CONCRETIONS

FROM

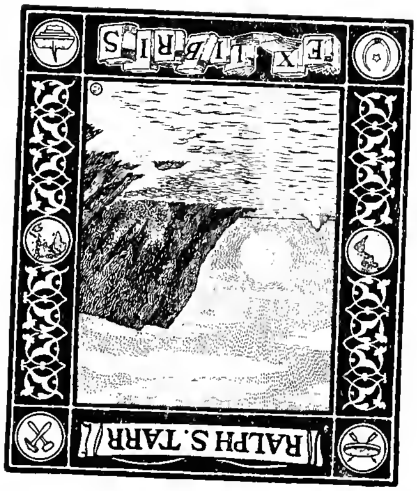
THE CHAMPLAIN CLAYS

OF THE

CONNECTICUT VALLEY.

BY

J. M. ARMS SHELDON.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J. M. ARMS SHELDON.

WITH ONE HUNDRED AND SIXTY ILLUSTRATIONS

BY

KATHARINE PEIRSON RAMSAY, L. R. MARTIN, AND F. S. AND M. E. ALLEN.

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TO

MARY LOWELL STONE.

"*An idealist who builded,*
A dreamer who wrought."

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PREFACE.

SINCE my childhood the so-called "claystones" of our valley have excited, first, my curiosity, and in later days my deep interest. It has been, therefore, a keen delight to picture in lasting form some of the many rare specimens I have unearthed, and to record the observations made during happy days upon the green banks and the blue waters of the dear old Connecticut.

THE AUTHOR.

DEERFIELD, Sept. 1, 1900.

ACKNOWLEDGMENTS.

GRATEFULLY but sadly I acknowledge my deep indebtedness to the late Sir William Dawson for bringing a portion of this paper before the Montreal Society of Natural History, and for the publication of the same in "The Canadian Record of Science," Vol. IV., Jan., 1891. Since that time the illustrations have been prepared, the analyses on p. 29 have been made, and much new matter has been added to the text.

I am also under great obligations to Hon. George Sheldon of Deerfield and to Miss C. Alice Baker of Cambridge for most generous help in many directions.

Through the kindness of Professor B. K. Emerson I have had free access to the large collection of concretions in the geological cabinet of Amherst College which includes the collection of President Edward Hitchcock from Massachusetts, and that of Professor C. B. Adams from Vermont.

To the late Frank W. Smith of Riverside, Massachusetts, I am indebted for substantial aid in collecting concretions on the Connecticut.

My cordial thanks are also due my valued assistant, Mrs. Edith E. Williams of Brookline, for work on the literature of the subject.

All the illustrations are original, and prepared expressly for this work. Unless otherwise stated, they are of nearly natural size, and are figures of concretions in the "Stone-Arms Collection," which numbers fourteen hundred specimens.

Figs. 1, 4, 5, 29, 31, 48, 50, 86, 88, 90–92, are drawn by Katharine Peirson Ramsay, and figs. 3, 11, 49, 93-96 by L. R. Martin, Assistant in the Museum of the Boston Society of Natural History.

The photographic work has been done by F. S. and M. E. Allen of Deerfield; to all these co-workers I am deeply indebted for their persistent and painstaking efforts.

Although the heliographic work of Messrs. Hart and Von Arx of New York is too well known to need commendation, I cannot forbear to express my thorough appreciation of their skilful and extremely accurate reproductions.

J. M. ARMS SHELDON.

CONCRETIONS FROM THE CHAMPLAIN CLAYS OF THE CONNECTICUT VALLEY.

PART I.

Observational and Descriptive.

MY observations on concretions in situ have been made at various places in the Connecticut Valley from Dummerston, Vermont, to Deerfield, Massachusetts, inclusive, a distance of about thirty-five miles. Besides these observations on concretions in their own abiding-places, I have spent some time upon a collection of interesting forms from Windsor and Hartford, Connecticut, given by Miss Rosa Bolles Watson of East Windsor Hill, Connecticut, and another collection from Ryegate, Vermont, contributed by John Ritchie, Jr., of Boston.

The towns lying on the right bank of the river within the distance mentioned are Dummerston, Brattleboro, Vernon, a small part of Northfield, Gill, Greenfield, and Deerfield; on the left shore lie Chesterfield, Hinsdale, the major part of Northfield, Montague, and Sunderland. I have found few clay beds exposed on the right bank, it being either green with vegetation, sandy or rocky, but on the left bank the beds are numerous.

It is only in seasons of drought when the Connecticut is lowest that the concretion collector is successful. The necessary equipment for collecting is a good boat, a shovel, trowel, and stout carving-knife; rubber boots; boxes and wrapping paper for packing away the concretions. When exploring on the river, one is first attracted by the peculiar blue color of the clay, which can be seen at a considerable distance. In some places, as between the two ferries, known as Rice's and Whitmore's, on the left bank in the town of Montague, the clay occurs interstratified with sand; in others, as on the right bank at Sunderland bridge, it forms projecting shelves into the stream which are often thickly strewn with concretions that have fallen from clay layers above in times of high water.

Again, as at the mouth of Saw Mill River, a little stream that empties into the Connecticut in the town of Montague, the clay forms a low wall which rises perpendicularly from the water. In the summer of 1878 this wall was much higher than at present; it was, in fact, one of the finest exposures to be seen in all the region. Stratification planes cut it horizontally, and joint planes obliquely, while the peculiar bluish color presented a striking contrast to the green vegetation above and the sparkling waters below. The concretions were exposed only at the water's edge, where there was no possible way of getting them excepting to stand in the river and dig, a trowel or stout carving-knife being the best implement for the work.

In collecting concretions along the bank it is better to row up the stream than down, for in the latter case the dislodged clay renders the water so turbid it is impossible to see the concretions that may have been brought down by the floods, and which may show new forms and be guides to beds containing them higher up the river.

It is of the greatest importance that the concretions of each clay bed be kept by themselves. The word "bed" is here used in the sense of an exposure or outcrop. The beds are made of many layers, and these consist of many laminæ. When the concretions of the different beds are kept separate, the interesting fact is proved that each clay bed has a form of concretion peculiar to itself. One never finds, for instance, a watch-shaped concretion (like that represented in Pl. I. fig. 1) and a cylindrical or club-shaped concretion (Pl. I. fig. 2) embedded together, or a botryoidal mass (Pl. I. fig. 3) and an animal form (Pl. I. fig. 4). These are four typical concretions of as many separate beds.

While each bed has its characteristic form, this is not attained with an unvarying degree of perfection. There seems to be an ideal and a struggle to attain it; the resulting concretions being more or less perfect as the conditions are favorable or adverse. When the conditions are favorable and constant, the typical form is repeated many times. One of the striking examples of this fact was found in a bed near the west landing of Whitmore's ferry in the town of Deerfield. Out of twenty-six specimens collected, twenty-four had the same peculiar crescent-shaped markings (Pl. I. fig. 5). One of the two exceptions I have little doubt was the incipient form of the others, and would have grown to be like them in time had it been left undisturbed. The other concretion was not found embedded, but was picked up from the surface of the clay bed; it was colored brown by carbonate of iron, so that I am confident it was washed from some bed up the river and had been exposed long enough to become discolored.

I have seen forty-eight specimens from one bed so similar it was impossible to tell one from another.

Occasionally, in certain localities, the typical form is doubled or even trebled in a single specimen. Remarkable examples of such concretions were found in the clay bank on the north side of Saw Mill River, near its mouth. The typical form (Pl. I. figs. 1, 6) is wonderfully symmetrical. A number of these concretions, all remarkably perfect, were dug from the clay. A few were found like those of Pl. I. fig. 7, where it may be that two are approaching each other to form a double concretion. This view is strengthened by specimens in situ (shown in Pl. I. fig. 8, and Pl. II. fig. 9), recently taken from the same bed. This union is completed as shown in Pl. II. fig. 10.

The upper connecting layer which has just begun to form in Pl. II. fig. 10 is finished in Pl. II. fig. 11.

There also occurred in this bank a modification of the double form (Pl. II. fig. 12; compare with Pl. II. figs. 10, 11). Again this form appears to be trebled in Pl. II. fig. 13. A unique combination of the double form with the single-type form is seen in Pl. III. fig. 14. Unfortunately the specimen is broken in its weakest part, the break showing in the figure, but when taken from its bed it was entire.

It is interesting to note in this connection that twenty-one years after these concretions were collected I visited the place again and took from the same bed the concretions figured in Pl. II. fig. 12a and Pl. III. fig. 14a (compare with Pl. II. fig. 12, and Pl. III. fig. 14) and many single forms like Pl. I. figs, 1, 6. This proves that in one bed, at least, the typical form may be found after a period of more than a score of years.[1]

Another series might be given, one of which is shown in Pl. III. fig. 15, where the only markings are two lines running along the outer edge. The resemblance of this concretion to a child's worn-out shoe is striking.

Many of the clay beds fail to yield proportionately so many perfected forms as in the cases just described. Pl. III. figs. 16–20 represent concretions from a bed a short distance north of Sunderland bridge on the west bank, where the flattened disc marked by a deep circle (Pl. III. fig. 20) is the completed form. It would seem, however, that the conditions were not favorable for the frequent production of the complete form, since the majority of the specimens are incomplete, only approximating more or less to the type form as seen in Pl. III. figs. 16–19.

In the process of growth it appears that the original circular concretion was surrounded by an additional broad ring (Pl. III. fig. 20). In Pl. III. fig. 16 two disconnected portions of this ring are formed, while in Pl. III. figs. 17–19 about two-thirds to nearly the whole ring is finished. A slight modification of this type is seen in Pl. IV. figs. 21–23, where that portion of the broad ring which has been formed is marked by a deep circular impression near the outer edge. In Pl. IV. figs. 21, 22 only about one-third and one-half of the ring is formed, while in Pl. IV. fig. 23 it is nearly completed.

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[1] I am indebted to Mr. Arthur E. Jackson of Deerfield for aid in collecting on Saw Mill River in the summer of 1899.

