the end opposite to that placed in the mouth in contact with the bottom of the bowl, after a time the vessel will become filled with soap-bubbles all of about one size, and which we know, if they had been formed separately, would each have been perfectly spherical,—as, in fact, can be seen on the top where those which are outermost present an outer limiting surface which is part of a sphere. But we see plainly that these little globes have pressed upon each other to such an extent that they have lost their spherical outline, and have sides which are more or less plane. If, now, a plate of glass be pressed down upon the accumulation of bubbles in the bowl, many of them will be cut in two in such a way that we may see through the glass that their section is an almost regular hexagon. In fact, such a collection of bubbles, thus cut in halves, looks very much like the transparent siliceous membrane of a diatom. It is impossible, however, to give any idea in words of the beauty of the diatomaceæ, and, in fact, the best of illustrations affords but a faint notion of them; they must be seen and closely observed to be fully appreciated. Their great interest to all students of nature will perhaps be understood from a perusal of this brief sketch, wherein their principal points of structure, habits, modes of occurrence, and uses, are set forth in such a way, it is hoped, as will be readily understood, and at the same time prove interesting to others than those intending to be students of these organisms.

Having now arrived at a pretty clear idea of the typical structure of diatoms in general, let us make ourselves more thoroughly acquainted with some of the various forms in which they make their appearance. If we take, as a representative of the usually free circular or discoid diatoms, the genus *Aulacodiscus*, we find the valves perfectly round in outline, and usually only slightly convex near the margin, the concavity for holding the cell-contents being thus somewhat flattened, its sides being limited as usual by the connecting membrane or zone, which in this genus is narrow. The structure of the siliceous material which goes to make up the valve is of the following character: On the exterior is a plate marked with coarse hexagons, which really are only net-like; that is to say, they merely constitute a hexagonal framework of boxes without tops or bottoms, set side by side, and arranged more or less regularly, so as to radiate from the centre to the edge of the valve. The radiant arrangement of these coarse markings varies in regularity in the different species of the genus, but in all is apparent. Inside of this coarsely marked plate is another, so that the large hexagons have the character of honey-comb; that is to say, the sides are perpendicular to the flat surface of the inner plate, which thus constitutes for them a bottom. And this inner plate is commonly, although not always, constructed after the same manner as the outer one, being set all over with small hexagons, which are so small that as yet their character has not been studied, but most likely it is similar to the larger ones, that is to say, being honey-comb-like; but its hexagons probably have not in their turn still smaller markings within them. At any rate, in most species of *Aulacodiscus*, both



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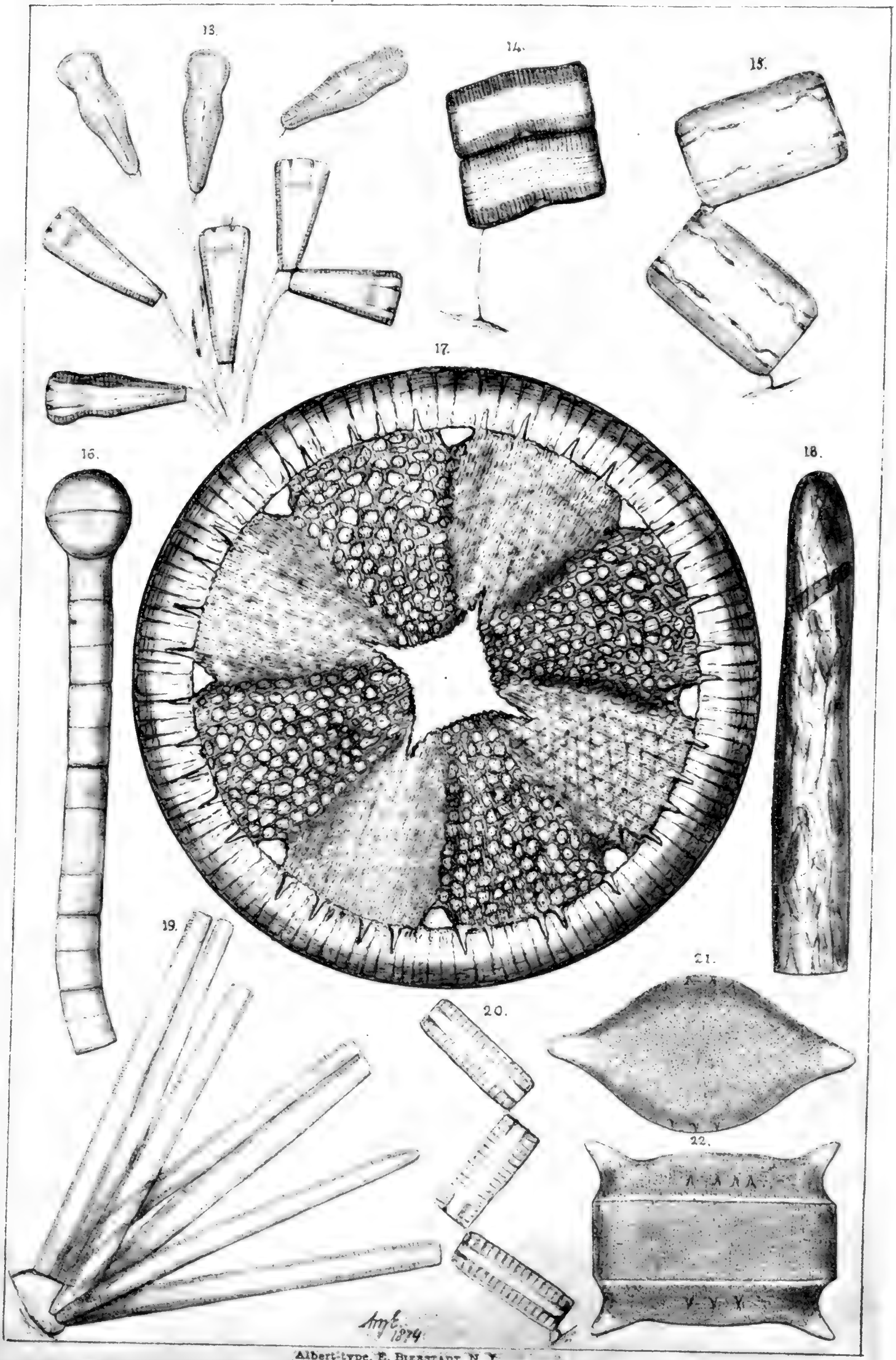
those with two sets of hexagonal markings and those with only one set of coarse ones, we find that under, and often filling up the whole bottom of each hexagon, and therefore on the inside of the inner plate, is a little plano-convex lens of silica. That such is the case is readily proved by the images formed of the source of light, as a candle, by the little lenses; and in fact it would doubtless be possible to measure their focus by means of a graduated fine adjustment to the microscope, such as is found on the larger instruments. Sometimes the sides of the large hexagons are not quite perpendicular to the inner plate, but approach each other as they descend, so that the bottom of the cavity becomes concave; and, as the convexity still occurs on the inner surface of the inner plate, we have a meniscus lens of silica formed,—that is to say, a lens which is still thickest at the centre, and therefore one which converges light like the plano-convex one more commonly found. The effect on light passing through such a diatom is very much the same as in the first case mentioned, but sufficiently different to be distinguished. Though these peculiarities of structure can be made out by a careful observer in *Aulacodiscus* and a few other genera, on account of their size and coarseness of structure, yet they can be seen only with difficulty in others, and in most diatoms cannot be shown at all. And this can be readily understood when we remember that markings of any kind upon many species can only indistinctly be seen when the best optical appliances for illumination and the finest microscope objectives and occulars are used. In fact, it has been for the purpose of exhibiting such markings that objectives have been specially made and apparatus invented, as has been already said.

The sculpture of the siliceous cell-wall just described is not peculiar to the *Aulacodiscus*, but is found in many other genera. This particular genus, however, is remarkable for possessing what have been called, for want of a better name, "feet." These consist of tubular masses of silica projecting outwards from the cell-wall, and usually placed near to the margin of the valve. In some species the portion from which the feet project is somewhat raised immediately under each foot, or in the form of a ridge all around the valve. Within this portion the valve is either plane, concave, or undulate, although the central portion is usually somewhat raised. The feet project outwards at a greater or less angle, and are either short and stout or long and slender, varying in this respect in different species. They also vary in number from one upwards, the number being constant in some species, while in others it varies very greatly. Usually the outermost end is somewhat swelled into something like a knob, and within this part the central canal, running through the foot, also swells into a spherical cavity. When a perfect specimen of an *Aulacodiscus* is examined on what is known as its "front view," that is to say, with the edge of the valve presented towards the eye, the presence of the feet makes the appearance of this diatom very characteristic. The description of this genus has been thus full, because the beautiful complexity of the diatomaceæ could thus be made evident, and many points of structure dwelt upon at the outset. So when we come to describe a few of the other forms as types, their resemblance to or variance from *Aulacodiscus* will be noticed.

The genus *Coscinodiscus* has the same general characters of outline and sculpture of markings as the genus just described, but is destitute of "feet," and, therefore, of the raised portion upon which they are placed. The two membranes are present, but the inner one is smooth. Both *Aulacodiscus* and *Coscinodiscus* are inhabitants of salt water, although there is a minute form, usually classed as a *Coscinodiscus* and called *minor*, which has been seen in fresh water; but it is now pretty well ascertained that it is not a true *Coscinodiscus*, but belongs to the genus to be described next.

In *Melosira*, the frustules have a general resemblance to *Coscinodiscus*, and are frequently mistaken for specimens of that genus, especially when dead and detached one from the other. Usually, however, the valves are so much more convex when viewed edgewise, that the whole frustule may approach in form a sphere, as is the case in the species chosen as an illustration. It however differs widely from *Coscinodiscus* in having its frustules united, by means of their valves, into long chains, which are quite flexible, so that they wave about in the moving water. Some species have the valves more flat, and then the live plant looks like a number of pill-boxes attached together. Some species are peculiar to fresh water, whilst others are found in the sea; but it would seem that a few of them can become acclimated to and live in either kind of water.

Actinoptychus, another beautiful genus, contains several species which



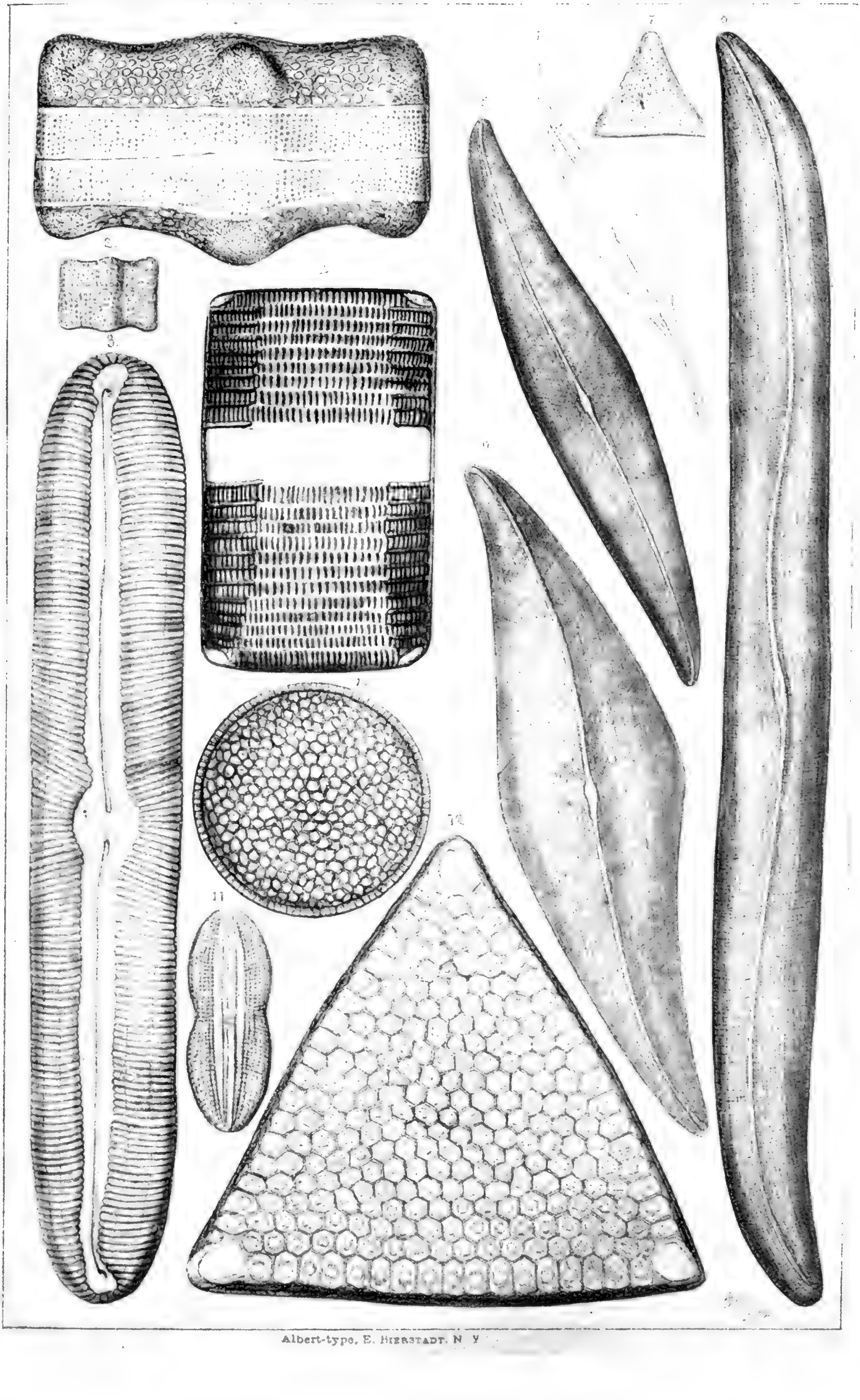
Albert-type, E. Bierstadt, N. Y.

are extremely graceful in sculpture. In form it is discoid, on what is known as the "side view," but, unlike any of those we have seen so far, the surface of the valve is divided into segments which radiate from the centre, and are arranged alternately elevated and depressed, so that on a front view the frustule appears undulate. When we look straight down upon the valve, it has very much the appearance of a wheel. In some species the markings of the raised segments are different from those on the sunk portions, while others have the markings of the same character all over the valve. They are, however, always of the same general character as those described as occurring in *Aulacodiscus*. This is likewise a marine genus, and some of the most beautiful species belonging to it have been found as yet only in the fossil state.

There are many other discoid forms which we cannot stop to describe, but must pass on to consider some other genera.

Nearly allied to the true discoid diatoms, and in fact having a few circular species, are two genera which it will be well to describe here. One of them is called *Biddulphia*, and is found only in salt water, although one species was seen by the late Prof. Bailey in the Hudson river at West Point, where the water is not all salt; but, strange to say, the tide reaching up as far as this, the salt water creeps up under the fresh, so that at this point salt and fresh water forms of vegetation appear alongside of each other. *Biddulphia* grows in chains attached to submerged objects, more commonly the larger plants. It has valves either orbicular, elliptic, or more or less pointed in two directions, and approaching in outline to the boat-shaped genera to be presently described. In fact, the outline of the valve in *Biddulphia* varies very greatly, as is seen by the figures given. At two opposite points on the valve are projections upwards very much like the feet of *Aulacodiscus*, and, in fact, they may be considered their analogues. So when *Biddulphia* is looked at on a front view, it looks like a number of little wool-sacks; and the species which Prof. Bailey found at West Point, and which is not very uncommon along the Atlantic coast of the United States, has very much that appearance, especially as the frustules grow in the form of a chain, with these projecting portions united, often alternately, so that the chain becomes of a zigzag form. Sometimes the surface of the valve also bears upon it certain spines, varying in number in different species, and usually placed near to the centre or at points midway between the centre and the edge, and half-way between the horn-like projections.

In outline, *Biddulphia* passes into a genus known as *Triceratium*, which, as its name indicates, is provided with three projecting horns or corners. In fact, what may be called the normal form of its valve is triangular, having three horn-like projecting portions like the two in *Biddulphia.* But although the commonest outline is triangular, we find certain species varying to such an extent as to have examples with four, five, and even six sides,—in this respect resembling *Aulacodiscus,* whose number of projections, or "feet," vary in the manner described. And there is a genus called *Amphitetras*, which apparently only differs from *Triceratium* in the fact that its normal form is with four corners. In truth, we find occasionally specimens of *Biddulphia* with three corners, *Triceratium* with four, five, six, and even nine corners, and *Amphitetras* with five corners, so it becomes extremely difficult to draw lines of distinction between these three genera. Besides this, we find that among themselves the species of *Triceratium* differ in minor characters; some have the sides convex, becoming more and more so, until at last we have a perfectly circular outline still retaining the three projecting horns. Then we find them with sides straight, then more and more concave, until the valve appears to be but three arms united by a very small body. Some have undulate sides. The front view is as various as the side view. In some the processes are nearly level with the surface of the valve, while others have them considerably elevated, and attenuated into spines. So, again, in this beautiful genus, the sculpturing of the valve is very various. We have coarse hexagonal reticulations, with or without finer ones within them, fine hexagonal markings, circular, dot-like, radiant or curved depressions, in some cases of such delicacy that high-power glasses are required for their elimination. Then, again, we have large, heavy bars of silica projecting across the valve in different directions, merely cutting off the corners, or dividing the central portion in various ways. In short, *Triceratium* is one of the most variable as it is one of the most beautiful genera of the diatomaceæ. It is found living in the ocean, growing in chains attached to algæ and shells, after the manner of *Biddulphia* and *Melosira.* Some of the most beautiful species have been as yet found only in the fossil condition in certain so-called "infusorial" earths.



Albert-type, E. Bierstadt. N. Y.

As has been said, the species of *Biddulphia* vary very greatly among themselves, until we have them approaching the boat-like form in outline, and in this way they are connected with the next group of diatoms, which we now come to consider. These are all more or less quadrangular in outline, or, rather, we might describe them as elongate, with more or less parallel sides, and having their ends acute or rounded. The genera belonging to this group are very numerous, but we shall describe only a few of them. It is a remarkable fact, that, almost with the exception of some of the *Melosiræ* and allied cylindrical forms, the discoid, two-, three-, four-, five-, and six-cornered genera are confined to salt water; but the boat- and stick-like forms are found in both fresh and salt water, so that in our streams and ponds we find the "naviculæform" and "bacillar" genera, as they are called, almost unmixed with circular forms. A few species of *Melosiræ*, and an allied genus called *Cyclotella*, are found occasionally intermixed with the boat-like ones, and rarely alone in lakes and fresh-water streams. So we already see that, by examining the species of diatoms, we can say with considerable certainty whether a piece of water be fresh or salt, and, if found in a fossil condition, whether the earth, of which they make up a part or the whole, was thrown down from a now extinct ocean, lake, or river. Our knowledge of the habits of the diatomaceæ is hardly complete enough as yet for us to tell exactly the character of lake, river, or ocean in which the diatoms grow; but already we have learned that certain forms are found on mountain tops, others in swift streams, and so on.

