COMPOSITION AND ORIGIN OF IOWA CHALK.

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As noted in volume I of the reports of the present Survey, the Cretaceous strata of northwestern Iowa include a considerable body of chalk and soft shelly limestone that has been variously known as the *Niobrara* of Meek and Hayden, the *Cretaceous No. 3* of the same authors, or the *Inoceramus beds* of White. The chalky deposit composing the Niobrara beds possesses no small degree of economic value, and there is little doubt that, in the not distant future, it will furnish the raw material for a number of important manufacturing industries. The peculiar characteristics of the beds referred to are such as to engage the attention of the most superficial observer. They are unique among the geological formations of the Northwest. Where typically exposed they are pure white, or yellowish white, in color; they are soft in texture, and they may be quarried in great blocks that are easily cut with a common saw into any required dimensions. Chalk-rock the common people of the region call the beds under consideration, but geologists have been somewhat chary about acknowledging that this soft, white, calcareous material is in reality chalk. For example, Professor Dana, in the second edition of his Manual, speaks of the beds of sand, marl and loosely aggregated shell limestone in the

Cretaceous strata of America, but he adds with intentional emphasis that "they include in North America *no chalk*." In the third edition of the Manual the statement is modified so as to read that "they include in North America no chalk, excepting in western Kansas, where, 350 miles west of Kansas City, a large bed exists." In the second edition of Le Conte's *Elements of Geology* we are told that chalk occurs "nowhere except in Europe"; but in the third edition the existence of chalk in America is recognized in the statement that "recently good chalk composed of foraminiferal shells, and containing flints, has been found in Texas." In the *Geological Studies* of Dr. Alexander Winchell the author, speaking of chalk, on page 64, says that "it does not occur in America," while the same impression is repeated on page 433 in the statement that the Cretaceous "produces no chalk in America."

These references are made for the purpose of showing how, until recently, the leaders of geological thought have been impressed with the notion that the American Cretaceous furnishes no true chalk. Notwithstanding all this widespread and long prevalent impression respecting the absence of chalk in this country, chalk does exist, and in immense quantities. The area over which it is spread extends from Texas probably to the Arctic ocean, and has a width reaching from western Iowa to the Rocky mountains. Chalk, soft and white as that obtained from the cliffs of southern England and made up of calcareous skeletons of Foraminifera and Coccoliths without the admixture of mechanical sediments, has a thickness of at least twenty-five feet along the Sioux river in Iowa (see plate viii); it is fifty feet thick at Ponca, Nebraska; a little further up the Missouri river, at Saint Helena, it stands in a vertical wall, above the Benton shales, with a thickness of ninety feet;

at Yankton, South Dakota, its thickness is 130 feet; and at the mouth of the Niobrara it attains a thickness of probably 200 feet. Near the mouth of the Sioux river some portions of the beds would be described as soft shelly limestone containing large numbers of *Inoceramus problematicus* Schlotheim, but at Saint Helena and points farther up the Missouri the material is soft and nearly homogeneous throughout, with no beds of Inoceramus, and with few mollusk shells of any kind except occasional small colonies of *Ostrea congesta*.

As has long been known the chalk of Europe is a deposit of calcareous material that was laid down in a clear open sea remote from land. The sea bottom on which it was deposited was at least so situated as to be beyond the reach of mechanical sediments carried by agents of erosion. Furthermore the chalk is composed of the more or less broken and comminuted skeletons of the simple unorganized animals called Foraminifera and of the still more minute limy structures that are probably parts of coralline plants, and which are known as Coccoliths. The bulk of all chalk indeed seems to be made up of Coccoliths, small disc-like bodies varying from 1-5000 to 1-2500 of an inch in diameter. The shells of the Foraminifera, often quite crowded and unbroken, are simply embedded in the fine chalky mud that is formed by the aggregation of foraminiferal débris together with thousands of millions of minute dust-like Coccoliths in each cubic inch of the deposit. Now our Iowa chalk resembles the English chalk in every essential particular. As to its present physical characteristics it is practically the same. It is white, soft enough to soil the fingers, may be used for writing on the blackboard, and may be put to all the commercial uses to which the chalk of Europe is adapted.

As to composition, it is the same as European chalk, for it is made up of shells of Foraminifera imbedded in a matrix of imperfectly cemented Coccoliths. The Coccoliths cannot be distinguished microscopically from those forming the larger part of the chalk of England; and the Foraminifera are, in many cases, identical with the species found in the corresponding deposit on the other side of the Atlantic. Furthermore the American chalk along the Missouri and the Sioux rivers was laid down on the bottom of a clear, open sea that received no gross sediments from contiguous shores. There is no reason in the world for refusing to recognize the deposit as true chalk.