It sometimes happens that a clay bed produces concretions which may vary individually within certain limits, but which nevertheless bear a general resemblance to each other. Thus a thin layer of clay just south of the west end of Sunderland bridge yielded eighty-eight concretions, sixteen of which are represented in Pl. IV. fig. 24. There seemed to be an inexhaustible supply of these queer little images, — fishes, birds, ant-eaters, elephants, dogs, babies' feet, — as we found them abundantly so long as we dug. While they vary in detail, one cannot fail to see a marked general resemblance. There are, for instance, no stout clubs (Pl. I. fig. 2), or spectacles (Pl. II. figs. 10, 11), or disks (Pl. III. fig. 20) among them; they are all tiny in size and irregular in shape.

Another bed on the east bank of the Connecticut, a short distance south of Rice's ferry, yields larger irregular concretions which are bevelled on both sides to a sharp edge. One of these (Pl. IV. fig. 25) was taken from its bed while in the process of forming, and its surfaces are roughened by the clay which adheres tightly to them. These concretions assume various shapes like animals (Pl. IV. fig. 26), boots (Pl. IV. fig. 27), etc. But amidst the diversity certain characters remain constant, — the flattened form, irregular outline, and the sharpened edges. One specimen belonging to this group has, in addition to these characters, a perforation (Pl. IV. fig. 28).

The animal-like forms represented by the seal (Pl. I. fig. 4) or the goose (Pl. V. fig. 29) and the group (Pl. V. fig. 30) are taken from another bed. These have plump bodies, and rounded instead of sharpened edges.

I have already given several examples showing a preponderance of the typical forms in their respective beds. Many more examples might be offered, since this represents the normal condition.

I have also given three examples proving that sometimes a close general resemblance is preserved when the specific details of form vary.

Now let us consider a case where the completed form is reached only by one out of eleven concretions collected from the same clay bed. The symmetry and beauty of this single concretion (Pl. V. fig. 31) cannot be reproduced on paper, though no pains have been spared in the execution of the drawing. A wreath of variously colored sand grains and tiny pebbles surrounds the central portion, and for this reason I call it the wreath concretion. Eleven other concretions, as we have said, were found with this one, but some of them are far removed in degree of perfection from the typical form. Notwithstanding this is true, one need only glance at the eleven specimens, ten of which are represented in the group (Pl. V. fig. 32) to see that they are more nearly related to the almost perfect type-form than to any other group. The conditions, however, for the frequent production of the wreath concretion in this clay bed are certainly very unfavorable.

All the concretions so far considered have been comparatively simple forms. By examining these first we are better able to understand the complex concretions, such as are illustrated by Pl. VI. fig. 33. The process of growth of this interesting form of concretion is shown in the series represented by Pl. VI. figs. 34–47. At the upper left-hand corner is the original form, which appears to be the first stage (Pl. VI. fig. 34). The slender, gourd-shaped concretions (Pl. VI. fig. 35) and the stouter form (Pl. VI. fig. 35′) are similar to the simple concretions we have already been considering. The two parts of which Pl. VI. figs. 35, 35′ are made up become modified until a third middle portion is formed (Pl. VI. figs. 36, 37, 38 and 36′, 37′, 38′). Examining Pl. VI. figs. 39–43, it is seen that Pl. VI. figs. 35 and 36′ are repeated again and again in these complex concretions. There are numerous variations; the part, for instance, corresponding to the body of the gourd is often large (Pl. VI. figs. 40, 41, 43), while the handle may be small.

The process of growth continuing, new little gourds like those in Pl. VI. figs. 35 and 36′ are added on the edges (Pl. VI. figs. 42–44) until these become surrounded and are found in the interior of the concretion (Pl. VI. figs. 45, 46). Oftentimes the largest specimens of this kind, like Pl. VI. fig. 47 (which is broken at both ends and also reduced about one-half) show the formation less clearly than those of medium size (Pl. VI. fig. 45.) The lines are often so obscure, in fact, that only the little gourds on the edges reveal what special form the concretionary process tends to produce. This series was selected from a miscellaneous collection of 210 specimens, of which 128 showed the little gourds distinctly and 23 indistinctly, while in 22 concretions they could not be made out, owing to the indefiniteness of the lines. The remaining 37 concretions were wholly unlike the others, and doubtless came from different clay beds.

The little gourds on the edges of the concretions are fastened tightly to the main body, as proved by the fact that although the collection of 210 specimens above referred to had been dumped into a pail without any special care, only five of the gourds were found broken off at the bottom of the pail. Amusing caricatures are sometimes found among these complex concretions (Pl. VI. fig. 48). If this figure is turned upside down, a second head appears. Another related form, although not so much flattened, is represented in Pl. VI. fig. 49, the head of which is seen alone in Pl. VI. fig. 50.

Long concretions are probably made by the coalescence of several lying in a straight line. The longest concretion in our collection measures twenty-two inches, and this is not complete, since in digging it from the clay it was broken and the end could not be found.

Still greater irregularity in form than has yet been described is shown in Pl. VII. figs. 51–55, and the irregularity is increased in the group Pl. VII. figs. 56–60, where it would seem as if the concretions were built up by a method of daubing or plastering. These concretions are from Ryegate, Vermont. I have never found any specimens like them. Possibly, if a larger number were collected, the prevailing tendency might be discovered, and order brought out of apparent confusion.

A unique concretion, perhaps belonging to the above group but differing in some ways from any other concretion I have ever seen, is now in the Museum of the Pocumtuck Valley Memorial Association at Deerfield. I am indebted to the president of this association, Hon. George Sheldon, for the opportunity of photographing this specimen and other instructive concretions in the society's collection.

The locality from which the concretion was obtained is unknown, but for various reasons it is presumably from the bank of the Connecticut; its reddish tint and general aspect being similar to those collected farther down the river in the State of Connecticut. This concretion (Pl. VII. fig. 61) is made up of rounded nodules overlaid in part by an indefinite number of clay laminæ. These laminæ tend to fill up the hollows and to embrace the rounded nodules. Their numerous edges are exposed, giving an excessively irregular patchwork appearance to the concretion.

The reddish-colored specimens from Windsor and Hartford seem to fit in here, if we have the right to judge from the limited number in our possession. These I did not collect myself, so that I am ignorant of the exact conditions under which they occur. They illustrate the method of plastering (Pl. VII. figs. 62–64), although oftentimes there is an effort to preserve symmetry. The two specimens (Pl. VII. figs. 65, 66) are interesting in this connection. On the convex and probably the upper side (Pl. VII. figs. 65, 66) there are many patches of clay, while on the flat and probably the lower side (Pl. VII. fig. 67, flat side of Pl. VII. fig. 65; fig. 68, flat side of Pl. VII. fig. 66) the pattern is marked. In one specimen (Pl. VII. figs. 65, 67) the effort seems to be to surround the previously formed concretion with rings of clay, while in the other specimen (Pl. VII. figs. 66, 68) the effort is to build out horizontally in four directions. Greater symmetry is attained in Pl. X. fig. 69, where one process of forming new rings is indicated.

All the concretions so far described which I have collected have been taken from clay beds on the banks of the Connecticut. It must not be supposed, however, that these nodules are restricted to the banks of the river. A few years ago Miss C. Alice Baker called my attention to a fine exposure on one of the rounded hills in Great River or East Deerfield, which is reached by the beautiful wooded road running from Old Deerfield Street, over East Mountain to Rice's ferry. This hill is a quarter of a mile from the Connecticut River and about seventy feet above it. The southerly exposure (Pl. VIII., from the front; Pl. IX., from the side) shows that the hill is largely composed of clay which has been baked until it has become jointed. This clay consists mostly of dark and light colored layers, with an occasional layer of sand. The dark clay has been used for modeling, while the light is too friable for this purpose. The latter sometimes has a gritty feel, indicating the presence of more or less sand. The dark-colored layers are harder than the light, so that they resist the action of the weather, and form little shelves (see Pl. VIII.) in the gullies or miniature cañons cut in the face of the hill by the rivulets of rain. Notwithstanding the fact that this hill is a quarter of a mile from the Connecticut, concretions are found in it in considerable numbers. As a rule they are small in size and more or less spherical in shape. The largest sphere I have ever found was taken from this hill. It occurred between two layers and not in a layer, and is represented in Pl. X. fig. 70, nearly natural size. Most of the balls are much smaller. They are single (Pl. X. fig. 71) or in twos (Pl. X. fig. 72) and threes (Pl. X. fig. 73) or in clusters (Pl. X. fig. 74). Small, somewhat flattened forms (Pl. X. fig. 75) occur, but they are rare, and are probably confined to a few thin layers of clay that do not contain much sand.

Some of the brooks which empty into the Connecticut offer interesting concretions. Canoe Brook, in Dummerston, Vermont, after leaving the hills has high clay banks which slope away on either side. These banks contain similar concretions, those from the left bank being represented in Pl. X. figs. 76–78, and those from the right by Pl. X. figs. 79–81. They are extremely irregular in outline and gritty in feel. At a point on this brook eighty rods from its mouth we found in the gravelly bank of the north side a large number of the concretions which the rains had washed from the high clay bank above. Here they may be collected by hundreds. Among them the form which reminds one of the cameo brooch (Pl. X. fig. 82) is not uncommon. I am indebted to my helpful friend, Giles F. Reed, and to my keen-eyed six-year-old collector, John E. Walker, for valuable aid while exploring this part of Canoe Brook.[1]

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[1] Since this paper was prepared, Miss Emma L. Coleman, of Boston, has handed me several dainty specimens, collected by herself many years ago on the bank of the Deerfield River, at the northerly extremity of Pine Hill, in Deerfield North Meadows. Four years ago I found the spot entirely overgrown with weeds and brush.

The prevailing form of the concretions is almond-shaped, one side being plain, and the other marked with a circling line about a quarter of an inch from the edge. The texture is extremely fine and homogeneous, resembling in this particular the concretion figured on Pl. I. fig. 5.

PART II.

Historical, Experimental, and Theoretical.

[The number after the name of an author refers to a corresponding marginal number under the head of Literature, p. 39.]

WE have been dealing so far with concretions as they are found in situ, or as they occur when washed from their beds. Observation of such forms and of the conditions under which they exist has suggested and helped to answer the three important questions: —

First, What are these concretions?

Secondly, How are they made?

Thirdly, What determines the shape of a concretion, and why does each clay bed produce its own peculiar form?