Taking *Pinnularia* as the first type of the naviculæform, or boat-shaped diatoms, we find it to be, of course, made up of two siliceous valves and a connecting membrane. The valves are boat-shaped in outline, sometimes with the sides parallel, and the ends pointed or rounded off. Frequently the sides are convex or bowed outwards, bent inwards, or undulate; but all of the various species, and they are very numerous, preserve the general characteristic boat-like form. The valves in this genus are commonly very convex, so that when looked at on a front view or endwise, the edges are distinctly rounded off. Running down the middle portion of the valve from one end to the other is a blank space, which, at each end and at the centre, expands into round nodules projecting into the cavity of the frustule, as likewise does the blank strip itself. In fact, this strip, with its end and middle swellings, constitutes a thickened part of the valve, and they have by some writers been called the "median line," and "central" and "terminal nodules." Considerable confusion has arisen in the nomenclature of what might be called the osteology of the diatomaceæ. This central thickened band is usually, if not always at some period in the life of the individual, traversed by a canal which runs the whole length of the clear space, but in the thicker ends terminates in enlargements, and is divided into two sections at the centre of the valve, where, likewise, it ends in two round cavities. The end enlargements of this canal have also been called "terminal nodules," and the swellings near the centre have been called "central nodules," as well as the parts just described. Lately it has been proposed to call the tube the "central canal," and by this name we shall designate it in this sketch. At one period in the life of the diatom it would seem that this canal is open outwards down its whole length; at least, such is the belief of some observers; but the writer has never been able to satisfy himself that such is the case, for in some of the *Pinnulariæ* he has noticed that the central enlargements of this canal open, by means of trumpet-shaped tubes set at right angles to the course of the canal, into the general cavity of the frustule, and that the terminal expansions, in a like manner, have a communication outwards at the ends of the valve. It is his opinion that this canal has something to do with the motion of the naviculæform diatoms, which always sail about in a direction parallel to their longest axis. The central canal, when the diatom valve is dead and dry, is filled with air, and then,—on account of the effect produced upon the light as it is transmitted through the object to the microscope,—appears black, or nearly so, if the objective employed is a good one, and more or less colored when an inferior one is used. The markings found sculpturing the valve of *Pinnularia* are different from what we have seen to occur in any of the genera described so far. We find no large hexagons nor finer ones here, but, instead, the valve is marked on each side of the median blank space with lines which indicate elevations in the form of bars or corrugations more or less parallel to each other, and set at nearly right angles to the central canal. These bars, or "pinnulæ," as they are called, reach from the edge of the valve over the convex margin, and up to the median blank space, where they stop in rounded off extremities.

There is a genus very closely allied to *Pinnularia* which has the same general form, except that in many of the species the sides slope off straight towards the somewhat acute ends, so that the whole valve is quadrangular in form. On account of the thickened portion at the centre of the valve being widened out so as to extend almost or quite across the valve as a band, and thus, with the median blank space, form a cross, it has received the name of *Stauroneis.* The markings on the valve, however, are not those found on *Pinnularia,* but consist of minute depressions, or dots set in lines, which run usually somewhat sloping from the middle portion to the edge. These rows of dots are usually known as "striæ," and are often extremely fine, so much so that in some species in which they occur they are very difficult to demonstrate, and hence the diatom becomes a very good "test-object." In *Navicula,* the genus which has by far the largest number of species, inhabiting fresh, salt, and brackish water, we have *Stauroneis* without the central cross bar, but merely the blank longitudinal space found in *Pinnularia.*

The variation in outline and in other respects, among the several hundred species which have been grouped together under the generic name of *Navicula,* is very great, so much so, in fact, that it would seem reasonable to believe that several genera must have been unconsciously fused together. And such is the opinion of the present writer, in which he rather agrees with some of the older writers on the diatomaceæ.

There is a genus which at one time was included in *Navicula,* but which has of late years been separated therefrom, and is known as *Pleurosigma.* It looks like a *Navicula* which has been twisted so as to bend the two opposite sides of the valve in different directions. Hence it has somewhat the form of an S, as its name indicates. It has a central canal like the other naviculæform diatoms; but the blank space through which it runs is very narrow. The central expansion is generally present; but the terminal swellings are not so evident. On this account, although in *Pinnularia* and other genera, in which they are pronounced, the terminal expansions of the blank, thickened portion have been called "terminal nodules;" in *Pleurosigma,* where they are not so apparent, that name has been applied to the swelled ends of the central canal,—an example of the unscientific manner in which the diatomaceæ have been treated by many who have written about them.

The markings on the valves of *Pleurosigma* are peculiar, and different from those found upon the other naviculæform diatoms considered. The genus can be and is usually divided into two groups, distinguished by the character of the markings. In the first group the valve is covered with dots set all over the surface in such a way that they are in lines at equal distances apart, running from the central canal to the edge of the valve. But the next row starts, as it were, half a dot behind the previous one: therefore its dots alternate with and come between those of the first line, and so on, so that the dots are at equal distances apart all over the valve, but, when traced across the valve, are in straight lines, and, when traced lengthwise of the valve, are in zigzag lines. As these dots are coarse and set far apart in a few species, they can then be seen to be circular, but, when they approach each other closely, they appear to become, by mutual compression, as would be the case if such were to occur, hexagons. In fact, it has been one of the difficult matters to solve concerning the diatoms, and one on which observers have differed for a long time, as to whether the markings on certain species of *Pleurosigma* are circular or hexagonal. Hence one species, especially named *Pleurosigma angulata*, has been selected as a "test object" for lenses of moderate power. But the second of the two groups into which *Pleurosigma* is divided has its markings arranged somewhat differently. In this group the dots are set in straight lines, if they be traced either across or lengthwise of the valve; that is to say, instead of being alternate, they are opposite in contiguous rows. Among themselves the different species of *Pleurosigma* vary somewhat: thus in many the sides run in one unbroken line from end to end, being only swelled out at the centre. In *P. angulata*, and still more so in *P. quadrata*, the bowing out at this point is decidedly angular. In *P. Balticum*, a species originally found in the Baltic sea, and hence the name which was given to it, but which has since been found pretty much all over the world, the sides are straight and parallel until near the ends, when they are curved over so that one end of the valve points to the right, while the other is turned to the left. *P. angulata* and *P. quadrata* belong to the group in which the dots of the markings are arranged alternately, while *P. Balticum* has its dots set regularly and opposite to each other. *P. fasciola* differs totally in outline from any of those described. The main portion of its valve is in shape like a *Navic-*

ula, being almost oval, but pointed at each end, and with a central canal running down the middle, just like a *Navicula;* in fact, it may be said to be almost shuttle-shaped; but from each extremity projects a long, horn-like portion, into which the central canal is continued, and which is curved one to the right, the other to the left, thus completing the sigmoid form necessary to constitute a member of this genus. Some species of *Pleurosigma* have markings of such extreme fineness that it becomes very difficult to see them unless the microscope employed be of the best quality. A few species are found in fresh water, but for the most part they are inhabitants of the brackish water of swamps and similar localities.

Some species of diatoms present us with examples of a peculiar structure not found in all. Thus, when we look at certain species of *Stauroneis* from a front view, we see at the ends and just below the terminal nodules, as a part of the valve, and just where it joins the connecting membrane or zone, a stout siliceous structure projecting a short distance into the cavity of the frustule like a shelf, but more so at the ends than at the sides, where it becomes so shallow as to be hardly apparent. When we look down upon the valve, or view the diatom on what is known as the side, we see that this projecting portion forms a ring all around the cavity, widest at the ends and narrowest at the centre, where it is hardly, or in some species not at all, perceptible. This has been called the "septum." In *Triceratium*, we find it appearing only as slight projecting shelves at the corners. Some genera have it very strongly developed, and projecting very far into the cavity, so that the two septa divide it into three distinct portions. Some genera have more than two septa, and in such cases they are not fused with and form part of the valves, but are attached to separate rings which lie between the edges of the valves and the connecting membrane or zone.

Septa are very marked characters in a genus named *Grammatophora*, which is found in chains of many frustules, united corner to corner, and attached to algæ in the ocean on almost all sea shores. The valves are shaped somewhat like a *Pinnularia*, but have the striæ, as the rows of markings have been called, running straight across, and extending quite up to the ends. The septa are four in number, and extend almost across the cavity of the frustule, leaving only a small opening of communication at the centre. Besides, although some species have them straight, in most they are undulate, so that on a front view they look somewhat like written characters, which has led to the name *Grammatophora* being given to the genus.

Nearly related to the genus just mentioned is one known as *Rhabdonema.* It likewise is found growing in chains attached to algæ, and similar submerged objects in the ocean. In this the septa are not continuous, but look as if they were punctured with several holes. The two last mentioned genera are attached to their supports by a small gelatinous cushion, but there is a genus named *Achnanthes,* in which this cushion is lengthened out into a long stalk, and as it is attached to one of the corners of the frustule, the whole individual looks very much like a flag floating out straight from a staff. This stalk is called the "stipes," and is remarkably developed in other genera. Thus, *Gomphonema* consists of a number of wedge-shaped frustules attached by their pointed ends to long and forked stalks, while in *Synedra* the stipes has again shrunk down to a cushion. The frustules of *Synedra* are like little sticks attached to the cushion by one end, and sticking out on all sides like the spines of a porcupine.

There are many other forms which the various genera of diatoms present, but we have had space only to describe and figure a few of them. The possessor of a microscope will soon, if he searches, come across others; and if he is encouraged to ask for more information concerning the beautiful atomies he sees, as it is to be hoped will be the case, he will be able, in the works of W. Smith, Rabenhorst, Kützing, Ralfs, and others, to find them more fully described, and better and more thoroughly illustrated. So to those works we must refer the reader who desires to learn more than we have been able to tell him in this little sketch concerning the diatomaceæ.

PART SECOND.

Movements of the Diatomaceæ.

It has been said that it is extremely probable that all species of diatomaceæ are at some period of their lives free, while for a short period perhaps for some, but always for some time, they are fixed or attached to some submerged object, as rocks, plants, woodwork, or similar substances. This opinion is not held by all observers; so much so that many,—and

W. Smith, the author of the Synopsis of the British Diatomaceæ, among that number,—have classified them in such a way as to constitute two great groups, namely, those which are free, and those which occur attached. It would seem most natural that those forms which commonly present themselves attached should become free at some period of their existence for the purpose of disseminating the species, for we do not find that the diatomaceæ produce seed which may be wafted about by the motion of the water, or young which are specially characterized by possessing organs of motion, so that this phenomenon may be accomplished. However this may be, it is a fact that many of them possess peculiar movements, produced by and inherent in themselves, and which have from the earliest times, when they were first observed, attracted the attention and aroused the wonder of possessors of microscopes. And when these seeming sentient movements are watched by means of the magnifying glass, it is not to be wondered at that many observers have been disposed to class them among animals possessing complicated organs of locomotion, digestion, and reproduction, if not reasoning powers to guide and direct those organs. And this power of active movement is not confined to those forms alone which are usually seen free, for many of the fixed forms, if detached from their support, will immediately take upon themselves motions precisely similar to those of their normally free brethren.

The extreme liveliness of some of the diatomaceæ has been considered by many as proof of their animal nature; but when we know that the seeds of many large and acknowledged plants growing in water, namely, the algæ, are even more active in their motions than our little friends, and, as in the case of those plants, this motion is evidently for disseminating the species, so we may naturally believe that some similar provision is made for the wide spreading of the diatomaceæ. If we watch, by means of a good microscope, an individual belonging to the genus *Navicula*, in which the form, when viewed in the direction which is usually presented to the eye, is that of a double-prowed boat, something like an Indian canoe, we find that it moves after the manner of a boat, but with either prow forward, as happens to be most convenient, apparently, for, after moving in one direction for a few seconds or minutes, it will immediately return upon its course, now propelling the other forward. And although in a few species, and those seemingly the larger, the motion is a steady progressive one, yet it is by far commoner to find that it is unsteady and trembling, as if it were the tottering steps of the infant, or of extreme old age. *Navicula* is one of those genera which are usually classed among the free forms, and in them all, with perhaps one or two exceptions, when they have any progressive motion, it is that which we have described. There is a genus which has very much the form of a horse saddle with the two flexures, and known as *Campylodiscus,* in which "the motion never proceeds farther than a languid roll from one side to the other."

As has been remarked, the earlier observers of these atomics, being insufficiently informed on the subject of the economy of the vegetable kingdom, considered the possession of the power of spontaneous motion by any being indisputable evidence of its animal nature; and, on this foundation, it became easy to rear up a mass of proofs that the diatomaceæ were certainly animals. The space within the two-valved shell, like an oyster or clam, was the animal matter furnished with special organs, if not with muscles, by means of which the movements were accomplished. Of course, the many clear vacuole-like-looking spots of oily matter were the stomachs, and, with the imperfect microscopes of the time, observers were (they thought) able to see the protrusion of a "foot" like that upon which the snail travels, through the central portion, which looked to them like a round opening, but which we now know to be a thickened portion of the shell. A late observer has asserted that he has seen, along the so-called "median line," an appearance indicating the protrusion of an organ or series of organs of some kind; but as others, equally competent microscopists, have not been able to satisfy themselves that there are such organs, this gentleman's assertion can hardly be said to be proven. There are still a few microscopists who hold to the belief in the animal nature of the diatomaceæ, although by far the majority rank them as plants. One gentleman in England says that he has seen (and, what is more, figures) the cilia, or hairs, which move about like arms, and by means of which these creatures change their place. Unfortunately, he first takes the animal nature of the diatomaceæ for granted, and then attempts to prove the existence of the cilia as organs of locomotion.

It will be naturally supposed, from what has been said on the subject, that the mode in which the motion is caused is not decidedly known; but however that may be, it is a remarkable characteristic of these creatures, and, although in most species it is regular and uniform, in some it takes place as a series of jerks. It would seem that it could hardly be called a voluntary motion, or, at least, that if it be so, the faculty governing and directing it within the creature is of a low order, or one which responds to stimulus in a very sluggish manner; for if an obstacle of any kind occur in the path of a moving diatom, like a *Navicula*, it is not avoided; but, on the contrary, if it be small enough, it is thrust aside; or, if it be too large, the diatom is arrested in its career for a certain length of time, or turned aside in its course. If it be stopped, it is a remarkable fact, noted by English observers, that the diatom waits exactly the length of time it would have taken for it to perfect its forward progression to the greatest extent, when it returns on its path again. In many species, however, the motion is not so regular as this, and the little creature goes tottering along its way. It has been remarked by one author that "the movements of the diatomaceæ appear rapid and vivacious under the microscope; but it must be remembered that the high powers usually employed in the observation of these minute organisms magnify their motions as well as their bulk." Using a seconds watch, and timing several species exactly, it has been found that one of the most rapid, known as *Bacillaria paradoxa*, took a whole second to move over one two-hundreth of an inch; and that one of the slowest, named *Pinnularia radiosa*, in the same space of time only travelled one thirty-four-hundredth of an inch;—so that the quickest would take three minutes to travel an inch, while its slowest relative would require a full hour to perform the same feat. But although a few observations of this kind have been made, we have by no means arrived at a knowledge of the rate of movement of these atomies, for it varies under different circumstances, as apparent condition of health and surroundings. Heat appears to accelerate as cold retards it; and yet I have seen *Bacillaria paradoxa* very lively when taken from beneath the ice on a cold winter's day. It is a curious fact, that often, as we watch a diatom sailing across the field of the microscope, it comes in contact with an obstacle, as a grain of sand. If it cannot move it, or pass under it, or, by a little shifting, around it, it waits exactly the length of time it would have taken for it to perfect its forward progression, when it returns on its path again. But this takes place only with such species as have a regular backward and forward motion; most of them are extremely erratic in their ways. As an illustration of the regularity of movement of the diatomaceæ, let us consider one of those species just mentioned, namely, *Bacillaria paradoxa.* This creature has a motion of its own, which is so peculiar, and at the same time so incomprehensible in its mode of accomplishment, that it well deserves a more particular description. This species is somewhat of the form of a straight ruler, when we consider the single individual, or, at least, it looks very much of that form, as commonly seen. But a careful examination shows it to be made up of two long and narrow boat-shaped valves, united together so that the keels project outwards opposite to each other, and enclose within their united bodies the general cavity of the frustule. When in a living state, the compound individual, or colony, whichever we may choose to consider it, consists of a number, more or less great, of these double boat-shaped frustules, united one to the other at their keeled sides; but the mode of union is entirely unknown, and, from the extreme freedom of motion which each frustule of the colony enjoys, it is hard to imagine what its character is. Thus united, they form a filament which is generally found floating freely in the water of brackish ditches within reach of the influence of the sea. But I have seen it in perfectly fresh water, far up the Hudson river in New York state.

The movement has been well described by an English observer, Mr. Thwaites, and I cannot do better than quote his words. He says,—

When the filaments have been detached from the plants to which they adhere, a remarkable motion is seen to commence in them. The first indication of this consists in a slight movement of a terminal frustule, which begins to slide lengthwise over its contiguous frustule; the second acts simultaneously in a similar manner with regard to the third, and so on, throughout the whole filament; the same action having been going on at the same time at both ends of the filament, but in opposite directions. The central frustule thus appears to remain stationary, or nearly so, while each of the others has moved with a rapidity increasing with its distance from the centre, its own rate of movement having been increased by the addition of that of the independent movement of each frustule between it and the central one. This lateral elongation of the filament continues until the point of contact between the contiguous frustules is reduced to a very small portion of their length, when the filament is again contracted by the frustules sliding back again, as it were, over each other; and this changed direction of movement proceeding, the filament is again drawn out until the frustules are again only slightly in contact. The direction of the movement is again reversed, and continues to operate in opposite directions, the time occupied in passing from the elongation in one direction to the opposite being generally about forty-five seconds. If a filament while in motion be forcibly divided, the uninjured frustules of each portion continue to move as before, proving that the filament is a compound structure, notwithstanding that its frustules move in unison. When the filament is elongated to its utmost extent, it is extremely rigid, and requires some comparatively considerable force to bend it, the whole filament moving out of the way of any obstacle rather than bending or separating at the joints.

This is not always the case, as I have myself frequently observed, as the filament often becomes bent by the force of its own motion. And there is one other fact which seems to have escaped the notice of Mr. Thwaites, and which adds considerably to the interest of an exhibition of this plant while in motion. After the extended frustules have returned to their normal position in the filament, so as to form a ribbon-like combination again, and just at the time when they are about to start on their way in the opposite direction, there seems as if a considerable amount of force were necessary to get them started past this point, for this force is very apt to dislodge the whole filament and swing it entirely round, so that that end which was, we may say, pointing towards the right hand, now points to the left. The consequence is, that now, when the frustules proceed on their path towards the opposite side of the filament from which they projected previously, they, in reality, extend towards the same side of the microscope as they returned from. This motion often continues to be exerted, so that the whole filament is periodically swung around on its centre as the frustules return to their places, and become again parallel one to the other. Often and often have I spent hours looking at this marvel of nature; the motion without apparent cause or mode, an invisible joint, which, as a friend of mine (an engineer) once remarked, would be a fortune to any one who would discover it, for here we have several sticks forming the bundle, moving over each other without separating, and yet the use of the highest powers of the microscope has failed to detect the means of their union into one mass, or composite group, of individuals. The more often I watch *Bacilleria paradoxa*, the more it puzzles me. Not long since I saw one specimen (of course, I mean one bundle of individuals) slide out to its utmost limit across the field of view, and then, becoming entangled with others, which likewise were made up of many individuals, some eight or ten of its frustules were twisted around, almost off from the rest, so as to lie at right angles to them; and when the group containing the largest number of frustules receded to their former position, which they soon did, the eight or ten seeming, by the act of twisting, to lose their power of motion among themselves for the time being, were dragged along in a helpless condition, and twisted completely around one revolution, so as thereafter to fall back again into their places, when all went on again as usual,—that is to say, the regular motion of all the frustules over each other succeeded. Now what kind of a joint can it be that permits of such eccentric movement? The motion of all diatoms is accelerated by a moderate heat, so that specimens gathered during the winter months, and remaining either quiescent, or only exhibiting very slight motion when viewed by means of the magnifying glass of the microscope, may be made to move vigorously by the cautious application of warmth, as by placing them in a warm room, or by holding the glass slide, upon which they are, upon the palm of the hand for a short time.

PART THIRD.

Mode of Growth of the Diatomaceæ.

When we speak of the growth of the Diatomaceæ, it must not be confounded with the reproduction of the organisms, although modern physiologists are coming to understand that growth or increase in volume, and reproduction or increase in number, are very nearly related, if they be not but modification, in degree and in direction, of a force acting within and essential to the existence of living beings.

We have seen what the structure of the outer coat or siliceous skeleton of the diatomaceæ is. Let us now, before asking how they grow or increase in dimensions, learn what is known with regard to their internal economy, that is to say, the anatomy of their softer parts. Unfortunately, on this point our knowledge is extremely unsatisfactory, and it even appears, as has been already hinted, that the result of modern investigations would be to upset a great deal of what we have up to a late date considered as settled in connection with this point.