Considering the attitude of geologists to our American chalk beds it may be interesting to note the successive steps whereby the foraminiferal origin and true chalky character of the deposits have finally come to be recognized. As long ago as 1841, Prof. J. W. Bailey received from a mission station in the Northwest a sample of what was called "prairie chalk," and in a communication to the *American Journal of Science and Arts*, volume 41, pp. 400–401, he describes it as being full of the "elegantly little." The "elegantly little" in this case are Foraminifera of which Professor Bailey gives four excellent figures drawn to scale under the camera lucida. No names are given to any of the species, but figure 2 may now be recognized as the form described by Ehrenberg a year or two later under the name of *Textularia globulosa*, a species common not only in our American chalk but occurring also in great abundance in the chalk of England. Figure 4 is one of the multitudinous varieties that have recently been marshalled by Brady under the name of *Globigerina cretacea;* figure 1 is a large Textularia, of the same species as 2, seen obliquely; while 3 is either a

Discorbina or a *Globigerina* seen from the concave or umbilical side.

In 1843, Ehrenberg published at Berlin an important *Memoir on the Extent and Influence of Microscopic Life in South and North America*. Most of the work is devoted to diatoms and desmids, but a few pages are given to the discussion of Foraminifera, including forms from the Cretaceous chalks and marls along the Missouri river. The identity of some of the species with forms from the European chalk is recognized, but other species, among which he describes *Textularia americana*, in his opinion are not known elsewhere. An extended notice of Ehrenberg's Memoir, by Prof. J. W. Bailey, was published in 1844 in the 46th volume of the *American Journal of Science and Arts*. A figure of what is supposed to be *Textularia americana* is given in a foot note, and copious extracts from the memoir are translated and incorporated in Professor Bailey's notice. In volume 48 of the *American Journal*, published in 1845, we have a list of American localities known at that time to Professor Bailey as affording material containing Foraminifera. The Cretaceous beds along the Missouri are mentioned, and the remarkable abundance of foraminiferal shells which they afford is noted.

For a number of years subsequent to 1845 little attention seems to have been paid to the composition of the chalk along the Missouri river. Dr. F. Roemer's *Kreidebildungen von Texas* appeared in 1852, with description and figures of *Orbitulites texana*, a gigantic foraminifer that seems to have furnished material for the construction of beds of chalk in Hill's Fredericksburg division of the Lower Cretaceous; and in 1857 Conrad, in the *Report of the United States and Mexican Boundary Survey*, volume

I, part II, describes and figures an even larger form from the Washita division of the same series, under the name of *Nodosaria texana*.

Between 1853 and 1861 Meek and Hayden worked out the succession of Cretaceous strata along the Missouri river. Numerous papers were published under the joint authorship of the geologists named. The chalk of the Niobrara division is frequently mentioned, sometimes as "chalk marl" and sometimes as "calcareous marl weathering to a yellowish or whitish chalky appearance above." In their detailed section published in the Proceedings of the Academy of Natural Sciences, Philadelphia, December, 1861, the "calcareous marl" of Formation number 3 is said to contain "several species of Textularia." They seem careful to avoid calling the deposit chalk, though lithologically and micro-paleontologically its practical identity with that material must have forced itself upon their attention. In the first Annual Report of the United States Geological Survey of the Territories, by Dr. F. V. Hayden, published in 1867, the author says concerning the Niobrara division that "Its principal character is a gray or light yellow chalky limestone; much of it so pure as to make a good chalk for commercial purposes." That the deposit is actually chalk is here for the first time rather hesitatingly acknowledged.

In 1870, Dr. C. A. White, in the Geology of Iowa, volume I, page 294, in discussing the Inoceramus beds, which represent in Iowa the Niobrara of Meek and Hayden, tells us that among other fossils, "minute Foraminifera (probably Globulina) are sometimes met with in great numbers." The *Canadian Naturalist* for 1874, volume VII, number 5, contains an article by Dr. G. M. Dawson, entitled *Note on the Occurrence of Foraminifera, Coccoliths, etc., in the*

Cretaceous Rocks of Manitoba. The rocks referred to in Dr. Dawson's paper are of the same age as the chalk beds in Sac, Woodbury and Sioux counties, Iowa, the same as the Niobrara of Nebraska, Kansas and South Dakota. In Manitoba the Niobrara beds seem to be harder and less like chalk than along the Missouri and the Sioux. Dr. Dawson takes pains to say concerning the American Cretaceous, that "this formation contains no beds of true chalk." The greater part of the rock that furnished his specimens was composed of shells of *Inoceramus problematicus* and *Ostrea congesta;* but the "soft, whitish, earthy matrix" in which the shells were imbedded proved to be rich in Foraminifera, Coccoliths and allied organisms. Four figures of Foraminifera are given and named respectively *Textularia globulosa, T. pygmæa, Discorbina globularis* and *Planorbulina ariminensis.* The Textularians are probably modifications of one species; the only form in Iowa chalk that can be identified with Dawson's figure named *Discorbina,* has the inflated, spherical chambers characteristic of the types referred by Brady to *Globigerina cretacea,* and the species referred to *Planorbulina ariminensis* by Dawson is a very thin Truncatulina slightly concave on one side and convex on the other, altogether unlike the figures of *Anomalina ariminensis* (*P. ariminensis*) given by Brady. All the forms are common in our Iowa chalk, and all but the last are characteristic of the chalk of Europe. After studying material from Nebraska as well as from Manitoba, Dr. Dawson says: "The general facies of the foraminiferal fauna of these Cretaceous rocks of Manitoba and Nebraska singularly resembles that of the ordinary English chalk. Both abound in Textularine and Rotaline forms of similar types, the most abundant in both being the form with globose

chambers, and each having its rarer analogue, with chambers flattened and more delicate."