The first question, What are these concretions? has been answered in various ways. In 1670 they were observed when, according to Hubbard (37), an accident fell out "at a place called Kennebunk at the northeast side of Wells in the province of Maine, not far from the river side, a piece of clay ground was thrown up by a mineral vapour (as is supposed) over the top of high oaks that grew between it and the river. The said ground so thrown up fell in the channel of the river, stopping the course thereof, and leaving an hole forty yards square in the place whence it was thrown, in which were found thousands of round pellets of clay, like musket bullets. All the whole town of Wells are witnesses of the truth of this relation; and many others have seen sundry of these clay pellets which the inhabitants have shewn to their neighbours of other towns."

October 11, the same year, John Winthrop (78), Governor of Connecticut, writing to Lord Brereton concerning "the strãge & prodigious wonder," says: "The relation w^{ch} I have frõ credible persons concerning the manner of it is this: That the hill being about 8 rods frõ Kennebunke rivers side, on the west side of the river about 4 miles frõ the sea, was removed over the drye land about 8 rods, and over the trees also, w^{ch} grew betweene the hill & y^{t} river, leaping over them into y^{t} river, where it was seene placed, wth the upper part downward, & dammed up y^{t} river for a tyme till the water did worke its selfe a passage thorow it. The length of the hill was about 250 foote, the breadth of it about 80 foote, the depth of it about 20 foote. The situation of the hill as to the length of it was norwest & southeast. The earth of it is a blew clay wthout stones, many round bullets of clay were wthin it w^{ch} seem to be of the same clay hardned. . . . I had from them [Major William Philips and Mr. Herlakendine Symonds] some few of those round bullets, & small pieces of the earth in other forms, w^{ch} were found vpon that now vpper part w^{ch} was before the lower, or inward bowells of y^{e} hill, as also a small shell or 2 of a kind of shellfish vsuell in many places of the sea, but how they should be wthin y^{t} hill is strãge to cõsider. I have sent all y^{t} I had of thẽ amongst other things to y^{e} Royall Society for their repository."

The following spring (Apr. 11, 1671) Governor Winthrop received a letter from Henry Oldenburg to this effect: "I soon delivered to the said Society [the Royal Society] their parcel, viz: the shellfish (called horsefoot) the Humming Birds nest, with the two eggs in it, being yet whole, the feathered fly, and the shells, bullets and clays taken out of the overturned hill, for all which that noble company returns you their hearty thanks. . . . Concerning the overturned Hill, it is wished that a more certain and punctual relation might be procured of all the circumstances of the accident." Bourne (8), from whom the last extract is taken, goes on to remark that "No intelligent person of the present day can hesitate a moment as to the explanation of this strange event. The same thing has occurred several times within the last fifty years. Oak trees then stood all along the banks of the rivers, and this wonder was one of those avalanches from the banks which have been of so frequent occurrence. . . . The little pellets, which were spoken of as seen after the slide, *were rolled up by the avalanche as it passed over the solid ground beneath.*" (The italics are mine.)

In 1734 the Journal Book of the Royal Society, Vol. XV., contains a catalogue of Natural History objects found in New England by John Winthrop (79), in which is this item: "Clay generated in the form of horseshoes from the bottom of Connecticut River." These "horseshoes" were doubtless concretions (see Pl. VII. fig. 67).

The most fully illustrated paper on concretions that I have seen is that of M. Parrot (55; see also 73), published in 1840. This author maintained that the concretions were organic in their origin, being probably the petrifactions of the soft bodies of some kind of mollusk.

Another view is reported by Professor Edward Hitchcock (33) in 1841, who speaks of receiving a concretion from an able English geologist, labeled "Kimmeridge Coal Money (use and age unknown,) found abundantly in the Kimmeridge Clay, Dorset Coast. — Supposed turned in a lathe and anciently used as money."

There are honest folk at the present time who think that many of these peculiar forms are fossil animals which lived in some prehistoric age. As recently as 1889 a concretion (figured in Pl. X. fig. 83) was sent to the Boston Society of Natural History with an explanatory letter, a portion of which ran as follows: "The accompanying letter will tell why I now address you. Herewith please find a specimen of petrified organic matter in the form of a *turtle;* some say *toad*, which I desire to have classified. It must have passed through three terrible ordeals, clay bed, brick machine, and fire. I will give you the history of the find in brief. In Bridgeport, Conn., in the autumn of 1874 curiosity called me upon a pile of brick which some laborers were moving on the wharf, and as I made a casual glance towards the men, one of them dropped a brick which broke in two equal parts, and being very near I noticed something protruding from one of the halves of the brick, when I jumped down, picked up the half, and to my astonishment found it was the accompanying specimen, one half out of his shell, the *brick*. I soon dislodged him from his situation, and gathered up the other half of the brick, and took the two parts to the store of a friend, where I left them, as they were cumbersome, and at that moment I thought them of no consequence, but since I have experienced sorrows and regrets for not preserving the two pieces of brick which would demonstrate beyond all question; but, however, the story is a fact all the same. I have always held the specimen valuable as a curiosity among some other little matters, and seeing a paragraph in the Boston Record which said some one had bought a specimen of a petrified turtle, — and the only one known, — for which he paid $40.00, I brushed the dust from my specimen in order to get its value and classification in its once animated form. Awaiting your decision, I am," etc.

These views and others mentioned by M. Virlet (73) and Gratacap (24) have influenced the popular mind. It is indeed surprising to find how general is the belief, outside of the strictly scientific circle, that these concretions, "claystones" or "clay-dogs" as they are called, are made of clay which has been worn into shape by running water.

A short and direct road to the solution of this part of the problem is found in chemical analysis. The following results I obtained from a series of analyses made to ascertain approximately the percentage of carbonate of lime or calcium carbonate in the concretions and in the clay immediately surrounding them.

Concretion, Deerfield, west end Whitmore's ferry.— Calcium carbonate ($CaCO_3$) in concretion, 42 per cent.
Calcium carbonate ($CaCO_3$) in clay surrounding concretion, 2 to 3 per cent.
Concretion, Deerfield, south of Sunderland bridge, west bank. — $CaCO_3$ in concretion, 43 per cent.
$CaCO_3$ in surrounding clay, 2-3 per cent.
Concretion, Brattleboro. — $CaCO_3$, 42 per cent.
Concretion, Hartford. — $CaCO_3$, 47 per cent.

Professor Hitchcock (33) gives four analyses, thus: 42.1, 48.4, 49.9, and 56.6 per cent of calcium carbonate. The last is an analysis of a concretion from Hadley, and the amount of the carbonate is large.

Professor C. B. Adams (1) publishes a number of analyses of concretions from different towns in Vermont in which the percentage of carbonate of lime runs as follows: claystone, Dummerston 51.08; Addison 45.09; Alburgh 53.17; Pittsford 42.88; Derby 49.66; Shelburne 52.58; Norwich 44.84.

T. Sterry Hunt (38) got the following results from analyses of concretions in the same State. We give only the percentage of carbonate of lime, with one exception. Ryegate 40.2; Bethel 40.9; Pittsford 44.3; Rutland 44.4; Norwich 40.8; Sharon 43.3; Ryegate 35.8. The last is an analysis of a concretion which contained 64.2 per cent of coarse sand and clay.

These figures prove that the quantity of calcium carbonate in these concretions, though not definite, does not greatly vary. We may say that about half a concretion is made of this substance, while the remainder, as shown by the analyses on p. 29, is largely either clay or sand (silicate of aluminum or silica).

In answer to the first question, What are these concretions? it may therefore be said that the concretions with which we are dealing are usually hardened masses composed largely of calcium carbonate and clay and having a more or less definite form. The essential difference between the concretion and the clay immediately surrounding it, as shown by the analyses on p. 20, is the small percentage of calcium carbonate in the latter compared with that in the former. The concretion really robs the clay around it of its lime.

In order to answer the second question, How are these concretions made? we must consider briefly the theory of concretionary structure which is now almost universally accepted by naturalists.

According to this theory the particles or molecules of certain substances, calcium carbonate for instance, when held in solution tend to flock together. This process of flocking together is called segregation. When, for one reason or another, a tiny particle of calcium carbonate has been precipitated in a solid form, this particle acts as a centre of attraction, and draws more calcium carbonate to itself. If the process were not hindered in any way, as for instance by the presence of a foreign substance, the resultant form would be a crystal of calcium carbonate. But if a foreign substance, such as clay, be present which the particles of calcium carbonate are not vigorous enough to push one side, then the calcium carbonate is deposited between and around the clay particles, and the resultant form is a concretion made chiefly of calcium carbonate and clay. This is a general statement in regard to the concretionary process. We naturally seek to know more than this gives us of the history of a concretion. Whence came the Champlain clays, the homes of the "claystones"? Whence came the carbonate of lime or limestone disseminated through these clays? What caused the carbonate of lime to dissolve and afterward to be deposited in solid form? What is the subtle force that binds the particles of an inorganic substance together?

While some of the details of this history are as yet unknown, others are well established. The Champlain clays originated by the decomposition of old feldspathic rocks. A vast amount of this decomposed clayey material together with sand and gravel was brought down from higher latitudes by glaciers. The warm climate which followed the arctic winter of the glacial period caused the melting of the ice, and large areas of land were in consequence covered by water. In these quiet seas the Champlain clays were deposited. Subsequently the region rose, the deposits became, in part, dry land, and rivers cut their way downward through the clay strata to the depth of many feet.

Analyses of these drift clays deposited during the Champlain period prove that they are not made of pure kaolin, but that they consist of various substances. According to Blatchley (7), the drift clays of Indiana show the presence of as high as 40 per cent of calcareous material. This is due, says this writer, to the grinding up and mixing with the clays of much of the surface limestones over which the glaciers passed. These eroded limestones and the clays were ground into an impalpable powder or "rock flour." [On this subject see also Crosby (11) and Shaler (64).]

Cooke (10), in his analyses of the Tertiary marls and clays of the Maltese islands, found the quantitative variations of the several components of the rock to be considerable, as shown by the following table:—

Carbonate of lime, 2 to 67 per cent.
Sulphate of lime, 4 to 30 per cent.
Carbonate of magnesia, faint traces to distinct traces.
Phosphate of lime, traces to 2 per cent.
Alumina, 25 to 58 per cent.
Oxides of iron, 4 to 10 per cent.
Residue insoluble in dilute hydrochloric acid, 3 to 10 per cent.

[See also analyses by Murray (51).]