Immediately within the siliceous skeleton of a diatom is supposed by many to be a membrane or skin which bounds and limits the soft parts of the organism; and it is this membrane, say those who believe in its existence, which secretes or forms the wonderfully sculptured epiderm we have been considering. Some observers think that there is also an outside membrane, and that it is in it that the silica accumulates. But as many good observers have been able to see neither of these membranes in the living diatom, and as even the believers in their existence acknowledge that they are extremely difficult of exhibition, most likely the fact is that the real individual matter of the diatom is a mass of structureless protoplasm, which deposits near its outer portion the silica it has absorbed from the surrounding water. Within the protoplasmic mass is the endochrome or colored matter we have already spoken of, and which is most commonly disposed in two portions contiguous to the two valves. In the clear central portion there is often to be seen a little sac or vesicle, which is quite transparent, except at one part, where a minute dot is seen. This vesicle is considered to be the "nucleus" of the diatom, while the dot is the "nucleolus," both of these things being required in a cell constituted under the type established by a German observer named Schwann. But now that Schwann's typical cell, consisting of a "cell wall" containing "cell contents," wherein are found a "nucleus" and often one "nucleolus" or several "nucleoli," is known to exist rarely, we are not surprised if we do not find all of these parts present in a diatom. And now that we understand the internal anotomy of the diatom, without taking into consideration disputed minutiæ of structure, we can see how the individual grows.

Schwann has shown us what he considers cell growth to be, and it is what is known as "cell subdivision." That is to say, the cell itself is stable as to size, but increase of volume occurs by its dividing into two, and these two into four, and so on, so that if the resulting cells remain united to each other there will eventuate a true increase in bulk, and eventually a large organism like a tree or a man may be formed. But such is not the way that the diatom grows, for it is not a polycellular, but a unicellular organism. There is a large group of very simple plants, even more simple in structure than the diatomaceæ, for they have no elaborately sculptured siliceous cell-wall, which are known as *Protophytes*, and in the life history of one of these we shall be able to study the simplest expression of cell growth. Dr. Carpenter, whose valuable treatise on the microscope is to be recommended to all intending to use that instrument, has epitomized what is known on this subject so well that I cannot do better than to give it in his own words. He says,—

The life-history of one of these unicellular plants, in its most simple form, can scarcely be better exemplified than in the *Palmoglœa macrococca* (Kützing)—one of those humble kinds of vegetation which spreads itself as a green slime over damp stones, walls, &c. When this slime is examined with the microscope, it is found to consist of a multitude of green cells (Fig. A), each surrounded by a gelatinous envelope; the cell, which does not seem to have any distinct membranous wall, is filled with granular particles of a green color; and a *nucleus*, or more solid aggregation, which appears to be the centre of the vital activity of the cell, may sometimes be distinguished through the midst of these. When treated with tincture of iodine, however, the green contents of the cell are turned to a brownish hue, and a dark brown nucleus is distinctly shown. Other cells are seen (B), which are considerably elongated, some of them beginning to present a sort of hour-glass contraction across the middle; in these is commencing that curious multiplication by binary subdivison, which is the ordinary mode of increase throughout the vegetable kingdom; and when a cell in this condition is treated with tincture of iodine, the nucleus is seen to be undergoing the like elongation and constriction. A more advanced state of the process of subdivision is seen at C, in which the constriction has proceeded to the extent of completely cutting off the two halves of the cell, as well as of the nucleus (I), from each other, though they still remain in mutual contact; but in a yet later stage they are found detached from each other (D), though still included within the same gelatinous envelope. Each new cell then begins to secrete its own gelatinous envelope, so that, by its intervention, the two are usually soon separated from one another (E). Sometimes, however, this is not the case,—the process of subdivision being quickly repeated before there is time for the production of the gelatinous envelope, so that a series of cells (F) hanging on one to another is produced.

Now the diatomaceæ grow in a manner precisely similar to that just described as taking place in *Palmoglœa*. This subdivision of the cell, so that the new individuals are formed from one in the diatomaceæ, results in the production of a series of frustules almost identical in all particulars with the original individual. In most cases, if not in all, the new individuals differ from that from which they sprung in two marked respects: First, they each possess one old and one new valve; and, secondly, the new valve is smaller than the old one, so that the two valves of all diatoms differ somewhat in dimensions, although alike in other respects.

As the siliceous exterior skeleton of the diatom does not permit of its expanding in all directions, the consequence is that when it absorbs nutritive material, increases in bulk, and proceeds to subdivide, it must multiply its bulk in one direction only; and, as the two valves are capable of being separated one from the other along the line of junction with the connecting membrane, it is in that way that the splitting up of the cell into two new ones takes place. The existence of the connecting membrane in the perfect diatomaceous individual, before subdivision starts, is denied by many. Under those circumstances, the siliceous skeleton consists of only two parts, the valves, to which, as soon as subdivision sets in the third portion, the connecting membrane is added. In *Palmoglœa* we have seen that the perfect cell subdivides by a process which shows itself by the bending in of the cell wall, if there be one, or by the periphery of the mass, if there be no limiting membrane. In this way, at first, two united and similar halves, and thereafter, two separate individuals, are formed exactly alike in all particulars. The nucleus and nucleolus, if there be one, of the diatom subdivide at the same time; and, to make room for the increasing cell-substance, the enclosing valves separate from one another, the space all around between them being closed in by the new hoop of siliceous substance, the connecting membrane which now makes its appearance and grows by additions to its two edges, as the accumulation of pabulum by the growing individual goes on. At the same time, two new valves have been forming exactly like the two old ones, except that in consequence of their forming entirely within the connecting membrane, which has the same diameter as the old valves, they are just so much smaller; and, as this mode of subdivision is repeated again and again, there are always two individual diatoms having one old and one new valve, which latest formed valve is continually being replaced by another still newer. That the cell-contents may be at no time exposed to direct contact with the surrounding water, the connecting membrane is formed of two pieces, by additions next to the two valves; and, as one valve of the diatom individual is always somewhat smaller than the other, one of these sections of the connecting membrane is smaller than and slides within the other. In some cases, however, it would seem that the connecting membrane is made up of but one piece, instead of two, as described. On account of this gradual diminution in size which must take place, we can readily understand how we shall be very likely to find diatoms growing together which are exactly alike, except that they vary in size. But instead of the smallest being the oldest, the largest were formed first, and, by the process of subdivision described, they have gradually diminished in dimension. And it would seem that there was a limit in each species beyond which the frustule did not diminish, but as soon as it was reached, then the stage had arrived when reproduction sets in in the manner to be presently described. Thus we see how one individual diatom may in a very short time populate a large lake or river; but all of these separate cells, which have now become separate individuals as well, will very closely resemble the first one from which they sprung. But circumstances may occur, while this rapid growth is going on, which may modify the characters of the diatom to such an extent that very marked variation may result. Thus, for example, if the original frustule existed at the head waters of a small stream, in perfectly fresh, running water, some of its descendants may be carried down into a lake where they may lodge along the shore, in still water, and thus become modified, or, they may pass on into a large river, to be there affected, or even carried down to its mouth, and there, where the salt and fresh waters mingle, be changed by that circumstance. So, of course, other circumstances, which will readily present themselves to the mind, will serve to form and perpetuate variation in the diatoms, until two frustules, descended from the same progenitor, by growing under different circumstances, will appear so unlike that they may be classed as separate species, or even as belonging to separate genera.

The time occupied in a single act of self-division in the diatoms has not been ascertained for all species, although it has been lately noted for a few; "but supposing it to be completed in twenty-four hours, we should have, as the progeny of a single frustule, the amazing number of one thousand millions in a single month,—a circumstance which will, in some degree, explain the sudden, or, at least, rapid appearance of vast numbers of these organisms in localities where they were but a short time previously either unrecognized, or only sparingly diffused."

In all cases, however, the two newly formed frustules do not entirely separate from each other, for, after subdivision has taken place, they remain united, so that in time others will be added, and eventually a long ribbon-like assemblage of individuals result. The genera *Fragilaria*, *Himantidium*, and *Rhabdonema*, are examples of such a mode of growth when the valves are oblong, and *Melosira* when they are circular. Then, again, the separation may be partial, so that the frustules remaining united by the alternate corners are attached to each other, and a zigzag chain is formed. *Diatoma* and *Grammatophora* are examples of this. If the frustules are not possessed of quite parallel sides, but if they, on the contrary, approach each other at one end, and then remain united after subdivision has taken place, a fan-shaped arrangement will result, as is seen in *Lichmaphora*; or, if subdivision continues, a spiral will be formed as in *Meridion*. Those forms which do not float about freely in the water in which they live and grow, are attached to submerged objects by either a small gelatinous cushion, a long single or branching stalk, pedicle, or "stipes," as it is called. And there are forms, as *Schizonema*, which are of a naviculoid form, but which secrete around themselves a membranous tube within which the process of subdivision goes on, and up and down the cavity of which the little boats sail with extreme activity. Thus, from this simple process of subdivision, as described, various forms may result, and many individuals be formed which shall have their number still further increased by the process of reproduction to be next described.

PART FOURTH.

Reproduction of the Diatomaceæ.

We have seen the manner in which the diatomaceæ increase in dimensions, or grow, and observed that it is essentially the same process as that which takes place in larger and apparently more complex organisms, both animal and vegetable. That is to say, we have found that in the case of the diatomaceæ it becomes very difficult, if not impossible, to distinguish the results of growth from the results of reproduction. And although at first sight this may appear a very remarkable fact, yet it ceases to be so if we remember that really physiology teaches us that reproduction is merely a form of modified growth, resulting after the casting off from the parent's body of one or more masses of matter which possess in themselves the power of assimilation of food, and its appropriation for the building up and elaboration of new tissues. Those genera of diatomaceæ which occur normally, or, we should say, most commonly, attached in some manner, as by a cushion, pedicle, stipes, or the surface of the valve or connecting membrane, or otherwise, to submerged objects, would never become very widely distributed through the agency of self-fission alone, as it has been described, and the consequence would be that they would be confined to certain localities were there not some other mode of increase or reproduction. To a certain extent, this distribution is provided for by the curious movements of the individual which we have just treated of, and which we have seen are quite lively in some species. But it is still more perfectly insured by the process of reproduction in which a new individual is developed from a parent. It is in the form of spores or seeds that most plants (or, at least, the larger ones with which we are acquainted) are enabled to endure the severe frosts of the winter months; and the same is likely to be the case with the diatomaceæ, although it is true that some species are to be found living and swimming actively about beneath the frozen surface of ponds and streams. And, although they be caught within the mass of solid ice, yet their vitality does not seem to be materially compromised, for, on thawing the ice they again move about in a lively manner in the water formed. Very little investigation has been carried on in the direction of the reproduction of the diatomaceæ, or, rather, we should say, that little has been published in this connection, so that we have few authorities to draw upon to enlighten us on this point in the economy of our little friends. From what little has been observed and recorded by a few investigators, it would seem that the diatomaceæ reproduce after a manner very similar to that which has been found to take place in the *Protophyta,* or simple unicellular plants; and this fact has been brought forward as an argument in favor of the vegetable nature of the organisms of which we are treating.

The first instance in which the process of reproduction was observed and published was by Mr. Thwaites, in *Epithemia,* a genus which is almost always found in the living state, attached to submerged plants, as mosses and the like. He found it to be essentially the same as the mode of conjugation, as it had been called, known to take place in several algæ or water plants of simple organization. He describes it in the following manner: "The process of conjugation consists in the union of the endochrome of two approximated fronds [using this term instead of frustule, to indicate the perfect individual], this mixed endochrome developing around itself a proper membrane, and thus becoming converted into the sporangium." The sporangium is what may be called the seed vessel, as, although it does not contain seeds, in the ordinary acceptation of that term, yet from it proceed the new individuals who are to perpetuate the species. "In a very early stage of the process, the conjugated frustules have their concave surfaces [it must be remembered that we are speaking of *Epithemia*, whose outline is somewhat bow-shaped, having convex and concave surfaces] in nearly close opposition; and, it may be observed, that from each of these surfaces two protuberances arise, which meet two similar ones in the opposite frustule; these protuberances indicate the future channels of communication by which the endochrome of the two frustules becomes united, as well as the spot where is subsequently developed the double sporangium, or, rather, the two sporangia. The mixed endochrome occurs at first as two irregular masses between the connected (conjugating) frustules; but these masses shortly become covered with a smooth cylindrical membrane, the young sporangia, which gradually increase in length, retaining nearly a cylindrical form until they far exceed in dimensions the parent frustules, and, at length, when mature, become, like them, transversely striated upon the surface. Around the whole structure a considerable quantity of mucus has during this time been developed, by which the empty frustules are held attached to the sporangia." Thus we see that, whether any two particular frustules are drawn towards each other or not (which we do not know), yet two contiguous individuals pour out their respective contents, which, melting together, are thus fused into a mass, around which is formed one or two new siliceous coats exactly alike in structure, but only differing in size, being larger than those which enclose the parent frustules. Enveloping these sporangia, or large cases from which the new individuals shall be evolved, is thrown a protecting, or, perhaps, nutritive globular mass of transparent mucous material. In different genera, slight variations are met with in the method of conjugation, as described. Thus, in some species of *Gomphonema*, which grows attached to the end of branching stalks or stipes, very much after the manner of the leaves on the ends of the twigs of a tree, the sporangia lie in a direction parallel to the empty parent frustules by which they have been generated, instead of across them, as is the case in *Epithemia.* Although in many cases the frustules, which are about to conjugate and form sporangia, split into two separate parts, so that their contents may freely coalesce, we find that there are examples where the valves only split apart at one end to a slight extent, but enough to serve for the escape of the endochrome. Instead, also, of the pair of conjugated frustules, producing between them two sporangia, they may develop but a single one. The *Melosiræ* and *Biddulphiæ* (the former looking like a string of pill-boxes attached together by their tops and bottoms; and the latter being somewhat like a number of wool-sacks united at the corners into a chain), Mr. Thwaites remarks, "would seem in their development of sporangia to offer an exception to most diatomaceæ; for, in those genera, no *evident* conjugation has been seen. However, something analogous to it must take place; for, excepting the mixture of endochromes of two cells, the phenomena are of precisely similar character. Thus, instead of the conjugation of two frustules, a change takes place in the endochrome of a single frustule; that is, a disturbance of its previous arrangement, a moving towards the centre of the frustule, and a rapid increase in its quantity; subsequently to this it becomes a sporangium. In a single cell, therefore, a process, physiologically precisely similar to that occurring between two conjugating cells, takes place; and it is not difficult to believe, taking into view the secondary character of cell-membrane, that the two kinds of endochrome may be developed at the opposite ends of one frustule as easily as in two contiguous frustules, and give rise to the same phenomena as ordinary conjugation." In such genera as have their siliceous frustules enclosed within membranous tubes, as *Schizonema,* conjugation seems to take place both without and within the tube, but oftenest upon the outside. As has been remarked, "one reason for the paucity of observations on this process in the diatomaceæ is no doubt to be found in the changes which usually take place in the condition of these organisms at this period of their existence. During conjugation the process of self-division is arrested, the general mucus envelope or stratum, produced during self-division, is dissolved, and the conjugating pair of frustules become detached from the original mass; they are thus more readily borne away and dispersed by the surrounding currents, or the movements of worms and insects, and their detection becomes in consequence more casual and difficult." The modes of conjugation have been reduced to four classes, thus: 1st. We have two parent frustules and two sporangia, as the result of their conjugation. This mode has been seen to take place in the genera *Epithemia, Cocconema, Gomphonema, Encyonema,* and *Colletonema.* 2d. From the conjugation of two parent frustules we have formed a single sporangium. This mode has been only seen to take place in *Himantidium,* but most likely will be found hereafter to be natural in allied forms. 3d. The valves of a single frustule separate, the contents set free, rapidly increase in bulk, and finally become condensed into a single sporangium. This has been seen in *Cocconeis, Cyclotella, Melosira, Orthosira,* and *Schizonema.* 4th. From a single frustule, as in the last mode, two sporangia are produced in the process of conjugation. This takes place in *Achnanthidium* and *Rhabdonema.* Thus far has observation gone; but no one seems to have traced the further history of the sporangium. For we find no record of the undoubted production of gonidia, as they are called, or seeds possessed of motion, from the contents of the sporangium. In fact, we have no proof that such contents are developed into spores, still or motile. It is true that Rabenhorst, a German observer, has figured and described what he supposes to be the development of gonidia or motile spores from the contents of a sporangium in a filament of *Melosira varians,* an extremely common species found growing in fresh water in all quarters of the globe. It would seem strange, therefore, that others have not seen the same thing; and later observers have doubted his record for this reason alone, apparently, that they have not chanced to see it. However, Smith, one of the best of the English authorities on this subject, says,—"On the whole, the facts at present within our knowledge seem fully to warrant the conclusions that the conjugated state of the diatomaceæ is the first step in the reproduction process of these organisms; and that the sporangial products of this condition become the parents of numerous young frustules destined to renew the cycle of phenomena which accompanies the life and growth of the species from which the sporangia have thence originated." It is very likely that the contents of the sporangium are converted into spores or gonidia, as Rabenhorst has stated, and that after escaping and moving rapidly about, and thus aiding in distributing the species, these gonidia develop around themselves siliceous shells or skeletons, and become diatoms of the normal dimensions of the species from and by which the sporangium was produced. On the other hand, the sporangia may constitute the "resting" state, such as is known to occur in several simple forms of life, in which the species encounters the severity of the winter only to reproduce the species in the spring. In this case, examination of localities, known to produce certain species during the summer, should, during the winter months, be searched when most likely there would be found abundance of sporangial forms. I am not aware that any such investigations have been as yet made; and the difficulties surrounding the study of these organisms is so great that but few have the patience requisite for such work. Hence we find that most of the papers relating to the diatomaceæ, which have been published, are by persons who delight in the naming of "new species," and have not cared to spend the time necessary to determine whether they be but transition forms, sporangia, or true species.

Although, then, as has been said, the whole life-history of the diatomaceous sporangium has not been established, yet we know enough to convince us, as Prof. Smith says, that "the ordinary diatomaceous frustule seems to owe its production to the protoplasmic contents of the sporangial frustule formed by the process of conjugation. These sporangia, like the seeds of higher plants, often remain for a long period dormant, and are borne about by currents, or become imbedded in the mud of the waters in which they have been produced, until the circumstances necessary to their development concur to call them into activity. At such times, their siliceous epiderms open to permit the escape of the contained endochrome, which is resolved into a myriad of embryonic frustules; these either remain free, or surround themselves with mucus, forming a pellicle or stratum, and, in a definite but unascertained period, reach the mature form of the ordinary frustule." Prof. Smith has made observations which appear to establish this fact of the formation of motile spores, which he details in the following words: "In the gathering of *Cocconema Cistula*, made in April, 1852, which contained numerous instances of the conjugating process, I observed the frequent occurrence of cysts enclosing minute bodies, variable in their number and size, and many of which had the outline and markings of the surrounding forms, and were obviously young frustules of the *Cocconema*. It would appear that production of the young frustules is preceded by the separation and throwing off of the siliceous valves of the sporangium, and the constriction or enlargement of its primordial utricle, according to the number of young frustules originating in its protoplasmic contents. In this gathering, forms of every size, intermediate between the minutest frustule in the cyst and the ordinary frustules engaged in the conjugating, were easily to be detected; and the conclusion was inevitable that the cysts and their contents were sporangia of the species with which they were associated, and indicated the several stages of the reproductive process." Although this observation seems to confirm the supposition that the contents of the sporangium must divide into a number of small frustules similar to the parents from which the sporangium sprung, yet further study is necessary before we can consider this fact established; and such study can only be carried out by those who are willing to keep alive for hours, days, or even weeks, such forms as they may meet with, and spend hours at a time at the microscope, watching any change that may take place in them.