Dr. Dawson's paper is the first, so far as I know, that recognizes Coccoliths as important agents in the formation of American chalk. Figures are given of a number of these interesting structures under an amplification of 1,250 diameters. The forms figured are very common in our Iowa chalk and constitute no small portion of its entire bulk. The English chalk likewise contains many Coccoliths, some of which are indistinguishable from the American species, but with these are some possessing characters unknown thus far in the Niobrara beds along the Missouri. The peculiar calcareous rod-like objects called Rhabdoliths are not uncommon in the chalk of Nebraska, Iowa and Manitoba, and, in the paper cited, Dr. Dawson gives a number of figures showing quite a variety of forms. The amount of material contributed by Rhabdoliths is inconspicuous when compared with that furnished by Coccoliths and Foraminifera. Rhabdoliths were discovered in 1872 in the recent ooze of the Adriatic, and Dr. Dawson's paper of 1874 contains the first announcement of the existence of these bodies in the fossil condition.

Prof. Robert T. Hill is probably the first American writer who came out squarely and called our American chalk by its real name, chalk. In the *Annual Report of the Geological Survey of Arkansas* for 1888, volume II, Professor Hill writes on the *Neozoic Geology of Southwestern Arkansas*. The entire volume, with the exception of two brief appendices, is devoted to the subject, and from beginning to end the author refers to the soft calcareous deposits of the Lower and Upper Cretaceous of Texas and Arkansas as *chalk*. Chapter XIV is especially devoted to a discussion of the physical characters of the

chalk in the southwestern states and the conditions under which it was deposited. The fact that Foraminifera make up a large proportion of the deposit is noted time and again, and the genera *Textularia* and *Globigerina* are identified.

In a *Check List of the Invertebrate Fossils from the Cretaceous Formation of Texas*, a publication issued in 1889 from the University of Texas — School of Geology — Professor Hill recognizes the fact that "the Cretaceous Rocks of Texas are mostly of foraminiferal origin including innumerable microscopic species." Only two, *Nodosaria texana*, Conrad, and *Orbitulites* (*Tinoporus*) *texanus*, Roemer*, are recorded; and they are both found in the Lower Cretaceous, in formations older than the Niobrara beds that contain the chalk of Iowa. In the same year, 1889, in Bulletin No. 4 of the Geological Survey of Texas, Professor Hill gives an *Annotated Check List of the Cretaceous Invertebrate Fossils of Texas* in which the Foraminifera mentioned in the preceding list are noted, and Textularia and Globigerina are added as forms found in the Upper Cretaceous. The Upper Cretaceous chalk of Texas is simply the southwestward extension of the chalk we find along the Sioux river in Iowa, and the Textularia and Globigerina noted by Hill are doubtless specifically identical with forms belonging to the same genera occurring in the Niobrara along the Missouri and the Sioux.

In the *American Geologist* for September, 1889, Professor Hill has a paper on *The Foraminiferal Origin of*

* It is not clear why Professor Hill should regard this species as belonging to the genus *Tinoporus*. The forms referred to *Tinoporus* by Montfort, Carpenter, Brady and others are all lenticular or disc-like with radiating marginal points or spines at more or less regular intervals.

certain Cretaceous Limestones and the Sequence of Sediments in the North American Cretaceous. That the material of certain horizons in the Cretaceous is chalk, and that it is composed in large part of the shells of Foraminifera, are propositions repeatedly and clearly stated.

Prof. S. W. Williston contributed a note on *Chalk from the Niobrara Cretaceous of Kansas,* which was published in the number of *Science* issued October 31, 1890, Vol. XVI, page 249. The fact is noted that "Professor Patrick, some years ago, stated that it, [the Niobrara chalk] contained no microscopic organisms, but afterwards, with the aid of a very high power objective found what he thought were organic remains. This is all the more remarkable" says Professor Williston, "as the chalk appears to be wholly composed of organic forms, very readily visible under a comparatively low power (a one-fifth or one-sixth objective and a C eye-piece)." The forms seen by Professor Williston are the minute Coccoliths and Rhabdoliths noticed by Dr. Dawson in 1874, and at the time of writing the note under consideration, the comparatively large Foraminifera that may be seen with a good pocket magnifier seem to have been overlooked. In the same volume of *Science,* page 76, there is a note from Dr. George M. Dawson referring to the note of Professor Williston and expressing the opinion that the organisms found by Williston are certainly the same as the Coccoliths and Rhabdoliths that Dawson had previously shown to occur in the chalk of Manitoba and Nebraska.