It is evident from the analyses already given that most clay contains more or less calcium carbonate in a solid form; how does this solid carbonate pass into a liquid state?

It is well known that all rocks, not excepting the so-called "impervious clay," allow the passage of percolating waters. The joints and irregular cracks in the clay are the highways for these ground waters from which they spread throughout the denser strata. In passing downward from the surface they come in contact with more or less decomposing organic matter which is giving off carbon dioxide, commonly called carbonic acid gas; the latter is taken up by the percolating waters, which thereby are able to dissolve the calcium carbonate. Julien (41) has pointed out that not only carbon dioxide but probably the humus acids — a complex group of the products of organic decay — play an important part in the solution of the calcium carbonate and in the origin of the concretions, as is stated more fully farther on (see p. 24).

It is easy to see that the ground waters must be subject to constant changes. They are influenced by seasons of drought and rainfall, by the quantity of carbon dioxide or other solvents present, by the amount of calcium carbonate in the clay matrix, and doubtless by other causes. Some of the changes would tend to bring about the solidification or crystallization of tiny particles of calcium carbonate, or, it may be, a saturated solution of this substance would deposit some of its calcium carbonate on already existing particles.

Questions arise concerning the exact process which are at present unsettled. Nichols (53) has shown that it is difficult to see why periods of solution and deposition of calcium carbonate corresponding to the changes in the character of the solvent waters "should cause the segregation into concretions of the previously scattered particles, for it is to be expected that deposition of material would take place upon the separate particles in the same ratio as solution, so that their relative sizes would be preserved, even though each increase or diminish in weight. At first thought it may seem that some particles may be more favorably situated than others, but here also those most favorably situated to receive material during periods of deposition will be most favorably situated to lose material during periods of solution." The writer continues: "If alternate solution and deposition by the solvent waters were alone sufficient to cause segregation and the formation of concretions, then the calcium carbonate in all calcareous clays and shales should be in the form of concretions. There is, however, an abundance of occurrences of calcareous clay and shale where the calcite yet remains disseminated."

An explanation for these phenomena Nichols finds in the modern theories of saturated solutions, which he maintains should be applied to this problem in the way that chemists have already applied it to the growth of crystals. "There are two conditions which, in the light of these theories," he says, "appear favorable to the formation of concretions. These are: (1) The presence of aragonite with the disseminated calcite of the clay beds; (2) the presence of the unstable humus acids."

Carbonate of lime occurs in clay beds in two forms, as aragonite and calcite. Aragonite is more soluble than calcite and therefore is dissolved first. It is well known to chemists that a saturated solution of aragonite deposits calcite, not aragonite, and it follows that this calcite would be attracted towards and be deposited on the already existing solid particles of calcite scattered through the clay bed.

According to this theory concretions owe their origin to the greater solubility of aragonite and the transformation of this aragonite into calcite. The second condition favorable for the production of concretions, as pointed out by Nichols, is the presence of the humus acids in the percolating waters. Certain modifications of this complex group of acids have a strong solvent action upon calcium carbonate, while other modifications render it nearly insoluble. The acids are so unstable that they are constantly undergoing changes. When they lose part of their solvent power they become supersaturated with calcium carbonate and deposit it upon the existing solid calcite particles, thus causing the concretions to grow.

The question, What is the subtle force that draws the particles of an inorganic substance together? cannot be answered satisfactorily. Call this force by what name we may, — chemical attraction, affinity, electrical agency, — it surely challenges our profoundest thought. Its origin unknown, its modus operandi imperfectly understood, it nevertheless is found operative throughout both inorganic and organic nature; for as we rise in the ascending scale of life, we find this power exhibited in varying degrees in the different groups of living organisms, until finally we reach human life, the most complex manifestation of organic nature, where its most perfect and most potent expression is in the life of the family and the larger life of the race.

It has been generally believed that every concretion has a centre of attraction or nucleus *of appreciable size*, like a shell, pebble, etc. Such a specimen with a good-sized pebble at its heart is seen in Pl. X. fig. 84. Weathering has caused the concretion to split in two, exposing the pebble in one half and the corresponding concavity in the other (Pl. X. fig. 85). Dr. Hall (26) speaks of concretions having for a nucleus a bit of iron pyrite, a shell, or a crystal of carbonate of lime.

With the aid of Professor W. O. Crosby, a concretion from the mouth of Saw Mill River was sawed in two vertically and polished (Pl. X. fig. 86). Lines of stratification were distinctly seen, but with this exception the mass looked perfectly homogeneous. There was not the slightest evidence of a nucleus or of concentric structure; the latter, however, developed gradually after long exposure to the air. One of the halves was sawed in two again, giving a sharp angle which proved the extreme fineness of the material. A quarter was etched in hydrochloric acid, and while this brought out a concentric structure, it did not reveal a nucleus. Little spherical cavities were seen, as if the tendency to concretionary structure was so great that the concreting material was not satisfied with forming one large concretion, and so made smaller ones within the larger. I also dissolved a concretion in hydrochloric acid and examined the insoluble residue upon a filter. It was impalpably fine clay, and no foreign particle of any appreciable size was present. Professor Hitchcock (33) says on this subject, "In no case in Massachusetts have I seen an organic relic as a nucleus." In 1859 Mr. Charles Stodder (66) exhibited at a meeting of the Boston Society of Natural History two concretions cut open, one showing a nucleus less than one sixteenth of an inch in diameter, while the other was without a visible nucleus. In the light of these facts it seems safe to say that many concretions have no nucleus of any appreciable size, though they may have one in the form of such a minute crystal of calcium carbonate that it cannot be detected by the eye. Professor B. K. Emerson (19), after stating that so far as all the Connecticut Valley concretions are concerned, the "initiating cause entirely eludes our observation," points out that in exactly similar concretions from other localities a nucleus exists in the form of organic matter. This nucleus in some cases is hermetically sealed and decomposition is thereby arrested; in other cases it is probably "wholly dissipated into liquid or gaseous compounds before the concretionary process is far advanced." "Such a nucleus, now wholly vanished," according to Professor Emerson, "may have determined the beginning of the concretions we are discussing;" and he finds proof for this theory in the fact that a distinct residue of inflammable organic matter was found in the analyses of these concretions made by Professor Hitchcock. (See Hyams' analysis, p. 30.)

We have spoken of the lines of stratification running through the concretion, and these have been seen in the vertical section of the Saw Mill River specimen (Pl. X. fig. 86). These stratification lines often run with unbroken continuity through the concretion and its surrounding clay. This is shown in Pl. X. fig. 87; *x* is the line of stratification which represents the thin lamina of reddish clay (Pl. X. fig. 87, *x′*) that is rendered more conspicuous than the other laminæ by its red color. This fact that the layers are continuous proves that the concretion was formed subsequently to the deposition of the clay, and that the concretionary process went on so quietly that the layers of stratification were not disturbed. When concretions have been exposed to the action of the carbon dioxide in the atmosphere, or, in other words, have "weathered," the edges of the laminæ are often brought out clearly (Pl. X. figs. 88, 89), and sometimes the specimen breaks into separate layers. Pl. X. fig. 90 is an unusually fine illustration of such weathering, showing how very evenly the upper layer has split off from the lower layers.

Sometimes the concretionary process ceases while in the very act of making a concretion, and then, after a longer or shorter period, begins again. In such a case the resultant form when weathered and broken shows the different stages of growth. This is seen in Pl. XI. fig. 91, where about one half of the upper layer has been taken off, thus exposing a portion of the central circular concretion that was first formed. In Pl. XI. fig. 92 nearly half of the same specimen has been broken away, revealing still more of the first-formed concretion. Pl. XI. fig. 93 is a specimen that has weathered in a different way. The first-formed concretion, represented by the central portion of Pl. XI. fig. 93, has separated from the later-formed portions (Pl. XI. fig. 94), and has split into layers. Thus the central part of Pl. XI. fig. 93, when removed and turned over, is shown in Pl. XI. fig. 96. The remaining central portion removed is represented in Pl. XI. fig. 95. These two figures (Pl. XI. figs. 95, 96) have peculiar markings which remind one of the impressions of fossil medusæ that Walcott (74) has recently discovered among the Cambrian rocks. I have not a sufficient number of these specimens for comparison and study to offer any explanation of their interesting markings.

Sometimes the different stages of growth are marked off from each other by a decided difference in color (Pl. XI. fig. 97), or by a difference in texture; when these specimens weather, they often show the different stages finely, as seen in Pl. XI. fig. 98, which represent Pl. XI. fig. 97 split in two.

We now come to the third question, What determines the shape of a concretion, and why does each clay bed have its own peculiar form? We will first consider a case where the conditions are most favorable for the production of concretions. We need, in such a case, a bed of sand, not clay, through which water percolates containing calcium carbonate in solution. As already stated, a particle of this substance, deposited in solid form, acts as a nucleus which draws to itself other particles of calcium carbonate. We have already pointed out (see ante, p. 21) that if this process continued without interference the result would be a crystal of calcium carbonate with even surfaces and sharp angles. It happens, however, with the sand as with the clay, that its grains are not forced out of the way, but remain in place, and are surrounded by the carbonate, so that instead of a crystal, a concretion results composed of carbonate of lime and sand.

The bed of sand is porous, and is usually made up of thick layers, so that the water holding calcium carbonate in solution can percolate freely in every direction. The concretion, consequently, grows on all sides, so that the resultant form is more or less spherical. This is the normal shape of concretions taken from sand beds. A fine illustration of such a spherical form is given by Worthen in Hall and Whitney's Geology of Iowa (27 and 81).

The conditions in clay beds, on the other hand, are very different from those of sand beds, and the concretions are therefore obliged to adapt themselves to circumstances. The clay is a compact mass through which, as compared with sand, water percolates with difficulty. The clay beds are made up of many layers (Pl. XI. fig. 99) which spread out horizontally, but which are, as a rule, much thinner vertically than the layers in a bed of sand. The water holding calcium carbonate in solution finds difficulty, as already stated, in percolating through the exceedingly fine material, but it makes its way laterally in one layer, or between two layers, with greater ease than vertically through several layers. As a result the concretion spreads out laterally, as seen in the embedded specimens (Pl. XI. fig. 100; Pl. XII. fig. 101), and also in Pl. XII. figs. 102, 103, where the top layer has been taken off.