Thus do we see the diatomaceous frustule becoming gradually smaller and smaller, through the carrying on of the process of self-division, and its return to the normal dimensions through conjugation, or the formation of gigantic sporangia, whose cell-contents shall return by subdivision, and the genesis of motile spores to the size of the parent frustules. A perfect cycle of changes would seem to be thus kept up, such as is by no means uncommon in the life-history of many simple plants grouped under the head Protophyta. And we are at the same time reminded, when witnessing these changes and transformations, of the equally wonderful metamorphoses, well known to naturalists, to take place in the jelly-fish and hydroids of our coast, or those of the insect world, and which we see going on day by day around us. The egg becomes a grub, the grub a caterpillar, which, in turn, changes into the quiescent chrysalis, in which commonly the winter is passed, only to burst forth, as soon as the revivifying rays of the spring sun warm it into being, as the gorgeously tinted and active butterfly, the parent of innumerable eggs, which shall in turn produce another generation of grubs.

PART FIFTH.

Modes of Occurrence, and Uses to Man of the Diatomaceæ.

And now it will be desirable to say something with regard to the various modes of occurrence of the diatomaceæ, specifying the particular habitats or kinds of situations or water (salt, fresh, or brackish), for the use of such as may wish to know more concerning these beautiful atomies than can be told within the limits of a short sketch like the present. Thereafter it will be well to say something of the importance to the geologist of knowing the life-history of the diatomaceæ, and, finally, their uses to man in the arts and otherwise, as they occur in mass in various parts of the world. And in this connection we are reminded of the words of the poet, who says,—

> Naught so vile that on this earth doth live,
> But to the earth some special good doth give;

for we find that the diatomaceæ have in past ages played, and, in truth, still are playing, a most important part in the grand drama of nature; and their minute dimensions is no excuse for the neglect to which they have been subjected by scientific and capable observers.

Diatomaceæ are to be looked for in both fresh and salt water, as well as in that which can be included under neither of these heads, the brackish water of seaside marshes, where the springs of to-day are overflowed by the rising tide of to-morrow. In general, the piece of water in which they are looked for must be permanent, for authors tell us that it is useless to expect to find them in the transient pools left by the rain. This is, however, not strictly the case, for, on one occasion, I found diatoms in a pool formed by the drainings of a stable-yard, and even little collections of water only two or three days old have occasionally yielded forms when carefully searched, but in such cases they were only few and minute. Prof. Gregory found them in moist earth about the roots of plants, and others have collected them from between the branches of mosses which clustered upon tree barks or house-tops. Even the dust which has fallen upon the sails and decks of vessels, far out at sea, have been found to contain them, by the German microscopist, Ehrenberg, who therefrom has deduced certain supposed facts with regard to atmospheric currents. Upon these foundations Maury has formed theories which, however true they may be in themselves, are not borne out by later researches, for the forms which Ehrenberg supposed to be peculiar to certain quarters of the globe have been found to be almost universally distributed; and, therefore, any deductions, which may have been established in consequence of their appearance upon a ship, do not prove that they were brought from the spot where they were first seen. In fact, the diatomaceæ would seem to be more widely distributed than any other group of organisms, animal or vegetable; and the student of them need never be at a loss for specimens to examine. The pool by the road-side, the mud of the river bank, the moss upon the house-top, the earth beneath his feet, or the air above his head, may be searched, and will all of them yield him material for observation, wonder, and delight. In the living state, and, as often found, floating upon the surface of the water of a pond or slowly running river, swamp, or ditch, the diatoms present themselves as a flocculent collection of more or less dark rust-colored matter, coherent in stringy masses, when such genera as *Melosira, Fragilaria,* or *Himantidium* occur, or consisting of particles readily dispersed and scattered when *Navicula, Pinnularia,* or other so-called free genera exist. The color of such a mass may vary from a golden orange to a dark brown, according to the thickness of the stratum or particular species present, or, it may take on a greenish tinge at certain seasons, which is supposed to indicate a change in the character of the endochrome having some connection with the process of reproduction. At times, I have found that bright green masses of floating confervæ,—which are filamentous water-plants found in all waters, both fresh and salt,—will yield beautiful specimens of diatoms, which are entangled among their branches, or grow adherent to them. But in most of such cases the species belong to the group of adherent forms, and for those we are to look to submerged plants, sticks, metal, and stones, and there they appear as a brownish or fawn-colored mass, either closely adherent, or with its free ends floating freely in the water, as delicate threads, borne hither and thither by the changes of the current. A sprig of some submerged plant, bearing a cluster of some such genus as *Himantidium, Fragilaria,* or *Tabellaria,* presents a beautiful object, as the fine hair-like filaments spread out on all sides, or bend with the motion of the containing water. A very little practice will enable the searcher after diatoms to distinguish them, or to choose localities likely to yield them. I have found that, if the adherent mud on the submerged wood-work of a bridge or pier be scraped off and transferred to a bottle with some water, and, when brought home, be placed in a saucer or plate, covered with the water and exposed to the diffused sunlight which comes in at a south window, many very beautiful forms may be procured in sufficient quantity for observation; and, besides, in such saucers the diatoms may be kept and grown for a length of time, and many points in their economy studied with facility. Thus they may be watched through the process of growth by subdivision and conjugation, and the changes which they then undergo observed without being under the necessity of making several visits to their native localities to make collections. The dead skeletons of many rare species are to be found in the muds of our tidal rivers and harbors, that from some of our southern streams especially, where the summer season of vigorous growth lasts longer than with us, having yielded forms not otherwise procurable. All algæ, as the water-plants which do not bear apparent flowers are called, both marine and fresh water, bear upon their fronds diatoms in greater or less numbers; and the results of dredgings in deep water will provide the student with ample material for many an hour's amusement and instruction. The various methods to be employed, in preparing clean or mixed gatherings of diatomaceæ, can for the most part only be learned from experience, as the books tell us little on this subject. Some general directions, however, on this point will be appropriate to this sketch, and will be given hereafter. As the diatomaceæ live, grow, and multiply, thus floating freely on the surface, along the bottom, or through the mass of the water, or wave in tiny filaments from other objects, they must die; and the most perishable part of their bodies, namely, the cell-contents, will be dissolved in the water or dissipated in gases, to return and again build up new individuals at some future time. But their less perishable portions, their siliceous skeletons, will fall to the bottom of the pond, lake, ocean, or river, and there collect. Their remains will also be found in the stomachs of such animals as are vegetable feeders, as are most of the mollusca, like the oyster, the clam, and the water snails, as well as the crustacea,—lobsters, crabs, and the like. So, likewise, the alimentary canals of sea urchins and sea cucumbers, as they are commonly called, but whose correct and scientific, although, perhaps, at first more incomprehensible names are echinoderms and holothurians, as well as many fish and countless smaller creatures inhabiting the waters, both fresh and salt, will be found to contain the skeletons of diatoms which they take in directly as food, or indirectly when browsing upon the algæ and other examples of aquatic vegetation. So the examination of the half-digested food, from the stomachs of these creatures, will often repay the trouble of preparing it for the microscope. And here is an appropriate opportunity of saying something with regard to that remarkable and important substance which goes by the name of guano, and which has proved to be an almost inexhaustible storehouse for beautiful forms of diatomaceæ. Very generally this substance is supposed to be the excrements of birds, which has accumulated in large quantities during the lapse of many years upon the rocky islands in the Pacific ocean and elsewhere, in latitudes where little or no rain falls to wash out the organic matter. This substance has been used by the inhabitants of the coast of South America from time immemorial as a manure; and, since it was introduced into Europe by Humboldt, in 1804, it has been largely exported to that country and this, to supply the exhaustion of our fields by the continuous crops necessitated by our always increasing population.

Some years since, the attention of the writer of this sketch was called to the subject of guano, when engaged as an analytical chemist in examining fertilizers of different kinds; and thereafter, when studying the diatomaceæ and the application of a knowledge of them to geology, he pushed his investigations still further, and at last came to the conclusion that the popular prevalent notion with regard to the origin of guano was erroneous. His ideas on the subject he embodied in a communication made to the Essex Institute of Salem, Mass., on the 4th of January, 1869, an abstract of which will be found in the Bulletin of the Association, vol. I, p. 11. Subsequently, with the Hon. E. G. Squier and Dr. A. Habel, who had visited the celebrated Chincha islands, and there observed some facts which confirmed the present writer's notions with regard to it, he again brought the subject prominently before the public at a meeting of the New York Lyceum of Natural History, held May 1,

1871. *(Proceedings Lyc. Nat. Hist. N. Y.*, vol. I, p. 224.) Therein it is shown that guano is most likely not the excrements of birds or other similar animals, deposited upon the islands and main land after their upheaval, but that it is the result of the accumulation of the bodies of animals and plants, for the most part minute, the diatomaceæ making up a large part of the mass, and subsequently upheaved from the bottom of the ocean by volcanic agency, which is known to be very active and pretty constant in that part of the world. In this way guano has become a storehouse of many otherwise rare and beautiful forms of diatomaceæ, which can be procured from it by employing a proper process with chemicals to destroy and remove everything but the siliceous skeletons, which are then left in all their purity, so that their forms may be viewed by means of the microscope. The process for cleaning guano, so as to obtain the microscopic organisms contained in it, will be described hereafter.

In a semi-fossil condition, the diatomaceæ are to be found in all parts of the world, and very extensively within the state of New Hampshire in the form of what have been called lacustrine sedimentary deposits,—that is to say, collections of their dead skeletons formed at the bottom of lakes, and going commonly by the name of "marl," although true marl contains few, if any, diatoms, and is largely made up of the shells of mollusca, snails, and the like. The mode of formation of these deposits will be described hereafter.

Still more ancient, and, what may be with propriety termed truly fossil deposits of fresh-water diatomaceæ, are not found on this coast of the North American continent, but, in fact, appear to be confined to the Pacific states, where they cover vast tracts of country. Their mode of formation will be described when we come to treat of the application of a knowledge of the diatomaceæ to geology, in a subsequent part of this sketch. Thus extensive strata of diatomaceæ have accumulated and become fossilized, and constitute the "infusorial earths" of geologists and others, many of those on our Pacific coast, as has been said, being made up of the remains of fresh-water species which have lived, grown, died, and been laid up in countless millions in the beds of now extinct lakes; while, likewise, in California, as well as in Virginia and Maryland, in Peru, Japan, and Algeria, are found layers which are made up of the skeletons of marine species. The city of Richmond, Va., rests upon such a stratum, which varies in thickness from twelve to twenty-five feet, and which extends to Fortress Monroe and over the Potomac river into Maryland, and all the way down on both sides of the Patuxent river in that state. The principal localities from which these deposits, fresh-water and salt-, have been obtained so far, will be mentioned in the directions for collecting, to be given hereafter.

Besides objects of great beauty and scientific interest, the uses to which the diatomaceæ have been put may be briefly summarized. It is to be hoped that the unlearned, whose attention has for the first time, perhaps, been called to them by this sketch, will feel that the elegance of their forms and the geometrical purity of their sculpture will recommend them sufficiently, without eliciting the question, which unfortunately has been propounded with reference to other scientific subjects, viz., What good are they? That they serve as food for numerous aquatic animals is plainly shown by the fact of their being found in their stomachs; but, if that were their only use, it could hardly be said that they were of value to man directly. Who would suppose that these little atomies, so seemingly insignificant, could serve as sustenance for the human race?—and yet such is the fact. In the bleak and almost barren parts of Lapland, during times of scarcity from failure of the crops, the infusorial deposits are turned to account, under the name of "*berg-mehl*" or mountain meal, to eke out the scanty supply of flour with which they are mixed before it is made up into bread and eaten. In some other parts of the world we find wild nations making a similar use of such "infusorial deposits;" but we can hardly say they serve as food, for although some authors have supposed that some of the organic matter they contain may be absorbed by the stomach or intestines, it is not likely that such is the case. It is much more probable that the earthy material serves to clog the stomach, and, by the mere act of distention, arrest for a time the pangs of hunger. Their siliceous character is opposed to their serving as food in the true acceptation of that word. In Samarancy and Java, under the name of "tanah," an earth of this kind, made up of the siliceous remains of diatomaceæ, is eaten. It is described as "generally solid, plastic, and sticky, and is rolled and dried in the shape of small sticks over a charcoal fire, and is eaten as a delicacy." The natives of our western coast, as well as the inhabitants of some parts of South America, use an "infusorial earth" as a pigment to decorate their bodies. In guano, doubtless the diatomaceæ play a very important part, when that substance is employed as a fertilizer and spread upon our fields, for they then present the silica in an extremely minute state of division to the moisture of the soil and the air, which gains admittance thereto, either along with the water or on account of the porosity of the earth. It has been found that under these circumstances the silica is dissolved and absorbed by the plant that requires it, in whose tissues it is deposited to form a strong support to its framework. The cereals especially require a certain amount of silica, as is well known, for the strengthening of the stem which serves to elevate the seed where it gets the benefit of the sun and the air. So we find that all the grasses, as wheat, oats, sugar-cane, maize, grow best on a soil from which they can abstract sufficient silica for the purpose indicated. Instances have come to my knowledge where recent wet deposits of diatomaceæ, especially those containing organic matter, and mentioned above under the designation of lacustrine sedimentary, have proved of real value as fertilizers, when mixed with stable manure and used for cereals, but, of course, they would be objectionable if applied to root, fruit, or leaf crops.

Many deposits of diatomaceæ are called tripoli and polishing powders; and these names indicate that they are possessed of properties which peculiarly fit them for polishing hard surfaces, such as metal. The extremely minute state of division of the silica in the diatom-valves, and the readiness with which those valves are fractured and broken down into still smaller angular portions, are remarkable, and could hardly be imitated by any artificially prepared powder. It has been suggested that the vast diatomaceous deposits found in some parts of the world, as the strata occurring in Virginia and California, might be turned to account, as presenting silica in a fine state of division, so that it can readily be acted upon by the alkali, and the so-called "soluble glass" made therefrom. One manufacturer has experimented somewhat in this direction, but with what result is at present unknown.

It is, however, to the scientific student that the diatomaceæ are of the greatest interest and really of use, for they have proved valuable in assisting him in the investigation of various subjects, as the matter of the conditions of existence of the simple cell, and, likewise, the former characters of certain strata in which they are found in vast numbers. The bearings of this latter subject will occupy our attention in Part Sixth.

PART SIXTH.

The Diatomaceæ and Geology.

The manner in which the diatomaceæ increase, both by true growth and reproduction, has been described in such detail that it is to be hoped that it is thoroughly understood. At the same time, it can be readily comprehended how, as they secrete, from its solution in the water in which they live, the siliceous material constituting their harder parts, and, as they die, this flinty matter must after a time form a deposit at the bottom of the lake or ocean which they inhabit. We are, then, prepared to take into consideration the formation of such deposits, both fresh and salt, and their connection with the science of geology.

The mode of formation of fresh-water deposits of diatomaceæ, as lacustrine sedimentary strata and as fluviatile fossil layers, has been fully described in a paper read by the present writer before the New York Lyceum of Natural History, Nov. 28, 1870, and published in the proceedings of that association, vol. I, p. 109; and the major part of that communication will be given here as embodying about all that is known on that subject, and detailing at the same time the author's ideas with regard to the enormous deposits of fresh-water diatomaceæ found spread over many parts of the western states of the North American continent.

We have seen how the diatomaceæ increase by subdivision, so that by this means alone they may multiply extremely rapidly, and a single individual, by means of its descendants, soon populates a large pond or lake. But while subdivision or true growth has been thus progressing, increase by generation or seeding may have taken place at the same time, and, from each individual in turn, several young may have been brought forth, which would multiply the rate of increase very materially, of course. It is true that the mode of seeding of these organisms is not thoroughly understood; but we know enough to say that it does occur, and very frequently, and that the number of new individuals thus formed is very great. At the same time, numerous individuals are dying, and, as they do so, much of the organic matter of which they are composed is dissipated, but some of it, along with the hard siliceous valves and connecting membranes which constituted the skeletons of the diatoms, falls to the bottom of the pond, and forms a layer of greater or less thickness, according to the time during which it has been accumulating. If it be exposed now, by draining such a pond, it may appear as a brown or grey powdery mass, but, if it has rested beneath the the water sufficiently long, almost all of the organic matter will be removed, and the clean, white siliceous skeletons alone remain. In some localities,—and this I have found to be the case in the state of New Hampshire, perhaps from the peculiar topography of the spots where these masses of the accumulated dead shells of diatoms are found,—these organisms grow in bogs of no very great superficial extent, but which, from their occurring in hollows between hills, are often quite deep. Under such circumstances, as I should judge from the character of a deposit I examined at Bowkerville in Cheshire county, the organic matter might for the most part decay out of a layer of considerable thickness, and nothing be left but a mass of finely divided siliceous material of a character well fitted for use as a polishing powder, or for other purposes to which this substance has been applied.

Such are the results, then, of this rapid growth of the diatomaceæ in ponds, lakes, marshes, and rivers; and, as the first examples of such deposits which I examined were found beneath layers of peat, I gave to them the name "sub-peat" deposits, and under that designation they have been generally known. After a time, however, specimens came into my hands which were procured from the bottoms of existing ponds, and these, besides consisting for the most part of little else than silica, and being of an almost pure white color, had no peat overlying them. Hence, of course, I saw the inapplicability of the term "sub-peat" to such deposits, and for them I have coined a new name, viz., lacustrine sedimentary, which I consider more appropriate, and at the same time indicating their usual origin, and including all deposits of fresh-water diatomaceous remains, with the exception of certain peculiar layers to be hereafter described. Of course the sub-peat then become a variety of these. Deposits of this character are extremely common in this country, as well as elsewhere, and it will be at once seen that, although any one of them might be of great thickness, yet it does not necessarily follow that it had been forming for any great number of years; and geologists and others are not warranted, from observance of this one fact of thickness, in supposing that a great length of time has intervened during its deposition. Thus, some years since, I examined one of these lacustrine sedimentary deposits, at a spot near the town of East Stoughton in Massachusetts, which was fully twelve feet thick, but only covered a few feet of surface, which circumstance was due to the occurrence of a dam across the course of a stream, which arrested its progress and formed a small, deep pond, into which all of the diatomaceæ, which grew for some considerable distance up stream, drained, and, dying, accumulated as a light grey-colored powder. I have received specimens of similar material from many points in this country, so that about one hundred have been examined. The state of New Hampshire has supplied quite a number, and they will be hereafter described, and the forms detected in them illustrated.

The first recorded discovery of a lacustrine sedimentary deposit of diatomaceæ in this country is found in *Silliman's Journal*, 1839, vol. xxv, p. 118, in an article "On Fossil Infusoria discovered in Peat-earth at West Point, N. Y., with some notices of American species of Diatomæ. By J. W. Bailey." Of this I have a small portion given me by Prof. Bailey himself, and, on examination, it is found to have the general characteristics of these deposits; that is to say, it is of a grey color, light in density and very friable, and is made up of the siliceous skeletons of such species of diatomaceæ as grow in small fresh-water lakes, ponds, and marshes. In fact, Prof. Bailey says that this deposit, which was "eight or ten inches thick, and probably several hundred square yards in extent," was discovered "about a foot below the surface of a small peat-bog immediately at the foot of the southern escarpment of the hill on which the celebrated Fort Putnam stands." He considers the remains present in this stratum to be "in a fossil state." And here, perhaps, it is desirable to say something with regard to the use of this term. Its origin would warrant its being applied to anything dug up out of the earth; and, as Mr. Page remarks in his *Handbook of Geological Terms*, "hence the earlier geologists spoke of *native fossils* or minerals, and *extraneous fossils*, or the bodies of plants and animals accidentally buried in the earth." For myself, I am disposed to restrict the term fossil to the remains, more or less perfect, of organized beings dating anterior to the present epoch, if we can conscientiously speak of epochs at all where the progression and rate of change have been so gradual. Considered thus, then, these remains of diatomaceæ cannot be classed as fossils; and at once the geologist perceives that they are to be taken into account in a very different manner from what they have been hitherto. So much, then, for lacustrine sedimentary deposits of diatomaceæ; and I trust that I have made clear as to what they are, and how they are formed and forming. At the time I made his acquaintance, Prof. Bailey expressed an opinion that similar strata would be found beneath every bog and pond in the country. The clear scientific vision of my late friend is evidenced in the fact that this prediction was proved almost literally true. I have over one hundred such specimens, and am continually receiving others. Several I have already described, and others remain to be examined, and facts with regard to the geographical distribution and other points will be elucidated by such investigations,—so that I am always anxious to receive contributions from all sources. It is only desirable that all facts connected with their mode of occurrence, as to amount in thickness and extent, over- and underlying material, etc., be noted at the time of making the gathering.