In a paper read before the Kansas Academy of Science in December, 1890, Professor Williston returns to the subject of the *Structure of the Kansas Chalk.* This time he recognizes in it the presence of Foraminifera and says: "The deposit seems wholly formed of Coccoliths,

Rhabdoliths and Foraminifera, with, perhaps, radiolarians and sponges. The Coccoliths exist as complete, or broken oval, or circular bodies from 1-3500 to 1-4500 of an inch in diameter with from one to six depressions, or nuclei; the Rhabdoliths are slender spicules, rarely attached to a central mass, or as rarely with a trumpet shaped extremity. In addition there are other, less slender rods, from 1-1000 to 1-2000 of an inch in length, that may be radiolarian spicules. I have recognized at least a dozen forms of Foraminifera, the one most common and conspicuous very similar to, if not identical with a Textilaria [Textularia] of the English chalk. In view of the foregoing facts, it seems to be time that the assertions of some of our leading text-books that there is no chalk in America should be corrected."

Between 1890 and 1894 several papers were published in the *Bulletin of the Geological Society of America* and elsewhere in which the deposit under discussion is recognized physically as chalk and genetically as having been produced by Foraminifera and other microscopic organisms. The latest, which relates once more to the Texas region and is by Professor Hill, appears in the *Bulletin of the Geological Society of America*, published in March, 1894. The subject of the paper is the *Geology of Parts of Texas, Indian Territory and Arkansas adjacent to Red River*. The paper discusses the general geology of the region considered; but on pages 319 and 320 the foraminiferal origin of certain beds of altered chalk is noted, and the genera Rotalia and Textularia are recognized.

The foregoing references, while incomplete as a bibliography relating to the physical characteristics and foraminiferal origin of American chalk, will yet help to make clear the successive steps whereby geologists have been

led from complete skepticism regarding the presence of chalk on this side of the Atlantic to the conviction that the Niobrara beds along the Sioux and the Missouri rivers, are, in all the particulars relating to physical structure, composition and origin, identical with the chalk of Europe. Advantage has been taken of the facilities afforded by the geological laboratories of the State University to investigate anew, and more thoroughly than seems to have been done before, the composition of the Niobrara chalk. In thin sections under the microscope the unbroken shells of Foraminifera are very conspicuous. They lie in close proximity to each other, and their inflated chambers, filled with crystals of calcite, sometimes occupy more than one-third the area of the entire field. It is certain that more than one-fourth, and in some instances more than one-third, of the volume of the chalk is composed of foraminiferal shells still practically entire. The matrix in which the shells are imbedded is made up of a variety of objects, the most numerous, and the most conspicuous under proper amplification, being the circular or elliptical calcareous disks known as Coccoliths. The small rod-like bodies to which the name Rhabdoliths has been applied are not very common, although their presence is easily detected with a moderately high power objective. Mingled with Coccoliths and Rhabdoliths are numerous fragments that are evidently the débris resulting from comminution of foraminiferal shells. When the chalk is treated with acid there remains a small amount of insoluble matter consisting of clay, fine grains of quartz sand, minute pebbles not exceeding five millimeters in diameter, and a very few internal casts of the chambers of Foraminifera. Nearly all the foraminiferal shells have the chambers filled with calcite; a few have these cavities still empty or filled

simply with air; but in a small number of cases the chambers were filled with an opaque, insoluble mineral, probably silica deeply stained with iron oxide, that remains as perfect internal casts after the shell has been dissolved in acid. The amount and composition of the residuum varies with the purity of the chalk. In some samples it scarcely exceeds one per cent; in others it is equal to ten per cent.

In all the chalk examined the Foraminifera are very numerous. Many are large, vigorous looking specimens of the types to which they belong, and an unusual number of the shells remain perfect. They are easily separated from the finer particles constituting the matrix by gently grinding the chalk with the finger in a shallow dish, using water enough to cover the material operated upon, and pouring off and renewing the water as long as it shows any traces of milkiness. The particular genera and species that will be found after the washing process is completed will depend somewhat upon the locality from which the material was derived. It is probable that the species differ at different levels in the formation, but the collections in the field were not made with a view to determining that fact. In a sample from the great bluff at Saint Helena, Nebraska, large forms of Textularia are most common. The chambers are inflated and spherical, and the shell widens rapidly toward the larger end as illustrated in figures 5 and 6, plate xix. This is the *Textularia globulosa* Ehrenberg, and, as has been already noted, it is one of the most common forms at certain horizons in the chalk of Europe.