Unless the concretions are of small size, like those from the clay hill at Great River (Pl. X. figs. 71–74), they are almost invariably flattened. This is shown by nearly all the concretions in our collection.

The concretionary tendency is so strong that it operates even when the conditions are so adverse that only crude, shapeless masses result such as is seen in Pl. XII. fig. 104. Although there are several centres of attraction, the whole mass is most imperfect. Another specimen (Pl. XII. fig. 105) seems to be in an unfinished condition, the lower unsymmetrical portion being nearly as hard as the upper more symmetrical part. In Pl. XII. fig. 106, there are two partly finished concretions with a shapeless mass of hardened clay between. Sometimes the irregularity is increased by the gravel stones that are partly or wholly surrounded by the concreting material (Pl. XII. figs. 107–109), which in some cases overlap the sharp edges of the rock fragment (Pl. XII. fig. 109).

We have already shown that the comparative thinness of the clay layers produces the flattened form of concretion. We had what was apparently a mass of clay composed of three distinct layers. When the specimen was broken in two, as shown in Pl. XIII. figs. 110, 111, there was revealed a concretion (Pl. XIII. fig. 111) in the process of making. The concavity into which the concretion fitted is seen in Pl. XIII. fig. 110. The middle layer containing the concretion was darker colored than the layer above or below, so that its vertical thickness could be easily measured.

This specimen is especially interesting as showing that some concretions, at least, are in a plastic state for a longer or shorter time before hardening. The concretion could be broken easily, being in this respect totally different from any other concretion I have collected. Analyses of this concretion and of the light and dark-colored layers of clay are given on p. 34.

In our collection the concretions from Brattleboro are among the thinnest (Pl. XIII. fig. 112, vertical view; fig. 113, horizontal view), and some of those from Hartford are the thickest (Pl. XIII. figs. 114, 115). The "baby's head" (Pl. XIII. fig. 116) which was found in a Deerfield clay bed comes nearer the Hartford specimens in point of thickness than any of the other concretions collected.

All the Brattleboro concretions that I have seen are irregular in outline and are bevelled to a rounded edge. They are not marked by lines of ornamentation of any kind. Their homogeneous texture, slippery feel, and bluish color show that they are remarkably free from sand grains or other foreign matter.

Another unique form of a flat concretion differing from any other in our collection is represented in Pl. XIV. figs. 117, 118. They are taken from a clay bed on the east bank of the Connecticut, nearly opposite the village of South Vernon. These concretions are of nearly the same thickness throughout, which is unusual. The edge is not bevelled, as in most cases, but is at right angles to the horizontal surface (Pl. XIV. fig. 118), like the tire of a wagon wheel or the milled edge of a silver dollar. One of these concretions (Pl. XIV. fig. 118) is interesting for another reason. One side, which is that shown in the figure, is marked by distinct concentric lines showing that the concretion grew by the addition of successive rings in the same plane.

Another important determining cause of the shape of a concretion is the varying amount of dissolved calcium carbonate in the different layers of clay. If, for instance, one layer is rich in this substance, and the layer above or below is poor in it, then one part of the concretion may be smaller than the other, as is the case with the Saw Mill River concretions (Pl. I. figs. 1, 6, 8; Pl. II. figs. 10, 11). Thus it is seen that the structure of clay masses has much to do with the shapes of concretions; nevertheless, it does not adequately explain why one mass should yield watch-shaped specimens, another spectacles, another animal forms, and so on.

It was with a desire to know more of the individual concretions of the separate beds in order to make comparisons between the different types, that I had several series of analyses made, which are given on p. 29.

This work has been done with painstaking care, and according to the most modern methods of chemical research, by Isabel Finzi Hyams, private assistant in the Massachusetts Institute of Technology, and for ten years assistant chemist in the State Board of Health Laboratory for water analysis.

These analyses were made with a view of ascertaining: first, whether similar forms taken from the same clay bed were alike or unlike in composition. Secondly, whether symmetrical and unsymmetrical forms had the same or different composition. Thirdly, whether there was a definite composition for a definite form, or whether the shape was wholly independent of the constituents. Fourthly, whether chemical analysis would throw additional light on the determining cause or causes of the different and peculiar shapes of concretions. I chose for these analyses four of the symmetrical specimens from the Saw Mill River bed, two of which were first photographed (Pl. I. fig. 6, and Pl. II. fig. 10); three irregular, unsymmetrical "east bank" forms, like those figured in Pl. IV. fig. 25; and three "river bottom" specimens (Pl. VI. fig. 33). These series represented the concretions taken from river clay beds; in addition to these I selected one series of three specimens of the spherical concretions (Pl. X. figs. 71–74) from the inland hill. The analyses in the first three series were made in duplicate to insure greater accuracy in the results.

The concretions ground in each case sufficiently fine to pass through bolting cloth were digested with hydrochloric acid [HCl (1: 1), that is, one part acid to one part water]. The insoluble residue was brought into solution by fusion with sodium carbonate (Na_2CO_3). The amount of this residue is given on the extreme left of the table.

After Treatment of Original Sample with HCl.	Residue	HCl.	* Res.	HCl.	* Res.	HCl.	* Res.	HCl.	* Res.	HCl.	* Res.	HCl.	* Res.	On Original Sample.
		SiO_2	SiO_2	Fe_2O_3	Fe_2O_3	Al_2O_3	Al_2O_3	CaO.	CaO.	MgO.	MgO.	MnO.	MnO.	CO_2
1 S. M. R.	Not Det	.15	27.88	3.53	.43	4.39	4.49	25.01	.71	1.05	0.0	4.58	0.09	21.76
1 S. M. R.	40.47	.24	27.97	3.04	.73	. . .	4.54	24.59	.69	1.12	0.5	4.56	0.05	21.60
2 S. M. R.	38.99	.21	28.21	2.74	.56	4.69	7.38	25.22	.88	1.76	.34	4.40	0.00	21.23
2 S. M. R.	39.10	.18	28.21	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	21.11
2 S. M. R., fused direct, *i.e.*, without dissolving in HCl.		28.	10	3.	39	15.	38	26.	79	1.	73	4.	32	. . .
3 S. M. R.	38.82	.15	29.11	3.71	.65	4.41	6.51	26.83	.91	1.98	0.00	5.25	0.00	21.60
3 S. M. R.	38.76	.13	28.94	3.66	.61	3.88	6.93	. . .	2.22	. . .	0.00	. . .	0.00	21.45
4 S. M. R.	38.44	.11	28.77	3.55	.46	4.45	6.23	. . .	1.83	2.01	0.00	. . .	0.00	21.18
4 S. M. R.	38.39	.16	28.94	3.61	.57	3.59	6.93	24.18	3.24	1.93	0.00	5.11	0.00	21.27
1 E. B.	25.91	.079	19.05	5.76	.44	5.00	5.19	29.13	2.34	. . .	. . .	5.44	0.00	25.51
1 E. B.	27.04	.063	19.06	5.66	.47	5.05	5.03	. . .	2.63	2.25	0.00	5.44	0.00	25.66
2 E. B.	26.81	0.00	18.74	5.40	.49	5.80	6.79	27.87	0.92	2.09	0.31	5.38	0.00	23.69
2 E. B.	26.83	0.00	18.64	5.59	. . .	5.91	. . .	27.45	0.97	1.55	0.23	5.36	0.00	23.84
3 E. B.	26.95	.18	19.10	5.78	.38	5.74	5.45	27.98	0.85	1.96	0.43	5.22	0.00	24.50
3 E. B.	26.96	.19	18.99	5.63	.41	6.01	5.29	28.36	0.95	1.89	0.43	5.41	0.00	24.57
1 R. B.	38.04	.22	27.73	3.61	.50	4.40	7.54	26.44	1.20	1.78	.16	4.32	0.00	22.60
1 R. B.	38.14	.35	27.30	3.20	1.02	. . .	6.24	24.88	.83	1.59	.47	4.25	0.13	22.52
2 R. B.	38.03	.29	26.40	3.43	.64	4.98	8.93	24.84	1.04	1.39	0.00	4.22	0.00	20.50
2 R. B.	38.16	.17	27.96	3.72	.50	4.56	7.33	26.51	.99	1.85	0.22	4.16	0.00	20.43
3 R. B.	38.50	.11	27.97	3.41	.58	4.54	7.66	27.63	.91	1.72	0.31	4.13	0.00	22.13
3 R. B.	38.46	.23	27.68	3.34	.64	4.59	7.66	26.59	1.89	1.77	0.35	4.11	0.00	22.23
1 G. R. Spheres .	40.53	30.36	.086	3.26	1.20	6.96	7.62	28.63	1.19	. . .	. . .	0.69	0.20	19.87 19.71
2 G. R. Spheres .	42.09	31.07	0.00	4.92	1.08	5.25	7.16	26.81	1.31	. . .	. . .	3.87	0.38	19.90 19.82
3 G. R. Spheres .	47.30	35.10	0.00	2.35	1.34	6.48	7.24	28.75	1.74	. . .	. . .	3.63	0.27	20.18 19.95
1 G. R., Light Clay	78.98	59.12	.18	4.74	0.5	6.77	12.82	1.02	1.23	1.85	0.62	1.97	Trace	1.47 1.34
2 G. R., Dark Clay	70.11	51.70	.20	8.02	0.79	10.35	10.08	0.97	. . .	0.51	0.76	.94	0.00	.30 .30
3 G. R., Enclosed Concretion	57.31	42.76	.17	12.65	1.01	15.95	9.54	1.18	1.89	2.09	0.00	1.10	0.00	.20 .18

* Residue from HCl solution fused with Na_2CO_3.

In both the hydrochloric acid solution and the insoluble residue the following substances were determined (excepting in the cases indicated by dots): silica (SiO_2); iron oxide (Fe_2O_3); aluminum oxide or alumina (Al_2O_3); calcium oxide or lime (CaO); magnesium oxide or magnesia (MgO); and manganese oxide (MnO).

It seemed better to give the results in the form of oxides rather than carbonates and silicates, since one cannot be absolutely sure that all the carbon dioxide is combined with the calcium to form calcium carbonate, as some of it may be united with the iron or the manganese. It is true we can calculate how much a certain per cent of calcium oxide will require of carbon dioxide to make the compound calcium carbonate, but this is an indirect and not absolutely certain method. Neither can it be told with certainty how much silica is combined with aluminum to form the silicate of aluminum, since it is probable that the silicates are mixed.