We now come to consider deposits of an entirely different character from those just spoken of, but which yet are also made up almost entirely of the siliceous remains of fresh-water diatomaceæ. These are the so-called "infusorial" deposits found in such enormous quantity in our Pacific states. From time to time, during the last thirty years, specimens of these have come into the hands of naturalists, from collectors and otherwise, and also "in place" they are well known to settlers in the districts where they occur. As their true character has not been understood, they have received various appellations, as "magnesia," "porcelain clay," "white clay," "chalk," "siliceous marl," "microphytal earth," "tripoli," "rotten-stone," "pipe-clay" or simply "clay," "trachytal tufa," and "phytolitharian tuff," by Ehrenberg. These specimens are almost always white in color, or nearly so, although there are records of some strata occurring of various tints. None of these except the white ones have come under my observation, so I am not prepared to state that the colored ones are diatomaceous. Besides, this material is of a somewhat hard, stony character, but porous withal, and light; as a general thing, also, it is readily broken, but not easily powdered, as are the lacustrine sedimentary deposits. On account of this hardness there is found to be considerable difficulty in preparing these specimens for microscopical examination. After so preparing, by a method I have devised, to be described hereafter, and viewing with a sufficiently high magnifying lens, this substance is found to be made up entirely of the siliceous remains of fresh-water diatomaceæ which have been matted together in the remarkable manner described. The species of diatomaceæ present, however, are found to be very different in character from those to be seen in the other class of recently formed deposits. Thus, while the genera most commonly represented in and making up the mass of the lacustrine sedimentary deposits are *Navicula*, *Pinnularia*, *Stauroneis*, *Synedra*, and similar elongated forms, the hard, white material is in general found to consist of myriads of examples of *Orthosira*, *Cyclotella*, and similar discoid forms. Although our knowledge of the forms of these minute organisms, peculiar to different kinds of collections of water, is rather imperfect, yet we know that the naviculæform genera spoken of above are found in small lakes, while in the larger pieces of water are to be seen growing more particularly the discoid genera like *Cyclotella*. From this fact alone, then, we should be prepared to assume that the waters, in which the organisms whose remains make up these deposits grew at one time, covered large tracts of country. And our surmises on this point are confirmed by the reports of explorers who have passed over this section of country, that is to say, on both sides of the Sierra Nevada Mountains, from Puget's sound to the southernmost border of California, for they tell us that these deposits extend over a considerable portion of the Pacific states.

I have examined many specimens from this district, and, on account of the mode of occurrence of this material, being capped by lava, basalt, or some volcanically-erupted rock, I have designated them sub-plutonic. The first specimens of such sub-plutonic deposits of diatomaceæ, which were put into the hands of scientists, were undoubtedly those brought home by Frémont, from his expeditions to the Rocky Mountains, in the year 1842, and to Oregon and North California, in the years 1843 and 1844. The discovery of these, as detailed in his report, gives a good idea of this portion of the country, and is as follows. It must be premised that, in that report, what is now known as the Des Chutes river, and which is one of the tributaries of the Columbia, is called "Fall river" *(Rivière aux Chutes)*; so, also, he spells Klamath lake "Tlamatt." Speaking of the tributaries of the Columbia river, he says (p. 200),—

These streams are characterized by the narrow and chasm-like valleys in which they run, generally sunk a thousand feet below the plain. At the verge of this plain they frequently commence in vertical precipices of basaltic rock, and which leave only casual places at which they can be entered by horses. The road across the country, which would otherwise be very good, is rendered impracticable for wagons by these streams. At such places the gun-carriage was unlimbered, and separately descended by hand. Continuing a few miles up the left bank of the river, we encamped early in an open bottom among the pines, a short distance below a lodge of Indians. Here, along the river bluffs present, escarpments seven or eight hundred feet in height, containing strata of a very fine porcelain clay, overlaid, at the height of about five hundred feet, by a massive stratum of basalt one hundred feet in thickness, which again is succeeded above by other strata of volcanic rocks. The clay strata are variously colored, some of them very nearly as white as chalk, and very fine grained. Specimens brought from there have been subjected to microscopical examination by Prof. Bailey, of West Point, and are considered by him to constitute one of the most remarkable deposits of fluviatile infusoria on record. While they abound in genera and species which are common in fresh water, but which rarely thrive where the water is brackish, not one decidedly marine form is to be found among them; and their fresh-water origin is therefore beyond a doubt. It is equally certain that they lived and died in the situation where they were found, as they could scarcely have been transported by running waters without an admixture of muddy particles, from which, however, they are remarkably free. Fossil infusoria of a fresh-water origin had been previously detected by Mr. Bailey in specimens brought by Mr. James D. Dana from the tertiary formation of Oregon. Most of the species in those specimens differed so much from those now living and known, that he was led to infer that they might belong to extinct species, and considered them also as affording proof of an alternation, in the formation from which they were obtained, of fresh- and salt-water deposits, which, common enough in Europe, had not hitherto been noticed in the United States. Coming evidently from a locality entirely different, our specimens show very few species in common with those brought by Mr. Dana, but bear a much closer resemblance to those inhabiting the north-eastern states. It is possible that they are from a more recent deposit; but the presence of a few remarkable forms, which are common to the two localities, renders it more probable that there is no great difference in their ages.

I have given in full all that Frémont says regarding this locality, as it presents us with the first discovery of strata of the remarkable character of which I am now treating, and is therefore of special interest. Bailey's report, contained in the same volume, merely mentions and figures the principal forms he detected.

The only other description of this locality and these remarkable deposits, fortunately, is a much more complete and scientific one. It is that of Dr. J. S. Newberry, as geologist of the expedition under Lieuts. R. S. Williamson and Henry L. Abbot, which explored the route for a railroad, from the Sacramento valley to the Columbia river, in 1855, and will be found in vol. vi of the Pacific Railroad Survey Report. Dr. Newberry gives a description of the geology of the Des Chutes basin, which is essentially as follows. It must be remembered that the Des Chutes and Fall river, mentioned above, are one and the same. The Des Chutes basin consists of a series of plateaus, having varying elevations from four thousand to twenty-two thousand feet above the level of the sea, separated by subordinate ranges of volcanic mountains. These plateaus are usually covered by a floor of trap, which extends in a smooth sheet from fifty to a hundred and fifty feet in thickness, unbroken except by and at the cañons of the various streams which, as a general thing, flow from the interior to the ocean at right angles to the coast line. Beneath this bed of trap is the whitish or light-colored material, consisting of the siliceous remains of diatomaceæ we are considering, sometimes occurring as a single bed only, sometimes as a series of beds locally intercalated with thin beds of trap. These infusorial strata, as they have been called, are cut in many places by the Des Chutes and its tributaries to the depth of more than a thousand feet, without exposing the basis on which they rest. They are usually quite horizontal, from a few lines to twenty feet in thickness, and very accurately stratified.

Psuc-see-que creek, one of the tributaries of the Des Chutes river, flows through a valley of a remarkable character, as its sides consist of several alternate strata of diatomaceous material and columnar trap or concrete. Near the base of this series of layers is a stratum, three feet in thickness, of brilliant white feldspathic pumice, so soft as to be easily crumbled in the fingers. Above, and lying upon this, is a line of dark carbonaceous matter, less than a quarter of an inch in thickness, from which, up into another layer of pumice, projects the remains of the branches of some small plant which had apparently been killed by the overflow of the pumice. Lieut. Williamson gives a striking view of this locality, and speaks of it in the following terms:

This river cañon is very remarkable. Its sides vary from eight hundred to two thousand feet in height. The river has cut down its bed to this immense depth through successive strata of basalt, with occasionally a deposit of infusorial marl and volcanic tufa, which has sometimes hardened into a kind of conglomerate sandstone ten or twenty feet in thickness, and of a white, grey, or reddish color. We followed down this cañon for about five miles, when a rocky spur cut off all further progress, and compelled us to attempt the ascent. This with great difficulty we accomplished, and found ourselves on a plain thinly dotted with sage bushes and clumps of grass. We continued our course, and, after crossing the bed of a torrent of the rainy season, came to a very small stream, called Psuc-see-que by the Indians. It was sunk in a cañon about five hundred feet deep, cut through successive strata of basalt, infusorial marl, tufas, and conglomerate sandstone like that found in the Mpto-ly-as cañon (pp. 84, 85).

Another locality in which these remarkable deposits occur is on the Pitt river; and Lieut. Williamson's description gives such a good idea of the mode of their occurrence that I transcribe it, also, below:

The banks of the Pitt river, both above and below the mouth of Canoe creek, are partially formed by regularly stratified sedimentary deposits, the first seen since leaving the valley of the Sacramento. They appear on both sides of Pitt river at intervals for several miles, being in many places interrupted or covered by beds of trap. They are, perhaps, best exposed in the cañon formed by the passage of the river through "Stoneman's ridge," the most conspicuous of the lines of upheaval which form what is known as the lower cañon of Pitt river. They here exhibit a thickness of about fifty feet, but are considerably tilted up, and are covered by a thick bed of trap which has been poured out over them. They exhibit narrow and parallel lines of deposition, but are very homogeneous, and can hardly be said to form more than two distinct beds. Of these, the upper is white, resembling very pure kaolin, derived from the decomposition of crystalline feldspar. The lower bed is light brown or dirty white in color, and has a slightly gritty feel between the fingers. These strata rest upon a thick bed of rolled and rounded fragments of traps, porphyry, and basalt of all sizes, from masses of two and even three feet in diameter, to pebbles. They are generally as large as one's head, and great numbers are each a foot in diameter. The surface of this bed of boulders is perhaps twenty feet above the present surface of the stream; but it bears indubitable evidence of having at one time been covered by it, or, at least, the stones composing it, so large and clear, have been rounded where they lie by a current or waves of water. The appearance presented by this bed of boulders is different from that of any of the beds of volcanic conglomerate which are so common in many parts of California and Oregon, or of the stratified conglomerates of the Sacramento valley, and it is undoubtedly of local origin. The trap which formed the greater part of the bank above is evidently of recent date, more recent than the infusorial marls, and the marls more recent than the conglomerate, and the conglomerate an accumulation of rolled stones and pebbles, which belongs to the present epoch. The trap which overlies the infusorial marls composes a large part of the walls of the cañon at this point, where it has been cut away by the stream, and forms nearly perpendicular faces of several hundred feet in height. The soft nature of the underlying strata has, however, very much assisted in its removal (p. 33).

There are several localities besides those mentioned at which this,—what I have chosen to designate "sub-plutonic,"—material is found, as at Klamath lake, on the northern border of California, and elsewhere all through the Pacific states. From these I have received gatherings, and have thus been enabled to examine, by means of the microscope, specimens from many points in what was once this chain of enormous fresh-water inland seas,—for such they deserve to be styled. For as the microscope reveals the fact, the organisms, whose stony remains constitute the mass of these deposits, were inhabitants of collections of fresh water which existed at some past period as large lakes; and a careful geographical examination of the country enables us even to indicate, to a certain extent, the situations once occupied by these now extinct seas, which at times varied in superficial dimensions, and certainly were in some cases drained, overflowed by lava, and renewed and replenished with living organisms as many as seven times.

And now that we understand how it is that lacustrine sedimentary deposits are formed by the accumulation of the dead shells of diatomaceæ, we can comprehend the manner in which these sub-plutonic strata have been laid down. If we look at the map of the western coast of the North American continent, we see that there are three great chains of mountains, about parallel to each other and the coast line, and thus enclosing between their peaks two long and wide valleys. The Rocky Mountains are the first of these chains, and they at one time formed the coast of this continent. Slowly and gradually, however, there appeared a line of islands at a distance from the coast, whose material was volcanic, and, as these islands rose higher and higher, the space between them and the coast cliffs also rose until it became dry land. Soon rain fell and accumulated in this valley so formed, and lakes and rivers appeared. In these, diatomaceæ appeared, thrived, grew, reproduced, and multiplied; lacustrine sedimentary deposits were thrown down. Now came a time when the volcanic cones, which constituted the peaks of the range of mountains nearest to the coast, burst forth with fire and lava; and, probably at the same time, earthquakes took place which drained many of the lakes and changed the courses of rivers. Into the lake basins the lava was poured, with its heat evaporating the moisture, and consolidating the diatomaceous material into a stony mass, from which all organic matter was burned out. A period of rest succeeded. Diatoms again appeared and accumulated, to be again overlaid by lava; and so on the same thing may have again and again taken place. In this way the enormous deposits of sub-plutonic diatomaceæ were formed; and in the cracks, made in the rock by volcanic agency, the rivers wended their way, and made the gates we now are in the habit of calling cañons.

But in the ocean diatomaceæ also occur, and in large quantities. When they die there, their siliceous remains must accumulate at the bottom of the water, and occur as deposits. It is in the black mud of our quiet bays and harbors that we must look for the greatest accumulation of these remains; and rivers are carrying them down to their mouths, where often they are piled up in such masses as to form bars. The mud of the river Thames in England yielded to Mr. Roper a large number of diatomaceous remains. Ehrenberg examined the mud of the Elbe in Germany, and found these minute shells to make up from one quarter to one third of the whole mass. He calculated that at Pillau there are annually deposited from the water from seven thousand two hundred to fourteen thousand cubic metres of these minute shells, which in the course of a century would give a deposit of from seven hundred and twenty thousand to one million four hundred thousand cubic metres of deposit, which might be hardened into a stony mass. That such hardening has taken place is evidenced by the occurrence of the vast strata of marine forms found in Virginia and Maryland, on the Atlantic side of North America, and in California on the Pacific coast.

This material is often almost white, but more commonly is tinted slightly yellowish or salmon-colored. It makes up the most part of the material of the coast range of mountains in California, and has also been found in Peru, Japan, Algeria, Spain, and the West India islands. In California, in the almost rainless districts, it is used for building, but generally is too friable for that purpose. The forms occurring in it are for the most part discoid, with a few triangular ones, and, when prepared and examined by means of the microscope, present one of the most beautiful objects which can be so viewed.

Something has been said with regard to the origin of the substance known as guano, and which has been so extensively used as a fertilizer;—but to the agricultural fraternity anything connected with this material must prove of interest, so it is thought best to enter more fully into the consideration of this subject on account of its important bearings, its value to geologists, and its general attraction, evinced by the manner in which the publications of the present writer thereon have been copied and circulated by the periodical press.

On May 1, 1871, a discussion took place at the Lyceum of Natural History, New York, on the subject of guano, when the Hon. E. G. Squier exhibited a map of the Guanape islands of Peru, where guano is found, drawings of a wooden idol and other objects discovered in the guano, and photographs showing that that substance is distinctly stratified, and not thrown down in the shape of a confused mass, as would be the case if it were, as is usually supposed, merely the excrement of birds and other animals deposited on rocky islands, in localities where little or no rain falls to wash out its soluble and valuable constituents.

Dr. A. Habel, who had visited the Chincha islands for the purpose of studying the mode of occurrence of the guano (or, as he prefers to write it, in consonance with the mode of its pronunciation, "whuano"), made an extended communication showing that the outer and uppermost portion of this substance does consist of the droppings of various species of sea-birds and mammals, mixed with the feathers and eggs of birds, and bones. This layer does not at all show signs of stratification, and is of a reddish brown color. Below this is the guano proper, which is of a different structure, and distinctly stratified. He says that "this stratification is so marked that even a superficial examination must convince every unprejudiced person that it is the product of sedimentary formation. It is made up of alternate white and yellow strata, varying in shade and thickness. All of these strata exhibit distinctly their inclination or dip, which varies not only on the separate islands, but in different parts of the same island. On the middle island, for example, the inclination or dip of the strata in one part of it does not amount to more than five degrees, while in another part it is eight degrees, and in a third, close to the first, fifteen degrees." In one place strata, running south-west and north-east, and dipping twenty degrees, rested unconformably on others running north and south, and dipping only four degrees. In all of the strata are imbedded stones of various sizes and weight up to fifteen pounds, as well as eggs and bones. Another proof that the guano has been deposited beneath the ocean is seen in the various strata of sea sand underlying it, and which are also stratified, and dip in one direction or the other.

The present writer said that he first made his hypothesis public, with regard to guano having been deposited beneath the water of the ocean, in 1868, at a meeting of the American Microscopical Society. In January, 1869, he entered more fully into a discussion of the subject before the Essex Institute, at Salem, Mass. He said,—

I have been for the last fifteen years or more studying the so-called "infusorial deposits" of marine origin. Among the specimens thus examined are some of the rocks or shales making up the great mass of the mountains of the coast range, which extend down the Pacific shore from Washington territory to the borders of Lower California, and even perhaps down as far as the southernmost extremity of that peninsula. These shales are usually of a light cream color, and mainly consist of the siliceous skeletons of diatomaceæ and polycystina, the former being commonly considered as plants, the latter as animals. These are of extremely minute size, and often require for their study the use of the highest magnifying powers. Many of them prove to be indistinguishable from forms living at the present day on the California coast. Exuding through, and often appearing at the upper portion of these rocks, to which situation they have evidently been driven by heat, are found the petroleum, bitumen, and asphalt of California. Hence the state survey has conferred upon these strata the name of bituminous shales. Along the Pacific coast, and lying parallel to it, are islands often bearing upon their summits deposits of guano, of more or less commercial value. In many cases the quantity has been small and soon removed; but I am informed that there are deposits of this material in that quarter of the globe still unworked. At the same time, it must be remembered that the whole Pacific coast, of both North and South America, is in an almost continual state of motion, and gradual but constant upheaval, caused, doubtless, by the action of internal chemical changes, which make themselves markedly evident in the volcanic vents found all along the mountains constituting the Cascades and Sierra Nevadas of North, and the Andes of South America. There have been identified at least three former lines of rise of coast, and still another is seen presenting its peaks in the islands, which will, at some future day, be united in such a manner as to constitute another coast range of mountains.

If, now, we consider the bearing of these facts on the origin of the substance known as guano, we find the following points worthy of note. Guano may be divided into two great groups, the ammoniacal and the phosphatic; but it is of the first mentioned, only, that I desire to treat at the present time, and to which I wish to apply my deductions. Guano is usually considered as the excrement of sea-fowl, and which has accumulated during a long period of time,—so long, that attempts have been made to calculate its age from its thickness. Thus Humboldt, who first made this substance known to the Eastern hemisphere in 1804, states, that on the Chincha islands it has a depth of fifty to sixty feet, and that the accumulation of the preceding three hundred years has formed only a few lines of this thickness. The facts brought forward by Mr. Squier show how difficult it is to arrive at any certain knowledge on this point, and, in fact, show that we have no means of ascertaining the age of the guano deposits, even if we accept the theory of their origin from the source usually ascribed to them. We find that guano is not confined to islands only, but occurs in large quantities on the contiguous headlands; and many ravines, extending into the interior of the country, contain guano in smaller and larger quantities. Thus, the ravines of Lolo, Culata, Sacramento, Animas, Morillo, Guajes, Colorado, Chucumata, and Pica are reported to contain pure guano deposits, covered by a thick coating of sand. Neither is it found in rainless districts only, for, as I have said, it is found on the islands off the California coast, which are by no means rainless; and Mr. W. H. Dall informs me that it occurs on the Aleutian islands, where the air is almost always saturated with moisture, and heavy rains fall during a large part of the year. With regard to the upheaval of such coasts along which guano occurs, it is well known, from Darwin's investigations, that the whole Pacific coast of South America is in constant motion and upheaval, and that on the main land near Lima, and on the adjoining island of San Lorenzo, Mr. Darwin found proofs that the ancient bed of the sea had been raised to the height of more than eighty feet above the water, within the human epoch, strata having been discovered at that altitude containing pieces of cotton thread and plaited rush, together with sea-weed and marine shells (*Lyell, Principles*, 1853, p. 502).