A more slender form of Textularia, figure 7, plate xix, is often associated with *T. globulosa*. In some beds it is the prevailing type. Figure 7 illustrates an unusually

large individual of this species. As a rule, however, it is not only more slender than the other, but is shorter and every way smaller, and it is doubtless the form figured under the name of *Textularia pygmæa* in Dawson's paper already cited, contributed to the *Canadian Naturalist* in 1874. The two forms grade into each other perfectly when a large number of individuals is examined, and there is little doubt that they are simply variations of a single species. I have seen nothing in all the thousands of specimens examined corresponding to Bailey's figure of *Textularia americana* as given in 1844 in the *American Journal*, volume 46. In some respects the internal casts left after dissolving the shell in acid resemble the figure in question, but the resemblance is not sufficiently close to render the hypothesis that it had been made from such a cast at all plausible.

Textularia globulosa attains its largest size and most perfect form at some distance above the mouth of the Sioux river — from Saint James or Saint Helena, Nebraska, westward. The shore line of the Niobrara sea in which the Foraminifera that make up so large a proportion of the chalk flourished and died, extended northeasterly from near the southwest corner of Iowa. From that old shore line the sea spread away westward to beyond the Rocky mountains; and the sites now occupied by Yankton, South Dakota, and Saint Helena, Nebraska, were many miles from shore and covered by moderately deep clear water unpolluted by detritus washed in from the land. In such pure, clear sea-water *Textularia globulosa* found the conditions exceedingly favorable. As, however, the shore was approached the conditions became more and more adverse, for the chalk from Sioux City, Hawarden, Auburn and other points east of the Sioux, contains specimens of

Textularia that on the average do not attain much more than half the size reached by the individuals from Saint Helena. In other words the smallest forms of *Textularia pygmæa* prevail. Furthermore the specimens from the localities named are often very irregular in their mode of growth, so that they were not only apparently starved and stunted, but they were very frequently deformed, by the unfavorable environment prevailing in regions nearer and nearer the shore. The most easterly point at which chalk used in the present investigation was collected was near Auburn, in Sac county, and here the Textularians are all of the ill fed pygmæan type; but at Sioux City, which is one of the intermediate points between Auburn and Saint Helena, the diminutive forms, while very numerous, have mingled with them a few conspicuously large individuals recalling those from the great chalk cliffs farther up the Missouri. There is one very marked difference however, scarcely any of the large specimens are symmetrical. Like the smaller individuals of the same region they are more or less distorted. What is more the later formed chambers of the larger specimens often depart from the biserial type and may be arranged in a single series, or, as more frequently happens, in three, four, or even five series, or, they may even be heaped together irregularly without any recognizable order.

The depauperating effects of the unfavorable environment seem to have acted in three ways; first, to retard growth; second, to cause deformity by unsymmetrical growth even when the biserial arrangement is maintained; third, to destroy the biserial arrangement of the later formed chambers among the more vigorous individuals and produce the irregular heaping together of the cells that is sometimes expressed by the term acervuline. It

may be with safety assumed that the Textularians of the region, with their endless variations as to size and proportions, including departures from symmetry and biseriality, are all varieties of one species which for the present we may call *Textularia globulosa* Ehrenberg.

While Textularia seems to have flourished best in the deeper and purer waters remote from shore, the reverse is true of the forms illustrated in figures 1, 2, 3 and 4 of plate xix. These shells have been variously referred to species of the genera Rotalia, Rotalina, Planulina and Discorbina, but the spherical form of the chambers, the thin walls, large foramina and other characteristics would exclude them from either of the genera named. The revised definition of Globigerina, as given by Brady in his Report on the Foraminifera dredged by the Challenger, extends the genus sufficiently to include the forms under consideration, and it is probable again that they are modifications of a single species, the *Globigerina cretacea*. Figure 3 represents some forms that occur rather sparingly in the chalk of Nebraska. In their general aspect they resemble *Globigerina digitata* Brady. The earlier formed chambers are in all respects like those of figures 1 and 2, but some of the later chambers are very much elongated. The form of the abnormal chambers varies greatly; they stand sometimes in one plane and sometimes in another, and I have regarded them simply as accidental variations in the terminal cells of the species illustrated in figures 1 and 2. Brady's specimens of *G. digitata* came from bottom dredgings. The species was never taken with the tow net at the surface. It is probable that in each case the abnormal chambers were added to the shell after the organism settled to the bottom, and their abnormality, I take it, may be due to the fact that upon the bottom the

restrictions to normal growth were very much greater than those affecting the animal when floating near the surface. We have seen in the deformed and otherwise abnormal Textularians that the simple protoplasm making up the bodies of Foraminifera responds to changes of environment in such a way as to affect profoundly the form and proportions of the shell, and it is at least conceivable that, in the crowded condition of the organisms resting upon the bottom, some of the Globigerine forms, accustomed in early life to perfect freedom from contact with other shells, were so unfavorably situated as seriously to interfere with normal symmetrical growth. It is an interesting fact that the deformed specimens of Globigerina are associated with the vigorous, symmetrical types of Textularia. Nearer the shores, in the material laid down at Sioux City, Hawarden, Auburn and elsewhere east of what is now the Iowa boundary, the Globigerine types of Foraminifera flourished in greater profusion than farther west; and distortion or deformity, when it occurred at all, affected only the regularity of the spiral without interfering with the globular form of the several chambers.