The carbon dioxide, expelled by boiling hydrochloric acid, was determined in duplicate in all the samples. The per cent of alkalies (Na_2O and K_2O) was determined in two samples by fusion with calcium carbonate, according to the J. Lawrence Smith method, and 2 to 3 per cent was found. The determination in the other samples seemed unnecessary.

The concretions were also tested to see if any of the silica was in the form of hydrated silicic acid, but it was not; a part was sand, and a part was combined with the bases of the clay.

The trace of water present in the concretions was not determined. One concretion was tested for titanic acid, but yielded none.

The organic matter was determined by the Kjeldahl process, and calculated as ammonia (NH_3) in one of the specimens from the east bank and in one Saw Mill River concretion. Only a trace was found, the former yielding one hundredth of one per cent, and the latter about half as much. It may be that the organic matter is present only in a carbonaceous form, but the indications are that it exists, if at all, in a very small amount.

The weights of the concretions analyzed were as follows:—

Saw Mill River Concretions.

1.	104.3 grains.
2.	92.5 "
3.	103.5 "
4.	200 "

River Bottom Concretions.

1.	36.2 grains.
2.	48.1 "
3.	17.3 "

East Bank Concretions.

1.	28.5 grains.
2.	20.2 "
3.	18.3 "

Inland Hill Concretions.

1.	1.9 grains.
2.	1.8 "
3.	1.2 "

It is clear that the per cent of each oxide in the hydrochloric acid solution, and in the fusion which was made from the residue from the hydrochloric acid solution, when added together, gives the whole amount of such oxide in the concretion. When this is done the following results are obtained with the four Saw Mill River concretions: —

Analyses of Four Concretions from Saw Mill River

	No. 1	No. 1	No. 3	No. 3
Silica	28.03	28.21	29.26	29.07
Iron oxide	3.96	3.77	4.36	4.27
Alumina	8.88	*——	10.92	10.81
Lime	25.72	25.28	27.74	——
Magnesia	1.05	1.17	1.98	——
Manganese oxide	4.67	4.61	5.25	——
Carbon dioxide	21.76	21.60	21.60	21.45
	No. 2	**No. 2**	**No. 4**	**No. 4**
Silica	28.42	28.10	28.88	29.10
Iron oxide	3.30	3.39	4.01	4.18
Alumina	12.07	15.38	10.68	10.52
Lime	26.10	26.79	——	27.42
Magnesia	2.10	1.73	2.01	1.93
Manganese oxide	4.40	4.32	——	5.11
Carbon dioxide	21.23	21.	21.27	21.27

* The line indicates that the oxide was not determined.

Comparing the *average* percentage obtained by these analyses, we find, without giving the hundredths, that the per cent of carbon dioxide is constant in the four specimens, and that there is 21 per cent of this substance present.

The insoluble residue after treating with hydrochloric acid is 38 per cent in two out of the four concretions, and the variation is 2 per cent only. We find 28 per cent of silica in three specimens out of the four, and the variation is only 1 per cent. There is nearly 2 per cent of magnesium oxide in three specimens, and the variation is less than 1 per cent. Of manganese oxide two concretions yield 4 per cent and two 5 per cent; of iron oxide two 3 per cent and two 4 per cent; the variation, however, in each of these oxides is less than 1 per cent. The calcium carbonate varies only 2 per cent. There is a greater difference in the oxide of aluminum, but while the variation in the four specimens is from 8 to 13 per cent, two of them yield 10 per cent.

Judging from these results, we may say that while the proportions are not fixed and constant, still these four concretions from one clay bed are remarkably uniform in their composition. Let us see if the same holds good in the case of the specimens from one of the clay beds on the east bank.

Analyses of Three Concretions from a Bed on the East Bank of the Connecticut, near Rice's Ferry.

	No. 1	No. 1	No. 2	No. 2	No. 3	No. 3
Silica	19.129	19.123	18.74	18.64	19.28	19.18
Iron oxide	6.20	6.13	5.89	——	6.16	6.04
Alumina	10.19	10.08	12.59	——	11.19	11.30
Lime	31.47	——	28.79	28.42	28.83	29.31
Magnesia	——	2.25	2.40	1.78	2.39	2.32
Manganese oxide	5.44	5.44	5.38	5.36	5.22	5.41
Carbon dioxide	25.51	25.	23.69	23.84	24.50	24.57

In this series the variation of carbon dioxide is 1.5 per cent. Insoluble residue 26 per cent in the three concretions, variation less than 1 per cent. Silica, 19 per cent in two out of three specimens, variation less than 1 per cent. Manganese oxide constant — 5 per cent. Iron oxide 6 per cent in two specimens, variation less than 1 per cent. Magnesium oxide 2 per cent, variation less than 1 per cent. Calcium oxide, variation 3 per cent, and aluminum oxide, variation 2 per cent.

Here, again, the composition of the concretions from the same bed is pretty uniform, although there is a greater variation in the carbon dioxide and the calcium oxide than in the first series. If now we compare the analyses of the symmetrical forms represented by the first series (p. 31) with those of the unsymmetrical forms (given above), we find marked differences. There is a larger amount of silica in the former than in the latter, the average excess being 9.62 per cent; a smaller per cent of carbon dioxide, the average being 3.12 per cent, also of calcium oxide, 2.94 per cent.

We will next consider the "river bottom" specimens which have a character of their own, being a colony, so to speak, of symmetrical single forms. These are called "river bottom" specimens because they are dug from the clay of the river bottom and not from the river bank.

ANALYSES OF THREE RIVER BOTTOM CONCRETIONS.

	No. 1	No. 1	No. 2	No. 2	No. 3	No. 3
Silica	27.95	27.65	26.69	28.13	28.08	27.91
Iron oxide	4.11	4.22	4.07	4.22	3.99	3.98
Alumina	11.94	——	13.91	11.89	12.20	12.25
Lime	27.64	25.71	25.88	27.50	28.54	28.48
Magnesia	1.94	2.06	1.39	2.07	2.03	2.12
Manganese oxide	4.32	4.38	4.22	4.16	4.13	4.11
Carbon dioxide	22.60	22.	20.	20.	22.13	22.23

It is interesting to note that the composition of these concretions is much nearer that of the symmetrical specimens from Saw Mill River than that of the unsymmetrical forms. (Compare analyses on pp. 31, 32, 33.) Stated in a general way, the results run thus:—

	Saw Mill River	East Bank	River Bottom
Insoluble residue	38	26	38
Silica	28	19	27, 28
Iron oxide	3, 4	6	4
Alumina	10	10-12	11-13
Lime	25-27	28-31	25-28
Magnesia	1, 2	2	1, 2
Manganese oxide	4, 5	5	4
Carbon dioxide	21	23-25	20-22

ANALYSES OF THREE SPECIMENS OF SPHERES FROM THE INLAND HILL.

	No. 1	No. 2	No. 3
Silica	31.22	31.07	35.10
Iron oxide	4.46	6.	3.69
Alumina	14.54	12.41	13.72
Lime	29.82	28.12	30.49
Magnesia	——	——	——
Manganese oxide	.89	4.25	3.90
Carbon dioxide	19.71	19.82	19.95

By examining these analyses of the spherical concretions from the inland hill, we find that the composition of the three specimens is similar, but that it differs essentially from the composition of the other concretions we have been considering. There is a much larger insoluble residue (from 40 to 47 per cent), and the amount of silica is greater (from 31 to 35 per cent). For some reason the manganese oxide, which is very constant in the other concretions, varies here from .89 to 4.25 per cent. In these specimens there is the smallest amount of carbon dioxide (19 per cent) so far found. We have seen from the foregoing analyses that concretions from the same bed are similar in composition, and that each bed, while it is consistent with itself, differs from other beds. This difference, however, is not sufficiently great to throw much additional light on the causes of the marked differences in the shapes of the concretions. Perhaps more could be ascertained, however, if a larger number of series of analyses were made.

Pieces of clay were cut from the strata of the inland hill some distance from those in which the spherical concretions were found. On breaking one piece in two some months later, to our surprise a concretion was revealed (see Pl. XIII. fig. 111). As stated on p. 27, the specimen of clay consisted of three layers. One was light in color and extremely friable, while the layer in which the concretion was embedded was dark-colored and could be used for moulding. An analysis of both layers and of the enclosed concretion gave the following results: —

Light Clay Layer.	
Silica	59.30
Iron oxide	5.24
Alumina	19.59
Lime	2.25
Magnesia	2.47
Manganese oxide	1.97
Carbon dioxide	1.34

Dark Clay Layer.	
Silica	51.90
Iron oxide	8.81
Alumina	20.43
Lime	.97
Magnesia	1.27
Manganese oxide	.94
Carbon dioxide	.30

Enclosed Concretion.	
Silica	42.93
Iron oxide	13.66
Alumina	25.49
Lime	3.07
Magnesia	2.09
Manganese oxide	1.10
Carbon dioxide	.18

The light layer consists principally of silica and alumina with a very small amount of calcium oxide and carbon dioxide. The dark layer contains more iron and aluminum oxide, and not even 1 per cent of either calcium oxide or carbon dioxide. Undoubtedly water and organic matter aid the iron in making the clay dark-colored and plastic.

The concretion was darker in color than most concretions, and this was doubtless owing to the iron, since there was present more than three times the quantity found in the Saw Mill River concretions. Although there is more calcium oxide in the concretion than in the dark layer, there is only 3 per cent, and less than 1 per cent of carbon dioxide.

Under these conditions it is surprising that the concretionary form should be so well marked unless the iron was the active agent in the work. If the manganese aids materially in hardening the concretion, as is probable, then the small quantity of it in this concretion may be one cause of its soft condition.

A secondary modification of the clay layers, produced doubtless by mechanical pressure, has caused certain peculiar modifications in the shapes of concretions. There is a specimen of clay in the geological museum of Amherst College in which the original horizontal layers have been pushed into folds. Although so far as I know there is no record of concretions having been observed in the crests of these distorted folds, nevertheless, bent concretions from unknown localities are found in collections. Professor Emerson (19) figures a specimen, and the original shows the folded layers even better than the figure. Pl. XIV. figs. 119, 120, are views of a bent concretion in our collection. The upper surface is seen in Pl. XIV. fig. 119, and the side view in Pl. XIV. fig. 120, which gives the angle of the fold. Crude specimens apparently warped, so to speak, from a horizontal plane are represented in Pl. XIV. figs. 121, 122. The latter was mounted on glass and unintentionally placed in such a way as to cast a reflection of itself, thereby showing more clearly the scooped out, twisted condition of the concretion. Another specimen telling of distorted and crumpled layers is seen in Pl. XIV. fig. 123, which in the original has the semblance of an old crushed hat.