And Darwin says,—"I have convincing proofs that this part of the continent of South America has been elevated near the coast at least from three hundred to five hundred feet, and, in some parts, one thousand to thirteen hundred feet, since the epoch of existing shells." Other proofs of this fact are not wanting, but these are sufficient for me to quote at the present time.

When the portions of guano, which are insoluble in water and acids, are examined by means of the microscope, they are found to be made up of the skeletons of diatomaceæ, polycystina, and sponges, invariably of marine origin, and sometimes identical with those living in the adjoining ocean, and fossilized in the adjacent infusorial strata. Also, we find that some of these forms occur in patches exactly as they grow in nature, and as they would present themselves if they were deposited from water, and not as they would be if they had to pass first through the alimentary canals of mollusca and similar small animals, then through the same organs of fish and birds, in turn, as they would have to do to get into the guano in the manner commonly supposed.

In California we have a deposit of "infusoria," improperly so called, accompanied by bitumen, which bitumen, the gentlemen of the state survey believe, has been derived from those "infusoria," and that contiguous thereto we have guano deposits. Now let us see if we have a similar association of facts anywhere else. At Payta, in Peru, Dr. C. F. Winslow discovered an "infusorial" deposit almost identical in character with the California one. Near by are bitumen springs; and lying off the coast are the guano islands of Lobos, Chincha, Guanape, and others. At Netanai, Japan, we have extensive "infusorial" strata and bitumen; it is not recorded whether guano occurs in that quarter. In the island of Barbadoes we have "infusorial" strata, bitumen, and, near by, the guano islands of the Carribean sea; and, I am informed, guano is abundant on the small islands and rocks nearly throughout the West Indian archipelago. In the island of Trinidad we have "infusorial" strata and bitumen, and, of course, adjacent guano. At all of these localities volcanic action is evident; but we have some localities of guano without "infusorial" strata or bitumen, as yet recorded; while we have the celebrated "infusorial" strata of Virginia, which, by a little stretch of the imagination, may be supposed to be related in some way to the petroleum of West Virginia and Pennsylvania. In Algeria we have "infusorial" strata and bitumen; but I never heard of guano having been found near by. From all of these facts, and others that I have collected of no less importance, derived from chemical and microscopical characters, I have come to the conclusion that guano is not the excreta of birds, deposited upon the islands and main land after their upheaval, but that it is the result of the accumulation of the bodies of animals and plants, for the most part minute, and belonging to the group which Haeckel has included in a new kingdom, separate from the animal as well as the vegetable, under the name of Protista, and subsequently upheaved from the bottom of the ocean. Subsequent chemical changes have transformed it into guano, or, heat and pressure have so acted upon it that the organic matter has been transformed into bitumen, while the mineral constituents are preserved in the beautiful atomies that make up the mass of the extensive "infusorial" strata found in various parts of the world.

The Chincha islands have been visited by a competent geologist, Mr. Kinahan, of Dublin, and he has pointed out that they have been upheaved by volcanic action within a recent period, geologically considered. I have found a remarkable confirmation of my theory in a paper, read before the American Institute, New York, some years since, by Mr. Alanson Nash, detailing the observations of a Mr. F. Nash made during a residence on the Chincha islands, while engaged in the guano trade, for nearly six months. Therein we find it stated that Mr. Nash was of opinion that guano was formed in the way I have described; that the anchors of vessels in that locality bring up guano from the bottom of the ocean; that "the guano is (much of it) not composed of bird dung, but is composed of the mud of the ocean;" that "the composition taken from the islands, called guano, is stratified, and lies in the same form it did before it was lifted up from the ocean;" that "the bottom of the ocean, on the west coast of Peru, contains vast deposits of guano. An island, during an earthquake, rose up in the bay of Callao, some years since, from the sea, containing guano four feet deep, the formation the same as the Chincha islands." In conclusion, he says, "the day will come when the guano at these islands will be dredged up with boats like mud from our rivers and harbors." And in this expectation I fully coincide with Mr. Nash.

Sea mud has been found to yield an excellent article of fertilizer, and is collected for that purpose at different points along our coast. That from the harbor of Charleston, S. C., yielded to the late Prof. Bailey a rich harvest of diatomaceous forms; and I have examined the same material, as well as that used in Salem, Mass., for the same purpose, and known as "mussel bed," and have found them both to be full of microscopic forms.

Some years since Prof. Gregory described a remarkable deposit of sand from Glenshira, which he considered to be fossil, and called it post-tertiary. It was full of the remains of diatomaceæ, both marine and fresh water, and had been formed evidently by the ingress of the salt water of the bay into a fresh water pond. Occasionally we find the bottom of fresh water marshes upheaved and everted by superincumbent pressure from railroads or other passage ways being built across them. Under these circumstances there are often developed deposits of the remains of diatomaceæ. I have one such specimen from Detroit, Mich. I have also seen two examples of the everting, in this way, of the ancient bed of salt marshes, and in both cases the remains of diatomaceæ are plentiful.

The importance of a knowledge of the diatomaceæ to the geologist has been lost sight of up to the present time; but now that the state of New Hampshire has taken the lead in this matter, it is to be hoped that they will be studied, as they occur in the rocks of other localities.

PART SEVENTH.

Directions for Collecting, Preserving, and Transporting Specimens of Diatomaceæ.

The diatomaceæ constitute a group of organisms of so much interest to the student of natural history, that it is desirable that specimens should be collected in various parts of the world. That such collections may be of value, it is necessary that they should be made in a proper manner; and for the purpose of facilitating the making of such collections these directions have been drawn up. The directions given should be closely followed, as the methods described have been found, after considerable trial, to be those yielding the most satisfactory results. As the fossil deposits containing the remains of diatomaceæ are most readily recognized, gathered, and forwarded, they will be first described.

Fossil Deposits. Included under this head must be considered the enormous sub-plutonic strata found on the Pacific coast of North America, so that the fossil deposits of diatomaceæ may be said to contain both fresh-water and marine species, though never in a mixed state. In some cases the particular species present indicate the character of the piece of water in which the deposit has accumulated, different forms, or groups of forms, appearing in bays, ponds, lakes, marshes, springs, and rivers, and at various points of elevation above the surface of the sea.

The principal fossil deposits of diatomaceæ hitherto discovered contain marine species, and extend over considerable tracts of the earth's surface. The most important stratum of this character is considered to belong to the miocene tertiary, and is found on the Atlantic side of North America, not far from, and, in fact, in some places, reaching down to the coast. It is known to extend from the Patuxent river, in Maryland, as far south as the city of Petersburg, in Virginia. How much beyond these two points it extends has not been ascertained, but is found underlying the cities of Petersburg, Richmond, and Fredericksburg, in Virginia, and at many other points in that state as well as in Maryland. It is desirable to obtain specimens from different points in this bed, as it varies in character, and contained organisms with every few miles of surface, and at different points in its depth.

Strata of this kind vary greatly in appearance, as well as in microscopic character. Therefore the following general directions will suffice to guide collectors in searching for and detecting them.

Gather all earths of light color, varying from a pure white, through different shades of grey, cream, and fawn, to an iron-rust tint. The texture is often friable, and then looks somewhat like clay, especially when it is wet; at other times it is of a hard and stony character, though always more or less porous, and, when soft, of little weight. A moderate magnifying power shows it to be made up of the shells of diatomaceæ. Collect enough to make up three or four pounds' weight, or, say, a block six or eight inches square, and, if possible, from the surface and at various depths, for the reasons already stated. Some of the localities of this material may be mentioned. In Virginia it has been procured in and near Petersburg and Richmond, at Shockhoe hill and Church hill, and at Hollis cliff; and in Maryland, at Lower Marlboro', Nottingham, Piscataway, and Rappahannock cliff.

Besides the above mentioned, an extremely interesting stratum of a similar character, but in general of harder texture, has been found on the Pacific coast of North America, and extending at least from San Francisco to the lower border of California, if not farther, in both directions. This substance makes up the major part of the rocks of the coast range of mountains, and has been named the bituminous shales. It was first detected at Monterey, and is known to microscopists in England as "Monterey stone," but it has since been traced and brought from various points. Santa Cruz, San Pedro, and San Diego have yielded excellent specimens containing many beautiful forms of diatomaceæ. It is usually light fawn-colored, and distinctly stratified. Large fossil shells are found in it; and associated with and in, if not derived from it, is the bitumen of California. At Baldjik, near Varna in Bulgaria, on the Black sea, is a stratum of stony character, having shells and bones dispersed through it. The diatomaceæ found in it are apparently of brackish-water origin, and this is the only stratum of this kind that is known. But very little of this material has found its way into the hands of naturalists. On the island of Jutland, in Denmark, is found a polishing slate which is rich in diatomaceous forms not found anywhere else. This, also, is rare among naturalists, and a good supply of it is very desirable. At Oran in

Algeria, Africa, and at Ægina and Caltanisetta in Greece, are deposits containing the remains of diatomaceæ intermixed with polycystina and foraminifera, and referred to the Cretaceous. In the island of Barbadoes are so-called marls made up of diatomaceæ and polycystina, the latter in great numbers and very beautiful. In the island of Trinidad, at South Naparima, a similar stratum has lately been discovered which "is considered as connected with the new red sandstone; adjoining to which is the sandstone, probably of the same description, in which the Pitch lake is situated." At Moron, in Spain, has been found a similar deposit of marine diatomaceæ; and still another was discovered by Dr. C. F. Winslow at a point about seventy miles south of the town of Payta, in Peru, and about fifteen miles from the Pacific ocean. Here is a plain separated from the sea by a range of hills several hundred feet high. Within the plain is a depression with nearly perpendicular walls two hundred feet high, the bottom of which depression is at about the level of the sea—perhaps a little lower. The surface of the soil thereabouts is covered with salt. For fifteen feet down there is a deposit containing recent shells, the bones of cetacea, and pebbles; then, for one or two feet, is a yellow loam, and, at the bottom, is the stratum, containing the diatomaceæ, which is from two to four feet thick. The amount Dr. Winslow brought away was very small, and this is all that has got into the hands of microscopists. Prof. Pumpelley brought from near Netanai, in Japan, specimens of a like deposit. Very small fragments of the strata from Jutland, Trinidad, Moron, Payta, and Japan have been secured; so it is extremely desirable that those localities should be again visited, the geological relations of the strata ascertained, and a plentiful supply of the material gathered. The sub-plutonic deposits seem to be confined to the Pacific coast of the North American continent, and near by. At Five-mile cañon, near Virginia city, Nevada, is an enormously thick stratum of this character, which is ground and sold considerably under the name of "electro silicon," as a polishing powder. At Klamath lake, on the banks of the Columbia and Pitt rivers, and elsewhere, at many points, these deposits have been found.

The rules already given hold good with regard to gathering specimens of all of these deposits. Everything that can be ascertained with regard to their position and relations should be noted. Also, any fossils contained in them, or in the strata above or below them, should be gathered, and their position noted on the labels accompanying them. All specimens should be kept carefully separate (not even permitting them to come in contact) by wrapping each one in paper, placing within a label having written upon it *in ink* the exact locality, date of collection, and name of collector. It is also desirable that note should be made of the depth from the surface at which the specimen was taken, together with any other information that may be deemed of interest, as supposed extent of stratum, slope-upwards towards north, south, east, or west, and thickness.

Lacustrine Sedimentary Deposits. These were called by me at one time sub-peat deposits, from the fact that all I had seen up to that time had been discovered beneath peat; but as the number of these strata which have come into my hands has increased, I have seen many which do not occur under such circumstances; hence the above name has been applied to them as being more appropriate, and indicating their most common mode of occurrence. In England they are called fossil; but in the true acceptation of that term the forms contained in them are not fossils, but are identical with living species.

They are generally of a pulverulent character, and, when dry, are of little weight, so much so as to attract attention. When free from organic matter, as occasionally occurs, they are quite white, looking almost like powdered starch; but most commonly they are grey, which looks dark while the material is wet, but when dried the color is light. A mass of about six or eight pounds' weight should be secured, and the same precautions as to keeping separate and labelling specimens adhered to, as have been already mentioned. As these beds are seldom of any great extent (they often soon become obliterated or covered up), it will be well to secure a good supply of the material while it is accessible. If any shell, wood, or other organic remains should be found dispersed through the deposit, or overlying or beneath it, they should also be secured, and their position recorded on the label. Likewise, a sample of any superincumbent peat should be kept for future examination. In Sweden and Norway, and in Lapland, these deposits have been used to eke out a scanty supply of flour during bad seasons; but they can hardly be said to be food, for they are not nutritious, but most likely only act by their mass distending the stomach, and thus allaying for a time the pangs of hunger. They have likewise very frequently been employed, under the name of "tripoli," as a polishing material, and are excellent for that purpose. In some parts of this country they go by the name of "marl," but they are not examples of that substance, which is calcareous, being made up of the remains of the shells of mollusca. Specimens from every locality are desirable.

Muds and Deposits from the bottoms of harbors, bays, lakes, ponds, estuaries, and rivers. As a general thing these are not of very great value to the microscopist for the remains they contain, and it is only desirable to collect them in localities or under circumstances where other gathering cannot be made, or when they are known to contain any organisms of great beauty or rarity. The blacker and softer the mud the better, for, if it contains much sand or gravel, the minute organisms will be present in just so much less proportion. As much as can be conveniently transported, say about a handful, should be collected, and, if possible, not dried, but placed in a bottle and tightly corked; or, it may have a little glycerine added to it, which will prevent its drying,—for it has been found that muds, and especially those from salt-water, when once dried, are only with difficulty broken down again so as to be cleaned. The mud and slime attached to anchors, buoys, and submerged woodwork, together with the scrapings from the bottoms of vessels containing shells, plants, zoöphytes, etc., may be simply dried in the sun, and then have a label attached. The mud from beneath fresh water is of little value, as it rarely contains any organisms of beauty; but the marine forms found in mud are occasionally fine, beautiful, and rare.

Guano. This substance often contains species of diatomaceæ not otherwise obtainable. It is the ammoniacal guanos alone, however, which I have found to yield any great number of diatomaceous forms; but there are certain guanos, of which one known as "Bolivian guano" is an example, partly ammoniacal and partly phosphatic, which contain some forms not otherwise obtainable. Quantities of a pound or two in weight should be secured, and the exact locality of the island or other place from which it was obtained, together with the latitude and longitude, and other information that may be collected and deemed of interest, should be marked *in ink* upon the label.

Shell Cleanings. The sand, mud, algæ, zoöphytes, and similar matters adherent to marine shells, which are commonly removed by students of conchology, have often been found to yield rich harvests of rare forms of diatomaceæ. Such material can be washed, or, still better, scraped off of the living or dead shells (the dirtier such shells seem the better, of course), placed in paper and plainly labelled with the exact locality, and, if possible, name of the shell and depth of water from which it was taken. Conchologists will do well to save all their shell-cleanings for this purpose.

Marine Invertebrata. Specimens of the entire animal, or the contents of the stomachs of echinoidea (sea urchins) and holothuroidea (sea cucumbers), should be secured, as it has been found that many, if not most of them, are vegetable feeders, and thus take into their stomachs algæ which have diatomaceæ growing upon them. The entire animal should be preserved in spirits (if alcohol is not procurable, brandy or whiskey will answer), but if that be not convenient, they, as well as the contents of the stomachs, may be dried without washing in any way. It has been found that holothurians, when they are immersed in spirit, often turn their stomachs inside out, and thus the contents, which are the part most valuable for the microscopic organisms, will be found at the bottom of the containing vessel. When the whole animal is preserved in spirit, the label may be written in ink on stiff paper or parchment, and, when quite dry, tied to the specimen and immersed with it in the spirit. In this way several specimens can be preserved in the same vessel, and space economized. This method will be found to be the best, as labels pasted or gummed on, or otherwise attached to the vessel, are liable to be obliterated from leakage of the contained fluid, or removed during transportation. The stomachs of mollusca (shell fish) and crustaceans (lobsters, crabs) also occasionally yield specimens of diatomaceæ, and it will be well to secure specimens of those creatures in the manner described. The stomachs of fish occasionally contain diatomaceæ, and may be secured.

Soundings. The material brought up from the ocean bed by the sounding-line, or the larger masses procured by means of the dredge, have been found to yield good returns of microscopic treasures when examined. The calcareous shells of foraminifera, as well as siliceous polycystina and diatomaceæ, are found in them. When kept for this purpose, note should be made of the latitude and longitude, depth of water, along with the name of the vessel and collector, and the date of collection.

The dust which collects at sea upon the sails or decks of vessels. This kind of material, although not common, has been found to be of interest when examined microscopically. It can generally be scraped up with a piece of paper. When the quantity is so small that it cannot be collected in this way, a piece of damp paper may be laid on it once or twice, in several places, and then folded up before it becomes dry. Latitude and longitude, direction of wind at the time of the falling of the dust, name of vessel, date, and collector's name, should be noted on the label.

Recent gatherings of Diatomaceæ. These are the most valuable, important, and rich of the gatherings containing diatomaceæ on which the student depends for material for investigation, and they are so various in character that it becomes difficult to give general directions that will serve to indicate the modes of procedure to be followed in securing them. To collect diatomaceæ at all thoroughly, a considerable amount of knowledge of their habits is necessary. In general, it may be said that gatherings should be made of marine plants, or algæ as they are called, which grow entirely submerged beneath the water, attached to rocks, piers, iron-, or wood-work. The dirtier such plants appear to the naked eye, the richer will be the harvest of minute organisms secured, as the brown coating, seen upon aquatic plants and similar submerged objects, obscuring them, is but a mass of living diatomaceæ. The larger and coarser algæ,—more especially those having a slimy feel,—do not usually yield many diatomaceæ; but the finer brown, red, or green filamentous kinds are commonly covered with them. Detached fragments thrown up upon the beach ought not to be kept if living ones can be found, for they usually have had the diatoms rubbed off from them, and are, besides, contaminated with sand. The living algæ taken from their attachment should be dried without washing or much compressing, and may then be placed in layers, each specimen being plainly labelled with the exact locality, date of collection, and collector's name. Fragments of algæ, which may break off from cabinet specimens, and would be rejected by students of the algæ, may yet be of value to the diatomist. Some of the finest collections I have ever seen were derived from this source.

When known, the name of the alga should be stated. If possible, it is extremely desirable to secure specimens of diatom-encrusted algæ in spirits. In this way the diatoms will be preserved in almost their natural condition; and those species, which are filamentous or grow in chains, will be available in that condition for study.

Fresh-water plants clouded with diatomaceæ may be collected and preserved in the same manner as marine algæ. As has been remarked, the finer filamentous species of water plants yield the best results; the marine fucoids, as the "bladder wrack," and similar species, secrete a mucus which seems to be repugnant to the growth of most diatoms; yet upon the stalks of Laminaria, and some other large olive-colored algæ, are found the finer red-tinted species, which are themselves beautiful objects of study, and are, in turn, the homes of hosts of minute forms of life. Water plants, marine or fresh-water, should not be cleaned in any way, but merely raised from the water, and, after draining for a short time, be either laid upon a piece of clean paper to dry, or hung up where the air and sun can rapidly evaporate the moisture. Marine plants will usually not dry thoroughly, as the salts present in the water absorb moisture from the air; hence they are liable to mould unless they are packed in paper. The moss-like carpeting seen upon submerged rocks is often made up of beautiful specimens of the filamentous species of diatoms alone, and it will be well to scrape the surface of the stone, and, placing the mass in a bottle, cover it with alcohol, which will become colored from dissolving the coloring matter of the diatoms, and preserve them in the very best manner for future study. Fresh-water forms are very often found hanging in green-colored festoons from the exit pipe of drains, sluices, or fountains, and may be preserved in the same way.