In the deposits about Saint Helena and Yankton, which were persumably laid down in deeper and clearer water than were the deposits farther east, Truncatulina, figure 10, and Bulimina, figure 8, are not uncommon, while in the eastern localities they seem to be entirely absent. Occurring more rarely than the preceding, but apparently confined exclusively to the exposures in South Dakota and Nebraska, we find Cristellaria, figure 9, Frondicularia, figure 14, and the Nodosarian forms, figures 11, 12 and 13. On the other hand the shallower sea, that during the Niobrara stage covered the region we now call Sac county, Iowa, contained a number of species not found in the

western localities. For example there were Globigerinæ with a few large chambers like *G. bulloides*. There were also hyaline Foraminifera with small chambers very irregularly arranged and resembling some of the acervuline species of Planorbulina. This genus, as now restricted, has not been reported from strata older than the middle or later Tertiary and hence its presence in Cretaceous deposits in Iowa is somewhat improbable; and, furthermore, before deciding the generic relations of the forms in question it is well to bear in mind the possibility of monstrosities of one genus assuming a superficial resemblance to some other. Then again that shallower sea, as is well illustrated in slides made from chalk from near Auburn, in Sac county, contained a number of Lituoline forms resembling Reophax, in which the shells are composed of small particles of sand or of other minute objects cemented together.

The causes affecting the distribution of species in the different localities mentioned in this paper will be better understood after a consideration of the physical conditions under which the chalk was deposited. The Niobrara beds, whether made up of shells of Inoceramus or of Foraminifera, are a part of the Cretaceous series of the northwest. The series, above and below the mouth of the Sioux river, begins with the Dakota sandstone, a deposit well seen in the lower part of the bluffs at Sioux City. When the Dakota sandstone was accumulating the region about Sioux City was covered with shallow brackish water. The sand composing the deposit was carried into the sea from land that was not very far away, probably only a few miles to the eastward. The sea bottom was not stationary, but was slowly subsiding, the rate of subsidence being greater, however, than the rate at which

the sandstone accumulated. As a result of the subsidence the sea became deeper over any given area, as for example Sioux City; it also for the same reason encroached gradually upon the land, and the shore line became more and more remote. With increasing depth of sea and increasing distance of the shore the coarser sand failed to reach Sioux City. Only the finer mechanical sediments were carried so far seaward, and then the second member of the Cretaceous, the Benton shales, was gradually built up. The subsidence continued, even after the Benton stage came to an end. The waters deepened still more over the site of Sioux City. The bottom was no longer affected by waves and currents, and the shore line, now east of the middle of the state, was so remote that practically no detritus from the land found its way to the area we are considering. Indeed it is possible that the continued subsidence had caused all the contiguous land areas to stand so low with reference to the sea that erosion was reduced almost to zero, and the whole area draining into this part of the Niobrara basin was reduced to the base level of erosion. Whatever the explanation, neither sand nor clay was deposited in any appreciable amount as far west as Yankton and Saint Helena; very little indeed as far west as Sioux City. Even in the localities east of Sioux City where Niobrara beds now occur, the amount of sediment derived from the land was so small as to be scarcely worth considering. Now it was in this clear, quiet sea that the Niobrara chalk was slowly deposited. Upon the bottom of this sea there flourished the Textularians and nearly all the other types of Foraminifera to which reference is made in the preceding pages. Floating in the same sea were the Globigerine forms already noted. It is only the younger individuals, however, of the

Globigerinæ that are able to float. For as the shells, with age, increase in size and thickness the animals sink to the bottom and their minute tests become mingled with those of other species that spend their entire life in that situation. Either floating in the water or resting upon the bottom were the peculiar coralline plants of which the bodies called respectively Coccoliths and Rhabdoliths were constituent parts. All these organisms, the microscopic plants and animals alike, secrete carbonate of lime, and it was the dead skeletons of successive generations of such organisms, accumulating under the conditions described, that made up the entire bulk of our American chalk. The units used in the construction of the Niobrara beds were, in the majority of cases exceedingly small; but their numbers were inconceivably great, and this fact coupled with the time during which the conditions lasted, was sufficient to pile up chalk over the whole area from Iowa to the Rocky mountains, and from Texas to the Arctic sea, to an average thickness of not less than two hundred feet.