GENERAL SUMMARY.

PART I.

THE concretions described in this paper are from the following localities: The banks of the Connecticut from Dummerston, Vermont, to Deerfield, Massachusetts, inclusive; the banks of the Saw Mill and Deerfield rivers and of Canoe Brook, tributaries of the Connecticut; an inland hill in the town of Deerfield; Windsor and Hartford, Connecticut; and Ryegate, Vermont.

The collection of concretions numbers fourteen hundred specimens.

The only time for collecting river bank specimens successfully is in seasons of drought when the streams are low.

The equipment for collecting is a good boat, a shovel, trowel, stout carving-knife, rubber boots, boxes, and wrapping paper.

In searching, the course should be up stream, that the concretions lying along shore may not be hidden by the turbid water.

The concretions from each clay bed should be kept separate.

Each bed has a typical form, which is more or less perfect as the conditions are favorable or adverse.

A watch-shaped and a club-like concretion have not been found embedded together, or a botryoidal mass and an animal form. These are typical concretions of as many separate beds. One bed yielded twenty-four similar concretions; another bed forty-eight.

The typical single form may be doubled or trebled, and illustrations are given which tend to prove that the double form is due to the union of two single forms.

Single and double concretions like those collected in 1878 from the north bank of Saw Mill River, were taken from the same clay bed after an interval of twenty-one years.

Under unfavorable conditions the typical form is not perfected so often, although there always seems to be an effort in that direction.

Three series of specimens are given which prove that a close general resemblance may be preserved when the specific details of form vary.

Simple forms give rise to complex forms by coalescence, as shown by the union of many gourd-shaped concretions. The little gourds are fastened tightly to the main body of the concretion, as was proved by the striking example on p. 15.

The longest concretion in this collection, measuring twenty-two inches, is probably formed by the coalescence of several concretions lying in a straight line.

As a rule one side of a concretion is flatter than the other and without ornamentation. An exception to this rule is illustrated by two specimens from Hartford.

Concretions are found not only in river banks, but also in inland hills; the latter are illustrated by the spherical concretions from the rounded hill in East Deerfield.

Part II.

In 1670 the question was asked, What are these shapely pieces of hardened clay? A brief historical sketch offers some of the answers that have been given.

Various chemical analyses for the determination of calcium carbonate and foreign matter have led to the conclusion that about half the concretion is carbonate of lime, and the remainder largely clay and sand.

The essential difference between the concretion and the surrounding clay, as shown by analyses, is the small percentage of calcium carbonate in the latter as compared with that of the former.

In order to answer the question, How are these concretions made? the theory of concretionary structure as generally held by naturalists to-day is given, and the views of Blatchley on drift clays and "rock flour," of Julien on the action of the humus acids, and of Nichols on the part played by aragonite are considered. The subject of the presence or absence of a nucleus is discussed, and it is shown that the sections and weathered specimens described do not reveal a nucleus of appreciable size, excepting in one case where a pebble is found at the centre. Etching with hydrochloric acid brings out a concentric structure, and also shows that the tendency to concretionary structure is so great that the concreting material makes small concretions within the larger one.

Stratification lines are shown to run not only through the concretions, but also with unbroken continuity through the concretions and the surrounding clay.

Illustrations are given which tend to prove that the concretionary process may stop while in the act of making a concretion, and afterward begin again; when such specimens weather, the different stages fall apart and are often distinguished by marked differences in color.

The shape of a concretion is partly determined by the structure and composition of the matrix which holds it, and by the amount of carbon dioxide and other organic acids present.

A single specimen described was found in a plastic condition.

Four series of analyses were made of concretions from four different beds, as follows:

Four symmetrical specimens from the Saw Mill River bed.
Three unsymmetrical specimens from near Rice's ferry.
Three compound concretions from the river bottom.
Three spherical concretions from the inland hill.

The analyses showed:—

First: similar forms from the same bed are essentially alike in composition.

Secondly: the composition of symmetrical forms differs from that of the unsymmetrical ones; this difference, however, is not sufficiently great to explain the marked differences in shape.

Thirdly: the composition of the compound concretions, made up of symmetrical single forms, is more nearly like that of the symmetrical single forms than that of the unsymmetrical specimens.

Fourthly: the composition of the spherical concretions from the inland hill, and that of the surrounding clay, differs from the river bank specimens in the presence of a larger amount of silica; this fact doubtless explains their spherical form.

Analyses of the plastic concretion showed an extremely small amount of lime and carbon dioxide, but a large amount, comparatively speaking, of iron.

Secondary modifications in shape are produced by mechanical pressure, as shown by bent concretions.

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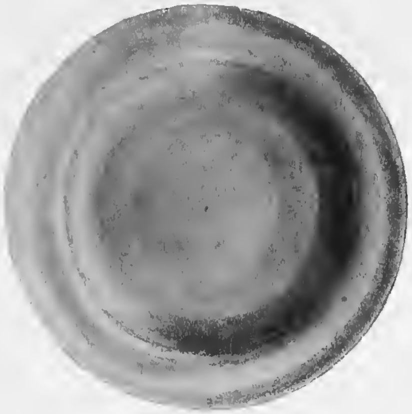
INDEX.

PLATE I.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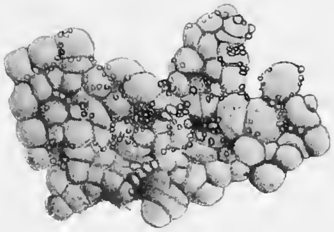
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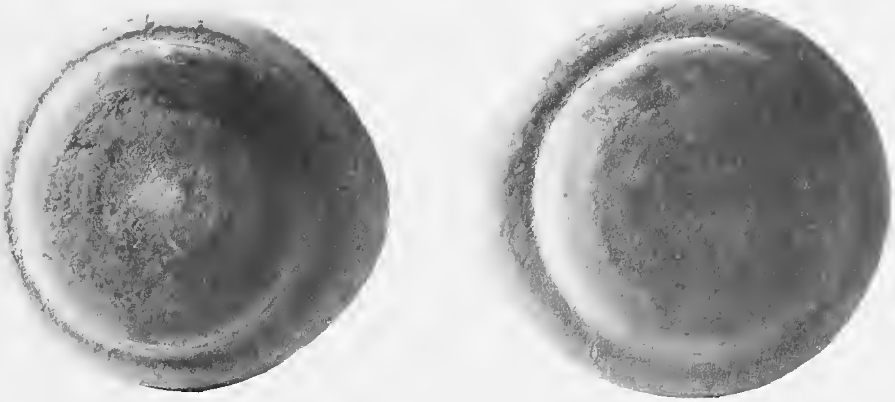
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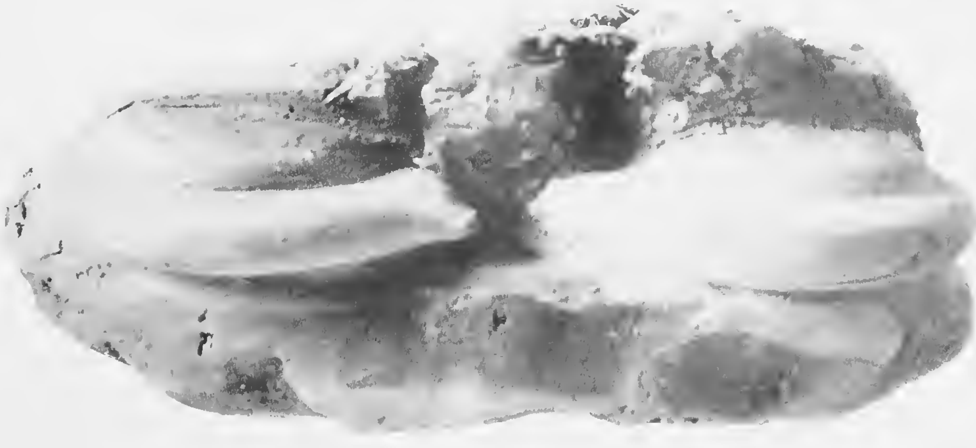
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HELIOGRAPH, HART & VON ARX, N. Y.


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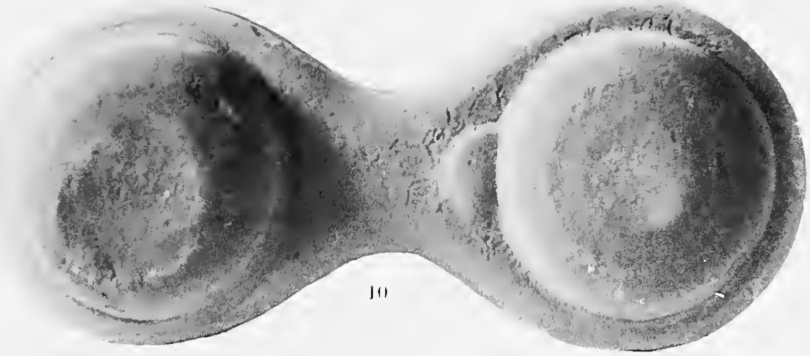
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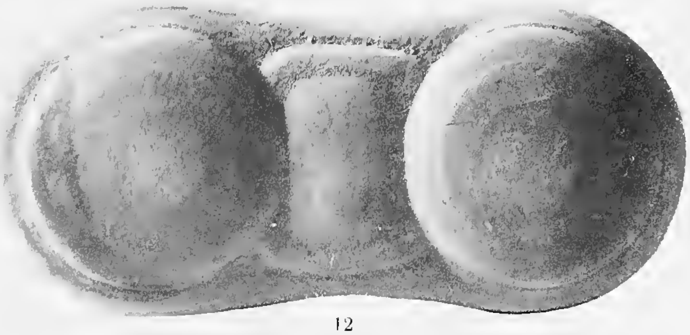
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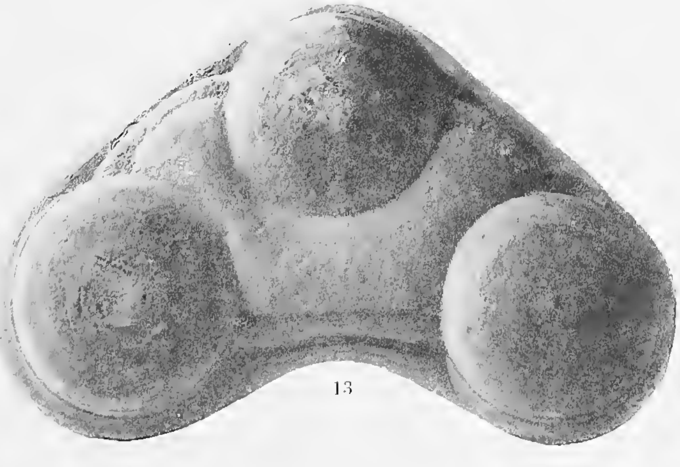
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HELIOGRAPH, HART & VON ARX, N. Y.