The green, brown, or fawn-colored scum which floats upon the surface of the water of road-side pools, ponds, bogs, marshes, or rivers, consists usually of little else but diatoms, and may be taken up by means of a spoon or bottle, and then preserved in alcohol or dried upon paper. The surface of the sea may be skimmed by means of a net of fine muslin, having an opening left in the bottom, in which a four- or six-ounce wide-mouth phial is tied, and towed at the stern of a vessel. If the sea-water be strained through such a net, either by towing behind a boat or even poured from a pail, the solid matter contained in it will be washed down and gradually collect in the phial, which can then be removed and tightly corked, and another substituted. Some very beautiful forms have been procured in this way. The stain occasionally seen on the surface of the sea in some latitudes, as well as the minute organisms causing the luminosity of the ocean, yield rich crops of diatoms, and should be secured. Such gatherings may be put up as obtained, or have alcohol added to them for better preservation. The collection of aquatic plants from the mouths of rivers is extremely desirable,—such as have been made in the delta of the Ganges yielding interesting results. The refuse of dredging for shells often yields mud, old shells, or algæ; and collectors will do well to secure such. Experience, however, will teach the best places to look for recent diatoms; but the above general directions will prove of service to those who are new to the pursuit, or who collect for others.

It should always be remembered that a knowledge of the exact locality is of the greatest importance,—so that upon the label should be written *in ink* the locality, date of collection, and name of collector. Other facts deemed of interest may also be added.

PART EIGHTH.

How to Prepare Specimens of Diatomaceæ for Examination and Study by Means of the Microscope.

Having accumulated a number of gatherings of rough material, which, a cursory examination has shown, contain specimens of diatomaceæ, and which, it is judged, it will answer to clean and otherwise arrange and put up, or, as it is technically termed, "mount," for future study, the intending diatomist requires to be informed how he may best set about preparing his specimens in the most advantageous manner. The author of the present sketch has published, in the seventh volume of the *Proceedings of the Boston* (Mass.) *Society of Natural History*, certain directions for collecting, preparing, and mounting diatomaceæ for the microscope; and, as that paper contains a large part of the information he desires to impart at the present time, he will draw upon it pretty freely, supplementing it to such a degree as later investigations warrant, or as may seem desirable.

Although most of the published treatises on the use of the microscope in general profess to give directions for mounting objects in such a manner as to preserve them for almost any length of time, and at the same time exhibit their characters to the best advantage, and although we have in the English language at least three books treating specially of this subject of the preparation of microscopic objects, yet hardly any one of these volumes gives any concise, practical, and, at the same time, reliable descriptions of the best methods of collecting, preparing, and mounting specimens of diatomaceæ. In books, generally, when the preparation of these organisms is treated of, it is usually the fossil deposits which are considered, and even such directions as relate to these are for the most part meagre and unsatisfactory; and, when the specific and special directions are, as is often the case, copied from one book into the other without having been tested by the copyist, any faults they may have possessed, as originally written, are merely repeated and not eliminated. To prepare and mount specimens of diatomaceæ, for the purpose of sale alone, is one thing, and to prepare and mount them, so as to preserve and exhibit their natural characters and fit them as objects of scientific study, is another and very different thing. The latter can only be attained after considerable practice, and to do it properly a considerable amount of knowledge of their natural history is plainly necessary.

The diatomaceæ should always be prepared and put up for a special purpose,—that of exhibiting characters peculiar to genera and species; and to do this those characters must of course be known. Muds, guanos, dredgings, and gatherings of that description can seldom be used for the purpose of exhibiting such characters, and when they can, in exceptional cases, be so employed, it is when the forms they contain are selected out in the manner to be described hereafter. Gatherings, likewise, which contain many species in a mixed condition, should, as a general thing, be rejected unless there be present something of special importance, such as rare species, or some large and fine or distorted forms of common species. But even in such cases it will be found best not to mount the gatherings as collected, but to select out the forms desired and place them upon slides by themselves, and in such media as will exhibit their peculiarities to the best advantage. Of course it may be desirable to study the geographical distribution of the diatomaceæ; and then mixed gatherings become of value as exhibiting the number of forms occurring at a particular station. Then, again, the fossil as well as the semi-fossil deposits and guanos may be cleaned and mounted as obtained; but even then it may become desirable, if space can be spared in the cabinet, to have the various species found in each gathering separately mounted, so that they may be at any time studied in comparison with similar forms from other localities.

General directions for collecting diatomaceæ have been already given in Part Seventh; but it will be desirable to again allude to a few points in connection with this portion of our subject. Some years since, an article entitled "Hunting for Diatoms" was published in a London journal called *The Intellectual Observer.* The author's name was not given, but internal evidence would seem to indicate that it was penned by a deceased botanist of note, who was a decided authority on this branch of biology. This paper contains some valuable hints respecting the places in which to look for diatoms, and some of the suggestions contained therein I have ventured to transfer to these pages, as they will be found of value to the intending diatomist. Thus, the exquisite *Arachnoidiscus*, *Triceratium Wilkesii*, and *Aulacodiscus Oregonensis*, may be looked for on logs of wood which have been floating in the sea, and imported from New Zealand, or Vancouver's island. So, on logs from Mexico and Honduras may be found the curious *Terpsinæ musica.* The nets of fishermen, especially from deep water, may yield algæ bearing such forms as *Rhabdonema arcuatum or Adriatium*, *Grammatophora serpentina* and *marina*, various *Synedras*, and other fine forms. On oyster shells may be found algæ bearing upon their fronds *Biddulphia regina*, *Baileyii* or *aurita. Rhizosolenia styliformis* is said to be almost sure to be there likewise. After a ship is unloaded, and as it floats higher in the water, its sides may be searched for treasures of the diatom world, and *Achnanthes longipes* and *brevipes* found, or even *Diatoma hyalinum* and *Hyalosira delicatula.* The sea-grass, or *Zostera marina*, growing along our coast, often bears upon its waving ribbons fine forms of diatoms, and that used for stuffing chairs, and lounges or mattresses, and imported from abroad, will yield foreign species to the collector. There is a plant known in England as "Dutch rushes," which is imported into that country from Holland, and which is used for chair bottoms. These plants grow in the brackish water of the marshes, and hence upon them are to be found the delicate *Coscinodiscus subtilis*, *Eupodiscus argus*, and *Triceratium favus*. Both of these two last named forms occur commonly on our Atlantic coast, and muds from Charleston, S. C., and Wilmington, Ga., have provided me with them in plenty. Cargoes of bones, which present green incrustations from having lain in the water for some time, are said to yield diatoms, some of which may be rare, as coming from foreign ports. The state of New Hampshire has not yet been sufficiently gone over for it to be said what the characteristic forms of diatomaceæ growing within its boundaries are, but yet we may safely predict that the lakes, ponds, streams, and sea-coast of that state will yield to the searcher ample material of beautiful forms.

If the microscopist wishes to mount a few slides of recent diatoms just to show what diatoms are, nothing is easier. It is only necessary to boil a small mass of them in strong nitric acid in a test tube over a spirit lamp, and, when the acid has ceased to emit red or yellowish fumes, wash them thoroughly with clean water, allowing them to settle completely. Then a little of the clean sediment, consisting almost entirely of the shells of the diatoms, is taken up by means of a "dip-tube," and placed upon the central portion of a glass slide. Here it is dried, and the slide warmed over a lamp; then a drop of Canada balsam is permitted to fall upon the diatoms. As soon as all bubbles have cleared off from the balsam, a warm cover of thin glass is carefully laid upon it and permitted to settle into place. When cool, it is ready for examination by means of the microscope, any balsam which has exuded around the cover being washed off with alcohol. In this way rough and tolerably clean specimens may be obtained; but such would not, or, at all events, should not, satisfy the student of the diatomaceæ. For him more elaborate methods are necessary, and these we will now proceed to consider.

Apparatus and chemicals necessary. A chemist's retort-stand, which is a heavy iron plate with an upright rod projecting from one side of it. Running on this rod, and so arranged that they may be fixed by set-screws at any height, are a series of rings of various diameters, which are to be used to hold the vessels in which the specimens are to be manipulated over the source of heat used. Mr. C. G. Bush, late of Boston, Mass., who has had considerable experience in cleaning diatomaceæ, tells me that he uses a lamp burning petroleum oil, as cheaper than a spirit-lamp, and, to support the vessels he employs, has a little metal arrangement on the top of the chimney, such as is supplied for the purpose of holding a small tea-kettle and the like. The only objection to the oil-lamp is, that, unless the wick be well turned down, we are liable to have our vessels blackened. However, the heat given off by burning petroleum is very great, and I have often used such a lamp with advantage. If desired, of course, the source of heat used may be gas, burned in a Bunsen's burner, or a spirit-lamp; and this last, especially if it be supplied with a metal chimney to cut off draughts, is, all things considered, the best, as it is very cleanly, not being liable to smoke the bottom of the glass or porcelain vessels used. If we are going to work with large quantities of material, we shall require a small sand-bath to heat the glass vessels upon. In small quantities, the diatoms may be boiled in test-tubes, when some sort of holder will be required. The metal ones, sold by dealers in chemists' apparatus, are extremely handy; but I have found that we can make very good ones out of old paper collars. One of the kind called "cloth-lined" may be cut into strips about three quarters of an inch wide and three inches long. Such a strip is folded around the test tube, near the top, and the ends, brought together, are held between the fore-finger and thumb. In this way the tube is firmly grasped, and can be held over the lamp without much danger of burning the hand, as the paper collar strip is a bad conductor of heat; or, the paper strip may be grasped in an "American clothes-peg," which has a spring to force its parts together. Large quantities of diatoms are best boiled in porcelain evaporating-dishes, glass flasks, or beaker-glasses. The last mentioned vessels are also by far the best things for washing them in. A few, say three or four, glass stirring-rods will be found useful; and one or two American clothes-pegs to take hold of hot evaporating-dishes with. Then there will be required a few dip-tubes, made of small glass tube, drawn out over a flame, so that the opening is considerably diminished. The mode of making these cannot be given here, but will be found in books on chemical manipulation; and it will be well for the student to learn to make his own dip-tubes, as a number will be required first and last, and they are easily broken. Of course there will be required a number of glass slides, of the usual dimensions of three inches by one. These should be of as white glass as possible, and it will be found best to procure those with ground edges, as they are the neatest in appearance. Only such as are free from scratches or other blemishes in the central square inch should be used; and, although even such as have bubbles or scratches near the ends only will not look ornamental in a cabinet, we should remember that microscopic objects are not generally mounted to look well in a cabinet, but to be useful out of it; so that if the central and useful portion of the slide be perfect it need not be rejected. Some persons make their own glass slides, but I have never found it answer to do so, as it is difficult to get the right kind of glass, not at all easy to cut it or grind the edges, and it is liable to be scratched while cutting or grinding. Thin glass, such as is made on purpose for microscopic use, will be required; and this, also, it will be found best to buy ready cut rather than attempt to cut it for one's self. The thin glass used for covers may be of different thicknesses, but the thickest made will not do for diatoms, and a certain amount of the very thinnest will be required for small and delicately marked forms, on which very high power objectives will have to be used. The covers must be perfectly clean, which may be insured by soaking in caustic potassa solution, and then washing thoroughly in clean water. The thinner kinds of glass are rather difficult to clean; but with a little extra caution it may be accomplished, the last polish being given to it by a piece of an old and well-worn cambric handkerchief. The covers, always round, should be separated into sizes and thicknesses, so that the exact kind of cover required can be found without having to search for it by turning over a number, scratching or breaking them, and losing much valuable time. We shall also require a pair of forceps for holding the slides over the lamp; and such as are sold at house-furnishing stores and by grocers, under the name of American clothes-pegs, and which have been already mentioned, are by far the best I have ever seen or heard of. A small pair of brass forceps which close with a spring will be needed, and they are best set in a wooden handle so as to protect the fingers from the heat; and another pair, which spring open and may be closed by means of the finger and thumb, will be wanted for taking hold of and adjusting the thin covers. I do not advocate the use of paper covers for slides, but labels of some kind will, of course, be required, and I have found the plain circular white ones to look the best. There are very pretty square labels sold by dealers in these things that I have used and liked. For making cells to hold specimens put up in fluid, a turn-table and brushes and some cement will be necessary. The cement I use and prefer above all others is good old gold size, used warm.

The chemicals required are nitric acid, sulphuric acid, hydrochloric acid, bichromate of potash, caustic potash, alcohol, and, above all, a plentiful supply of clean, *filtered* water. The water should be such as leaves hardly any residuum when a quart of it is evaporated to dryness; and it must be filtered just before use, to remove any minute organisms, diatoms especially, which it may contain. A certain amount of washing soda will be wanted, if guanos are to be cleaned.

We will now proceed to consider the manipulations necessary to prepare the various kinds of gatherings, always remembering that these methods will have to be modified to a certain extent for each specimen.

Recent Gatherings. If there be sand in the gathering, it will be well to remove it before using acid by shaking it in clean water and pouring off before the diatoms, which are lighter than the sand, settle. The water holding the diatoms in suspension may be poured into a test-tube or beaker, the diatoms allowed to settle, and as much of the water poured off as possible. The diatoms are now covered with nitric acid to about the height of half an inch, and allowed to stand for a few minutes. Usually, some chemical action takes place, and it will be well to wait until it subsides. The test-tube or beaker is then held over the lamp and carefully heated until the reaction of the acid upon the organic matter of the diatoms ceases. Thereafter, and while the liquid is still hot, I have found it often advantageous to drop in one or two fragments of bichromate of potash. The organic matter is more thoroughly destroyed in this way than when the acid is used alone. Thereafter it is well to pour the acid and diatoms into a capacious beaker of clean water, washing the tube or smaller beaker out with a little water, and adding this to the other. After the diatoms have all settled, which will often require hours, the supernatant fluid is carefully poured off, and a fresh supply added; and this must be repeated several times until all of the acid and colored chromium compound has been removed. When this point is arrived at can only be ascertained from experience. In this way the valves and connecting membranes of the diatoms are usually separated and cleaned ready for mounting, which process will be described hereafter.

Muds will have to be treated in a somewhat different manner from recent gatherings. If the mud is dry, it will have to be broken down by boiling for a few minutes in a solution of caustic potassa, the strength of which must be apportioned to the particular specimen under treatment. After it has been broken down into a soft mud, all of the potash is thoroughly washed off by means of clean water, and replaced by nitric acid, as in the case of recent gatherings. This is boiled, and a little bichromate of potash added as before, and the whole washed. It very seldom happens that the diatoms occurring in mud will be sufficiently cleaned by this process, so that it has to be supplemented by another. The sediment is therefore washed into one of the evaporating-dishes and allowed to settle, and as much of the water poured off as possible. Then sulphuric acid, in quantity to a little more than cover them, is poured in, and the vessel gradually and carefully heated. As soon as the liquid shows signs of boiling, bichromate of potash is added, a very little at a time, until the green color first formed by its reaction upon the organic matter begins to assume a yellowish tint, when no more is dropped in; but a few drops of hydrochloric acid are permitted to fall in, and the liquid is allowed to cool. Of course it will be best if the person undertaking to clean diatoms is somewhat versed in the use of chemicals; but at any rate care must be taken not to drop any of the acids upon the clothes or skin, and great caution must be exercised in not inhaling any of the vapors given off. Those evolved after the addition of the hydrochloric acid are especially irritating and dangerous, and must be avoided. As soon as the liquid has cooled a little, water should be added cautiously, as great heat will be generated thereby, and there will be danger of its boiling over. Thereafter it may be poured into a large beaker-glass of water and thoroughly washed, as in the former case. If it be found that the precipitate is not quite white, it will be necessary to boil it again in sulphuric acid, with bichromate of potash and hydrochloric acid, until it is quite clean. If, on examination by means of the microscope, it is found that there is much flocculent matter present besides the diatoms and sand, this can be removed by boiling for a few seconds in a weak solution of caustic potash, and washing quickly and thoroughly with plenty of clean water. When we have recent gatherings of filamentous or stipitate forms of diatomaceæ, which we desire to preserve in the natural condition, they should be immersed for about twenty-four hours in alcohol to dissolve out the endochrome. If this does not answer, it will be well to soak the mass of diatoms or plants upon which they are adherent in a solution of hypochlorite of soda, an impure variety of which is sold in the shops under the name of Labarraque's disinfectant, for about the same length of time. This will generally destroy all color, and leave the specimens transparent. It is best, however, in many cases not to remove the endochrome, but leave it, and mount the specimens in such a way as to show them in as natural a condition as possible. How this may be done will be described hereafter.

Guanos. The preparation of these substances so as to obtain the microscopic organisms they may contain is rather difficult, tedious, and dirty, and should only be undertaken by a person somewhat versed in chemical manipulations, and in a proper room as a laboratory, where there is no danger of harm resulting from the fumes evolved. As the ammoniacal guanos are those which contain the most diatoms, and consequently which answer best to clean, we will begin with them, and take as a type that which comes from the islands on the coast of Peru. As it comes into commerce this guano is a moist powder of a light iron-rust color, smelling strongly of ammonia, and having scattered throughout its mass lumps of ammoniacal salts of a more or less solid consistency. The guano should be thinly spread out upon a stiff piece of paper and exposed to the air, and, preferably, to a moderate heat for several days or even weeks. In this way most of the moisture and much of the ammonia will evaporate, and less acid will be required to clean the guano. It will now have become much lighter in color, and crumble to a dry powder. A tin pan is now about half filled with a solution of common washing soda in clean filtered water, and placed over some source of heat, as on a stove. The strength of this solution is not a matter of any great moment, and must vary with the guano manipulated. As soon as it begins to boil, the guano is dropped gradually in, a little at a time, while the liquid is stirred with a glass rod or stick of wood. Considerable effervescence takes place, ammonia being given off, and therefore it must be kept continually stirred, and care exercised to prevent its boiling over.

After a while it is poured into a plentiful supply of clean water and washed therewith several times, care being taken to permit all of the diatoms to settle. As soon as the wash-water is only slightly colored, the guano is transferred to a good sized evaporating-dish, and covered with nitric acid, and boiled. While it is boiling, a few crystals of bichromate of potash are dropped in, and the material washed as in the case of muds. Thereafter the diatoms are boiled in sulphuric acid with bichromate of potash and hydrochloric acid, as before described.

Phosphatic guanos, as that from Brazil, are somewhat more difficult to treat. They are generally drier than the ammoniacal kind, and must be boiled in a large quantity of hydrochloric acid as many as three times, and the acid must be poured off while still hot. Thereafter nitric acid and sulphuric acid and bichromate of potash must be employed, as in the other case.

Lacustrine Sedimentary Deposits. For the most part these are pulverulent, and easy to clean. Some, as found in nature, are so pure that they require no cleaning except washing in clean water. Burning on a plate of platinum or mica will often serve to clean some specimens, but it will, in general, be found best to boil in nitric acid with a little bichromate of potash, and subsequently in sulphuric acid and bichromate of potash, with the after addition of hydrochloric acid. Occasionally a certain amount of flocculent matter will be left, which it will be necessary to remove with very careful heating, not boiling, in a weak solution of caustic potash, and immediately pouring into a large quantity of clean water and thoroughly washing.

Marine Fossil and Sub-Plutonic Deposits, being stony and possessed of very much the same physical characters, are manipulated in the same manner. A small lump of the deposit is placed in a test-tube, and covered with a strong solution of caustic potash. It is then boiled for a few minutes, and usually it immediately begins to break up and fall down in the shape of a soft mud-like material. At once the liquid, with the suspended fine powder, is poured off into a large quantity of clean hot water, and if the whole of the lump has not broken down into a powder, what remains has a little water poured over it in the test-tube, and it is again boiled. It will be found that a little more will now crumble off. This is added to the rest in the large vessel, and if the lump has not now broken down, it is again boiled in the alkaline solution and in water alternately, until it has all been disintegrated. It is then all permitted to settle for at least three hours, when it is thoroughly washed and boiled in hydrochloric acid for about half an hour. There is then added an equal amount of nitric acid, and the boiling continued for a short time. It is then washed and heated in sulphuric acid, with the addition of bichromate of potash and hydrochloric acid.