The subsidence that began with the deposition of the Dakota sandstone reached its maximum near the close of the Niobrara. Then the opposite movement began and the sea gradually retreated toward the west. As the land became more and more elevated erosive agents became more and more effective. Mechanical sediments were carried by the drainage waters; and the conditions favorable to the growth and multiplication of the hosts of minute lime-secreting organisms that crowded the waters during the Niobrara stage came to an end as the mud which formed the shales of the Pierre group settled down and smothered out that whole array of microscopic life to which the chalk owes its origin. It was about the time

that the subsidence reached its maximum that the chalk was deposited near Auburn, in Sac county, Iowa, and it was about the same time that the typical beds at Yankton and Saint Helena were built up. The differences already noticed between the Textularians at Saint Helena and those at Sioux City and Auburn are in some way connected with the facts that while the region about Saint Helena was covered with clear and relatively deep water, the waters covering the regions farther east were shallower and the bottom received the small amount of sediment which the sluggish, nearly base-leveled streams of the period carried into the sea. No one can tell how such slight differences of environment would react on the living matter of Textularia, but that they did affect it profoundly becomes obvious upon comparing the shells of the beautiful, symmetrical, thrifty-looking specimens from Saint Helena with those of the starved, impoverished, deformed specimens from Sioux City and Auburn.

In the case of the Globigerine forms that during most of their lives float near the surface, the condition of the bottom was not a matter of so much moment. The water at the surface was doubtless clear enough, for even the small amount of sediment carried into the region must have been limited to the lower strata of the water. Near the surface, too, food was even more abundant than it was at the same depth farther west, and thus it happened that near the shore the Globigerinæ flourished, and their full-grown shells bearing every indication of life under most favorable conditions settled down among the unhealthy and depauperated Textularians to which life had been a perpetual struggle with adverse surroundings. The shallow-water chalk is composed of large numbers of shells of vigorous Globigerinæ mingled with many small and

deformed shells of Textulariæ, while the deeper-water chalk abounds in robust, normal Textulariæ with relatively few Globigerinæ. Among the Globigerine shells of the deeper water are a few rather remarkable monstrosities.

A few samples of English chalk have been investigated for the purpose of comparison with our Iowa product; but the opportunities for getting typical specimens have not been very favorable and the results are not satisfactory. The English chalk affords Textularia, rather smaller on the whole than our more vigorous examples of *T. globulosa*, but evidently of the same species. I recognize also a Bulimina, but it is specifically distinct from ours. Truncatulina somewhat different from the species in the Iowa chalk is present and is on the whole the most abundant form in all the specimens of foreign chalk I have been able to get. Nodosaria and Frondicularia are present, but the species are slightly different from those found on the Missouri. I have been led to believe that the specimens examined are not fair examples of the average chalk of Europe for the reason that they are all singularly poor in perfect shells of Foraminifera. From a gram, for example, of Iowa chalk we would get probably fifty times as many perfect Foraminifera as from an equal amount of the white cliff chalk of England, so far as examples have come into my possession. The Coccoliths are practically the same in the two cases compared. There are some types in English chalk, as already noted, that I have not seen in ours, but they are not very common. Minute angular pieces, apparently of Foraminiferal shells, are more plentiful in the English chalk than in that of Iowa. But it is not claimed that the comparisons I have been able to make are at all satisfactory, and final conclusions

must be deferred until a sufficient number of specimens of the English chalk to give fair average results have been examined. Enough, however, may be determined from the comparisons already made to prove that the two deposits considered are fundamentally the same in composition and origin. The water in which the English chalk was deposited was probably deeper than the Niobrara sea between the present site of Yankton and its eastern shore somewhere near the middle of Iowa. Differences in depth determine to some extent the species inhabiting the sea bottom; and the amount of mechanical sediments accumulating in any given region will also, as a general rule, bear some relation to the depth of the water.

It is interesting to know that while Textularian and Globigerine Foraminifera were revelling in clear, quiet seas in the longitude of the first meridian, and contributing their dead shells to form the chalk of Europe, almost exactly similar conditions existed more than a quarter of the way around the globe; and in another clear sea with low flat shores, the same or very similar species of Foraminifera were contributing material to form the chalk beds of Iowa.

DESCRIPTION OF PLATE XIX.