All mixed gatherings of diatomaceæ, and particularly all muds and deposits, should be separated into densities, so that for the most part the larger forms are collected together, free from sand, and separate from the smaller species and broken specimens. This is done by using a number of beaker glasses, of various sizes, in the following manner: Into a one-ounce beaker the cleaned diatoms are placed, and the vessel filled with water. It is then well stirred up by means of a glass rod, and, after resting about five seconds, poured off carefully into a six-ounce vessel so as not to disturb the sand which has settled. Again the vessel is filled up with water, stirred, allowed to settle for the same length of time, and poured into the same vessel. This is repeated until it has been done at least six times, when we shall find all of the sand, free from diatoms, in the small beaker. This can be thrown away, and as soon as the material in the large beaker has settled it is returned to the small one, and the same process gone through with, only extending the time of settling now to about ten seconds. The next density is that which settles in twenty seconds; and so on, five or six densities may be obtained, and if carefully prepared they will be found to contain forms varying very much one from the other. The large species of *Triceratium*, *Aulacodiscus*, and the like, will be found in the coarsest density, and the broken diatoms in the lightest.

Preserving and mounting specimens so as to have them in a condition for study at any future time. Of course, when possible, diatomaceæ should be studied in the living condition. But there are many forms which have not been as yet found living, and these can only be studied as dead skeletons; and, in fact, it is in the dead skeletons of the diatomaceæ that many of the most marked characteristics are to be found; and on such characteristics species have been founded. Besides, the most beautiful sculpturing of the valves is only to be seen after everything has been removed but the siliceous cell-wall I have termed the skeleton. Therefore I advocate the cleaning of a portion at least of every gathering in the manner described, so that nothing will be left but the clean siliceous cell-wall.

If we desire to keep specimens in a state as near that they present when living as possible, we have to put them up in some preservative fluid in which they will not decay, and in which the softer parts will be preserved. Unfortunately these soft parts do not keep well; but the fluid which I have found to be the best for the purpose is distilled water, which has to every fluid ounce two or three drops of wood creosote added, and thereafter a sufficient number of drops of alcohol, which will be about double the number of the drops of creosote, to make the creosote soluble in the water, which it is only to a very slight degree under ordinary conditions. I do not advocate any fluid containing glycerine, or, in fact, any of the preservative fluids described in the books treating of the preparation of microscopic objects. The vessel in which the fresh specimens of diatomaceæ are put up are what are known to microscopists as "cells," but how these are made cannot be gone into here, as the description would occupy too much space and time. Suffice it to say that I prefer cells made of old japan gold-size, which can be procured of dealers in microscopic materials. Within such a cell, of sufficient depth and immersed in the preservative fluid, a few of the diatoms, or a scrap of the plant upon which they are growing, is placed, and the glass cover fixed over it in the manner described in the books upon manipulation. The filamentous forms are thus preserved almost in their natural condition; but, on account of the presence of the endochrome, the sculpturing of the siliceous cell-wall is almost invisible. To show this character, while the filamentous form is preserved, another method of mounting is employed. A thin, clean covering glass is selected, and laid upon a clean piece of paper. A large drop of distilled water is then allowed to fall upon it, and in this drop the filamentous diatom is thinly spread out. Then the cover is taken up by means of a pair of forceps and held over the flame of a spirit-lamp, which has been turned down so as to be quite small and steady. The cover is held some distance above the flame, and judiciously manipulated, so that the heat is evenly distributed over it, and it does not crack. As soon as all the water has been driven off without the formation of bubbles, the glass is brought gradually down almost in contact with the flame, and held at that point for a few minutes. Then the diatoms will be seen to turn black, on account of the charring of the organic matter contained in them. After a while this black carbonaceous matter will burn off, and they will become quite white. If, however, there seems to be any difficulty in burning off the last portions of carbon, the cover is lowered once or twice to come in contact with the top of the flame, and then raised again. In this way it will become red hot for a moment; and everything will be burned off except the siliceous portions of the diatoms. Now the cover is removed slowly from over the flame, and held in the forceps until it is cold, but by no means laid down upon any surface until it is quite cold,—otherwise it will fly into pieces. Then it can be laid upon an ordinary glass slide, and examined to see if it is worth preserving, which may be done in one or two ways: first, the glass cover is warmed, and a drop of good spirits of turpentine let fall upon it, covering the diatoms. Just before the spirits evaporate, a small drop of thin Canada balsam is added, and a slide taken, warmed, and a drop of balsam placed upon the centre part of it. Then the cover is brought down upon the slide, the two balsam-covered sides together, in such a way, by tilting the cover slightly, that no air is allowed to come between them, and the cover permitted to fall gradually into place, driving a wave of balsam before it. In this way we have the filamentous diatoms arranged as they grow, but with endochrome removed which would obscure the markings, and in balsam, which renders them transparent. Some forms, as some of the *Fragillariæ*, become too transparent if put up in this way, and therefore another method of mounting must be adopted with them. They are burned upon the cover, as just described, but mounted dry in air; that is to say, a cell of gold-size is made, the glass cover slightly warmed, and then placed upon the cell, with the side upon which the diatoms are fixed, downwards. The warmth slightly softens the gold-size, and the cover becomes fixed.

Other forms besides the filamentous species may be mounted in fluid, or burned upon the cover and subsequently put up in balsam, or dry. But the commonest way of treating such forms is to clean them by means of chemicals, as already described, and then previous to mounting them divide the clean gathering, consisting of a white sediment of large and small diatoms along with fine sand, all mixed up together into densities. Of course, if some of this sediment were to be mounted in this condition, extremely unsightly slides would be procured; so it is best to separate the finer from the coarser diatoms, and these in turn from the sand. This is accomplished by what is known as elutriation, or, separating into densities after the manner already described. Then slides may be mounted from each of the densities in the following manner. A slide is thoroughly cleaned, and a good sized drop of water placed upon the centre portion. A little of the diatom sediment is then taken up in a dip-tube, and the point of the tube brought just into contact with the drop. As soon as a few diatoms have run out of the dip-tube, it is removed. Then a small splinter of wood or stiff bristle is used to disseminate the diatoms through the drop of water in such a way that they will be pretty evenly distributed and not overlie each other. The water is then driven off by heat, a drop of thin Canada balsam placed upon the dry diatoms, and a cover placed on them in the usual manner. In many cases, especially when dealing with the smaller forms, it will be found desirable to mount them upon the cover in this same way, instead of upon the slide, as they will then be brought as near as possible to the objective of the microscope. Single or remarkable specimens of diatoms may be picked out and mounted by themselves; but the manner of accomplishing this would occupy more space than it has been thought desirable to devote to this portion of our subject, and the reader is referred to the books on mounting microscopic objects for the particulars of the process.

The main principles of preparing and mounting diatomaceæ for preservation and study have been given, and the intending student will be able to devise modifications and improvements for himself, so that he will be able to put up specimens in as finished a manner as any to be procured from the dealers.

Description of Plates.

All of the figures, with the exception of 23 and 24, are magnified five hundred diameters, or two hundred and fifty thousand times superficial. Fig. 23 is magnified about three hundred diameters, and Fig. 24 one hundred diameters. All of the figures, with the exception of the two mentioned, are exact portraits of specimens in the collection of the author, and are intended to be as perfect delineations of the diatoms represented as could be obtained, as the drawings have been made with special care to that end. This fact is mentioned, as most of the plates of diatoms published do not give correct ideas of these organisms, and are usually drawn or engraved by persons not possessed of an intimate acquaintance with the objects intended to be represented. The plates have been obtained by photography direct from the author's drawings, without the intervention of any engraver, and are, therefore, truthful reproductions of them.

Plate I.

Fig. 1. Front view of *Triceratium Montereyii*. From the marine fossil "infusorial stratum," of Monterey, Cal. This figure shows the connecting membrane, which is differently sculptured from the valves.

Fig. 2. Front view of *Triceratium punctatum*. In this specimen no connecting membrane has been developed. From the harbor of Charleston, S. C.

Fig. 3. Side view showing the valve of *Pinnularia nobilis*. From Germany.

Fig. 4. Front view of *Rhabdonema arcuatum*. From the harbor of Salem, Mass.

Fig. 5. Side view of *Pleurosigma angulata*. From the coast of France.

Fig. 6. Side view of *Pleurosigma fasciola*. From the harbor of New Haven, Conn.

Fig. 7. Side view of *Triceratium punctatum*. From Charleston, S. C.

Fig. 8. Side view of *Pleurosigma Balticum*. From the coast of England.

Fig. 9. Side view of *Pleurosigma quadratum*. From the coast of England.

Fig. 10. Side view of *Coscinodiscus radiatus*. From the marine fossil stratum of Oran, Algiers. In this specimen, as is very commonly the case, the radiant arrangement of the markings is obscure.

Fig. 11. Side view of *Navicula didyma*. From the coast of France.

Fig. 12. Side view of *Triceratium favus*. From the harbor of Charleston, S. C.

Plate II.

Fig. 13. A specimen showing both front and side views of *Gomphonema constrictum*, as well as the arrangement of the stipes or stalk. From Marion, N. J.

Fig. 14. Front view of *Achnanthes brevipes*, showing the flag-like appearance of the perfect individual when attached to some submerged substance by means of its stipes. From the coast of England.

Fig. 15. Front view of a chain of two frustules of *Grammatophora marina*, from the harbor of Salem, Mass.

Fig. 16. Front view of a filament of *Melosira varians*, terminated by a sporangium or seed vessel. From Englewood, N. J.

Fig. 17. Side view of *Heliopelta Metii*, from the marine fossil stratum of Nottingham, Md. The species has been lately removed from the genus *Heliopelta* and placed in *Actinoptychus*, and can therefore be considered as a representative of that genus. It is one of the most beautiful of the diatoms, and has never as yet been seen except in the fossil condition, and at the locality named.

Fig. 18. End and portion of a tube of *Schizonema obtusum*, from the harbor of New York. The little navicula-like frustules of the *Schizonema* are seen within the tube.

Fig. 19. A group showing both front and side view of *Synedra tabulata*, from the harbor of New York, showing the manner in which the frustules are attached to submerged objects by means of a cushion or short stipes.

Fig. 20. A chain of *Diatoma vulgare*, from England, showing the front view only.

Fig. 21. Side view of *Biddulphia rhombus*. From the harbor of Charleston, S. C.

Fig. 22. Front view of *Biddulphia rhombus*, showing both valves and connecting membrane. From the harbor of Charleston, S. C.

PLATE III.

Fig. 23. A, B, C, D, and E, different stages of growth of *Palmoglœa*.

Fig. 24. *Lichmophora flabellata* on its stipes or stalk. From the coast of England.

Fig. 25. Side view of *Navicula Barklayana*. From the coast of England.

Fig. 26. *Epithemia turgida*, conjugating or reproducing. From England.

Fig. 27. Side view of *Pinnularia lata*. From New Hampshire.

Fig. 28. Side view of *Aulacodiscus Oregonensis*. From the Sandwich islands.

Fig. 29. Side view of a *Navicula prætexta*. From the Gulf of Mexico.

Fig. 30. Side view of *Himantidium pectinale*.

Fig. 31. Front view of a filament of *Himantidium pectinale*, from a spring near New York.

Fig. 32. Side view of *Meridion circulare*, showing the wedge-shaped frustules united together so as to form a spiral. From West Point, N. Y.

Fig. 33. Side view of *Stauroneis acuta*.

Fig. 34. Front view of *Stauroneis acuta*. From England. In these two figures the septum, which projects like a shelf into the cavity of the frustule at the ends, can be seen.

Fig. 35. Side view of *Navicula lyra*. From Germany.

Fig. 36. Side view of *Navicula serians*. From New Hampshire.

Fig. 37. Side view of *Navicula quadrata*. From Germany.

APPENDIX.

NEWARK, N. J., September 1, 1874.

Prof. C. H. HITCHCOCK, State Geologist:

Dear Sir—As you request, I send what information I can at the present time concerning the specimens of diatomaceæ which I have received from you or others, or collected myself in the state of New Hampshire. The specimens have been of two characters. For the most part they have consisted of lacustrine sedimentary deposits, and these have been collected by yourself, or the other gentlemen connected or not connected with the survey. A few recent gatherings have likewise been sent to me by you, or procured by myself and a friend, in and around Hanover and elsewhere. The lacustrine sedimentary deposits are thirteen in number, and are from the following localities: Bemis lake, Carroll county; Bowkerville, Fitzwilliam; Stamp Act island, near Wolfeborough; Littleton; Laconia; Bristol; Chalk pond, Newbury; Epsom; Pike's pond, Stark; Bow; Cold pond, 2000 feet above the sea, one eighth mile from Crawford house; Umbagog lake, Coös county; Concord. Besides these, I have received prepared slides from Manchester and from Durham.

As it may be of interest to those who study the diatomaceæ to know, I will state when and how these deposits came into my hands.

Bemis Lake. The first specimen of this deposit was sent to me by Mr. Charles Stodder, of Boston, Mass., in 1859. I examined it and published a list of the species I found in it at that time in the *Proceedings of the Boston Society of Natural History*, May 2, 1860. This list is as follows:

Cocconema parvum.

Cyclotella Kützingiana.

Cymbella cuspidata.

Eunotia serra.

Gomphonema acuminatum.

Himantidium gracile.

Navicula affinis; Navicula cuspidata; Navicula firma; Navicula interrupta; Navicula rhyncocephala; Navicula serians.

Nitzschia ——— ———?

Pinnularia major; Pinnularia stauroneiformis; Pinnularia tabellaria; Pinnularia viridis.

Stauroneis phœnicenteron.

Surirella biseriata; Surirella linearis.

Tabellaria fenestrata; Tabellaria flocculosa.

I have again and more carefully examined this deposit, and find that I have to make some corrections in the above list, as well as add to it; but, as my investigation has not been completed, I shall not at the present time make these corrections and additions. Besides the specimen sent me by Mr. Stodder, I received further supplies from Mr. R. C. Greenleaf, of Boston, in 1866, and from the discoverer and owner of the deposit, Dr. S. A. Bemis, in 1865 and 1870.

Bowkerville. The first specimens of this deposit which I received were from yourself, in May, 1871. In the following July I visited the locality with you, and made further collections.

Stamp Act Island. This deposit I received from you in September, 1871.

Littleton. The first samples of this deposit were procured from the Bailey collection in the possession of the Boston Society of Natural History, and were sent me by Mr. Charles Stodder. Subsequently specimens were sent to the survey by Mr. B. W. Kilburn, and were transmitted by you to me.

Laconia. The first specimens of this I received from Mr. R. C. Greenleaf, in November, 1865. In May, 1867, he sent me a further supply, and told me that it occurred on a farm belonging to Col. Crockett.

Bristol. This was sent to me by Mr. C. Stodder, June, 1862, who said that he had received it from a Mr. Webster.

Chalk Pond, Newbury. A very small sample of this deposit was sent to me by you, October, 1871; and in June, 1874, you sent me a further supply.

Epsom. This I procured from the collection of the Essex Institute, Salem, Mass., in December, 1864.

Pike's Pond. This was discovered, I understand, by Mr. J. H. Huntington, of the survey, and was given me by you, June, 1871.

Bow. This I also procured from the collection of the Essex Institute, and it was labelled as having been presented by Dr. Prescott.

Cold Pond, near Crawford House. A very small sample of this was sent me by you, July, 1872.

Concord. This I procured from the Bailey collection in Boston.

Umbagog Lake. This you sent me in July, 1870.

The slides labelled *Manchester, N. H.*, and *Durham, N. H.*, I received from Mr. E. Samuels, of Boston, Mass.

The recent gatherings of diatomaceæ which I have from New Hampshire, are as follows:

No. 1. Brook emptying into Shaker pond, Enfield.

No. 2. "Muck hole," Hanover.

No. 3. On mosses from Shaker pond, Enfield.

No. 4. Mink brook, Hanover.

No. 5. Trout pond on farm of J. E. Lawrence, Bowkerville.

No. 6. Lake of the Clouds, on Mt. Washington.

No. 7. Haystack lake.

No. 8. Large pond, Bowkerville.

Nos. 9, 10, 11. Hanover.

All of these, with the exception of Nos. 6 and 7, are my collections. Nos. 6 and 7 you sent me.

Besides these gatherings, I have received fresh-water diatomaceæ from the following localities in New Hampshire, through the kindness of Mr. R. C. Greenleaf, of Boston, Mass.:

Lake Mouran, on Cannon mountain, 1865.

Saco river, 1865.

Echo lake, 1865.

Profile lake, 1865.

Spring near Tip-top house, Mt. Washington, 1865.

Small pond near Crawford's, 1865.

Spring near Lake Mouran, 1865.

Pond on Mt. Lafayette (Lake Greenleaf).

Snow arch, Tuckerman's ravine.

Androscoggin river, Gorham.

Gibbs falls, Crawford.

Brook in Bethlehem.

In June, 1862, Mr. Charles Stodder sent me a specimen of a lacustrine sedimentary deposit, labelled "New Hampshire: locality and history entirely unknown; sent by some one in Lawrence to Mr. Ordway, of Manchester, N. H."

In Ehrenberg's *Mikrogeologie*, T. XXXV, A. VI, is represented a deposit of diatomaceæ said to come from Perth, N. H. [?], and this is mentioned as described in the *Transactions of the Berlin Academy* for 1843. In the same work, T. XXXIII, X, is represented another similar deposit from New Hampshire,—more particular locality not being mentioned. This is said to be described in the *Transactions of the Berlin Academy* for 1845. This work is not accessible to me at the present time; therefore I am unable to give the particulars mentioned by Ehrenberg concerning them.

These, then, constitute all of the material I possess up to the present time representing the diatomaceæ of the state of New Hampshire, and as soon as I shall be able to work up the forms contained in them I will transmit you a full report thereon. In the meantime it is extremely desirable that we should receive recent collections from other parts of the state; and I would particularly call attention to the fact that we have not, as yet, received any gatherings from brackish or salt-water. Specimens of marine algæ encrusted with diatomaceæ, as they almost always are, would be particularly acceptable. Respectfully yours,

A. MEAD EDWARDS, M. D.

NEWARK, N. J., September 1, 1874.

Prof. C. H. HITCHCOCK, State Geologist:

Dear Sir—I have thought that it might prove of interest to students of the Desmidiæ to know that while making collections of diatomaceæ in and around Hanover, N. H., in the summer of 1871, I procured the following species belonging to that family:

Didymoprium Borreri.
Desmidium Swartzii.
Microsterias denticulata; Microsterias crenata.
Cosmarium Botrytis.
Staurastrum polymorphum.
Docidium nodulosum.
Closterium angustatum.
Pediastrum Boryanum.

As special gatherings for obtaining these organisms were not made, the above list is very brief; but hereafter I hope to add to it, as the desmidiæ of the United States have not been much studied, and a great deal remains to be done in our micro-zoölogy and micro-phytology. Respectfully yours,

A. MEAD EDWARDS, M. D.

NEWARK, N. J., September 1, 1874.

Prof. C. H. HITCHCOCK, State Geologist:

Dear Sir—During my excursions in and around Hanover, N. H., three years since, in search of diatomaceæ, I collected a few specimens of wild plants infested with diseases caused by the growth upon them and in their tissues of microscopic parasitic fungi. These I submitted to my friend, Mr. M. C. Cooke, of London, Eng., the well known fungologist, and he was so good as to identify them. They were the following:

Æcidium Violæ, Schum., on wild violet. *Viola.*
Æcidium grossulariæ, D. C., on wild gooseberry. *Ribes hirtellum.*
Æcidium Dracontii, Schw., on Indian turnip. *Arum triphyllum.*
Æcidium asterum, Schw., on a plant whose name was not ascertained.

The mere announcement of the discovery of these species in New Hampshire will not perhaps prove of interest to the majority of the readers of the survey report; and this will arise from the fact that they will not be sufficiently informed with regard to the important bearing these minute plants have upon the occupation of the agriculturist. There is no doubt that it would be greatly to the advantage of the farmer were he better informed concerning both the animals and vegetables which prey upon his crops. If he knew something of their habits and modes of attack, he would be the better prepared to resist their depredations, or even to attack them in such a way as to preserve his crops, and thus save for himself much money and labor. At some future time, and as further specimens come into my hands, I shall take the opportunity of transmitting to you some remarks on the fungi injurious to the crops of the agriculturist. In the mean time, students of these plants may be glad to know that those I mention have been found in New Hampshire.

Respectfully yours, A. MEAD EDWARDS, M.D.