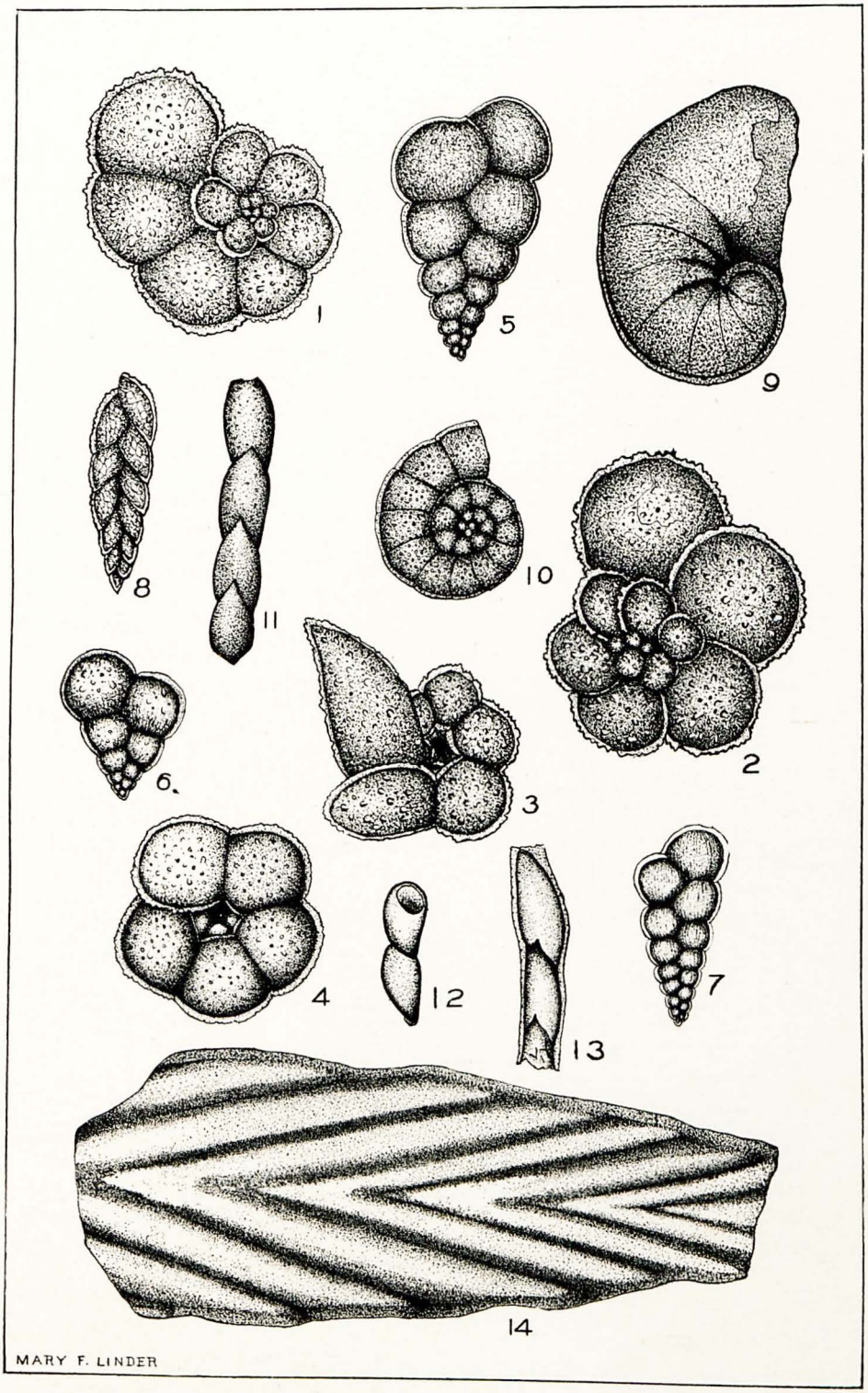
(All figures magnified 100 diameters.)

1. *Globigerina cretacea*, with right spiral, seen from convex side.
2. *Globigerina cretacea*, with reversed spiral, from convex side.
3. Form resembling *G. digitata*, from concave or umbilical side.
4. *Globigerina cretacea*, concave side.
5. *Textularia globulosa*, average form.
6. Similar, more rapidly expanding form, Saint Helena.
7. Very large individual of the less robust type, figured by Dr. Dawson as *T. pygmæa*.
8. *Bulimina*, a form common at Saint Helena.
9. *Cristellaria*, rare at Saint Helena.
10. *Truncatulina*, common at Saint Helena and Yankton.
11, 12, 13. Nodosarian forms, undetermined, from Saint Helena.
14. *Frondicularia*, fragment of a very large and very beautiful specimen from Saint Helena.

NOTE.—While it is true, as stated on page 220, that Professor Hill was the first American writer broadly and persistently to affirm the existence of chalk beds on a large scale and covering wide areas in North America, it is justice to say that the chalky character of certain portions of the Niobrara beds had been pointed out a number of times by previous writers. For example, in 1863 Professor Jules Marcou had noted the existence of chalk in the Cretaceous deposits around Sioux City and in the adjacent parts of Nebraska. He communicated the fact to the scientific world in papers read before the Geological Society of France. Referring to these papers in the American Geologist, volume IV, page 366, Professor Marcou says respecting one of them: "I took the precaution to carry with me pieces of rough chalk taken from near Sioux City, and I drew on the blackboard with them the three sections which accompany the paper, and at the end I said, writing with that chalk, 'Craie d' Amerique,' that in order to prove the constancy of lithological characters on vast surfaces of the earth, I had used only American white chalk that evening for my communication before the Geological Society of France."

Another writer, Mr. D. C. Collier, in the American Journal of Science for May, 1866, describes beds of chalk occurring 350 miles west of Leavenworth. The following language leaves no doubt as to how Mr. Collier regarded the deposit: "On one occasion, in company with a companion, I was able to climb to the top of a bluff of pure chalk, so soft that I could cut and carve it with the knife I carried in my belt, and so fine that it covered my clothes as thoroughly as when in my college days a classmate wiped the blackboard with my back."

There are other references equally as pointed, but a complete bibliography of the subject, I take occasion to repeat, is aside from the purpose of the paper.



ORGANISMS IN IOWA CHALK.