PLATE III


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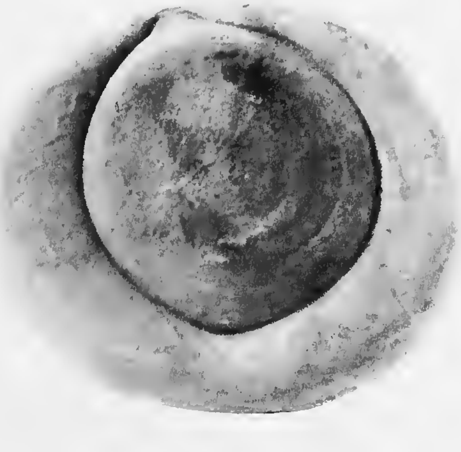
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PLATE IV.


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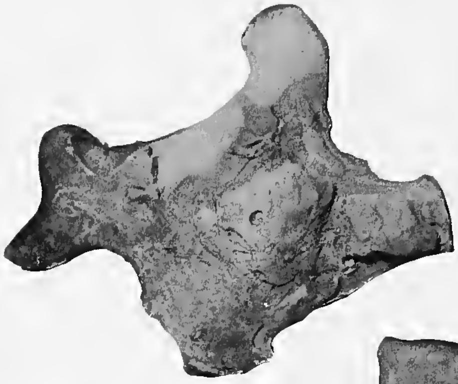
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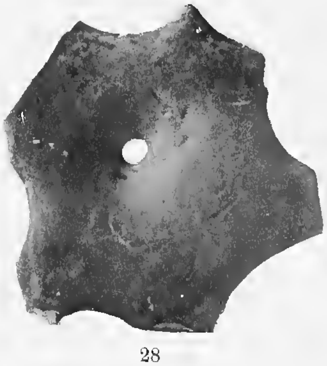
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HELIOGRAPH, HART & VON ARX, N. Y.

PLATE V


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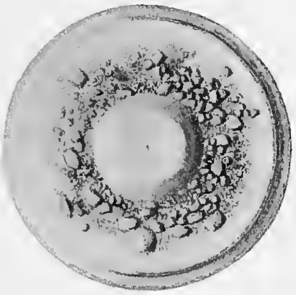
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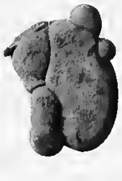
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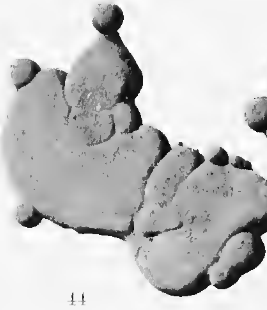
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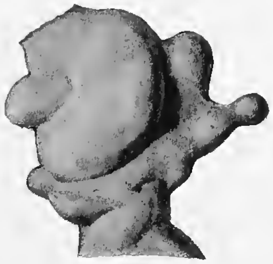
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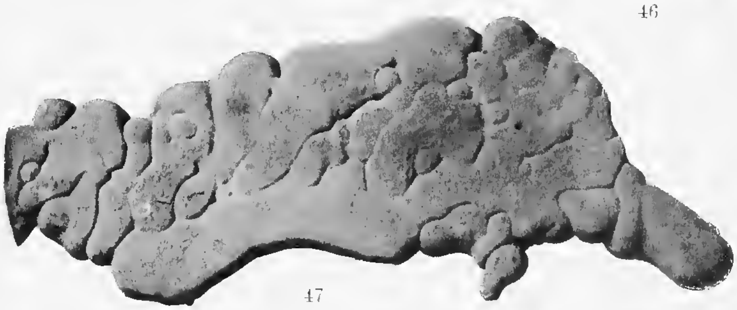
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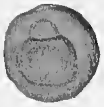
HELIOGRAPH, HART & VON ARX. N. Y.

PLATE VII.


51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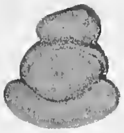
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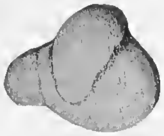
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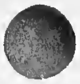
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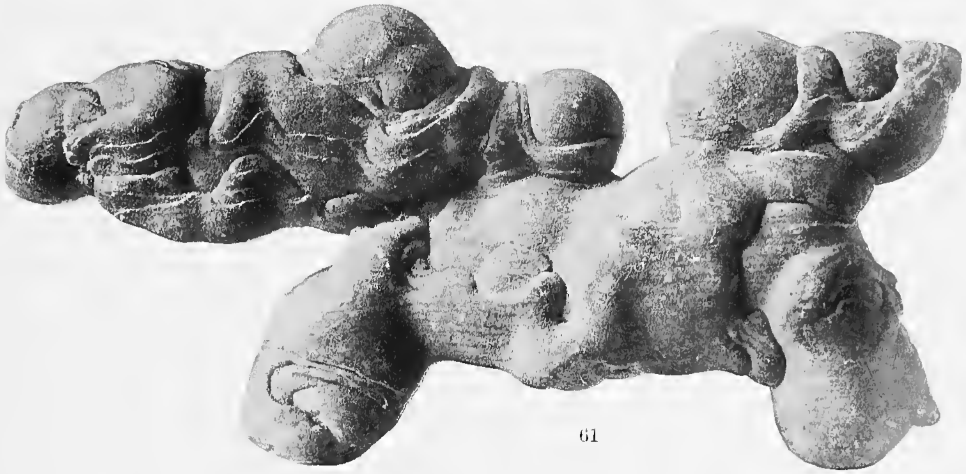
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HELIOGRAPH, HART & VON ARX N.Y.

PLATE VIII

HELIOGRAPH, HART & VON ARX N.Y.

PLATE IX.

HELIOGRAPH HART & VON ARY, N. Y.


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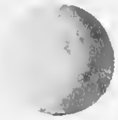
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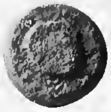
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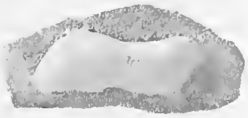
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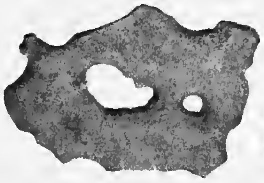
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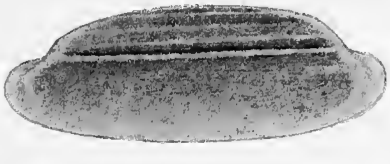
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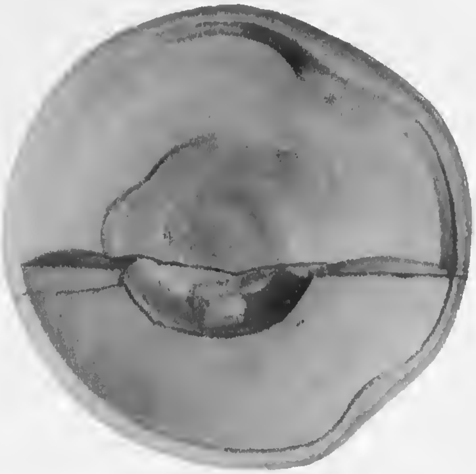
HELIOGRAPH, HART & VON ARX, N.Y.

PLATE XI.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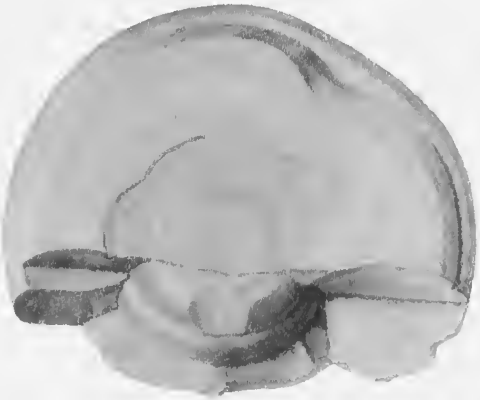
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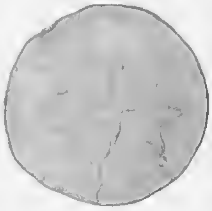
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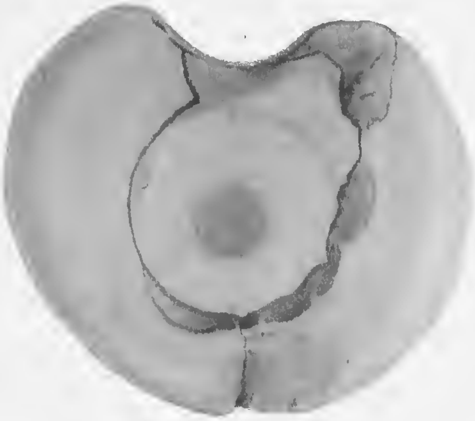
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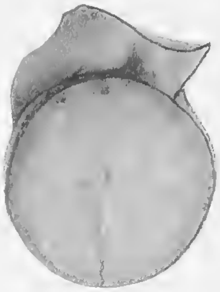
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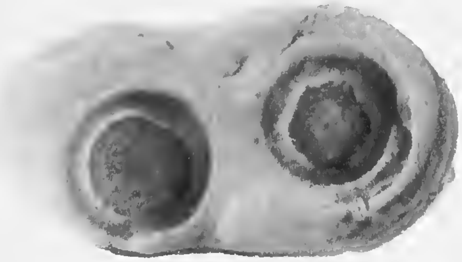
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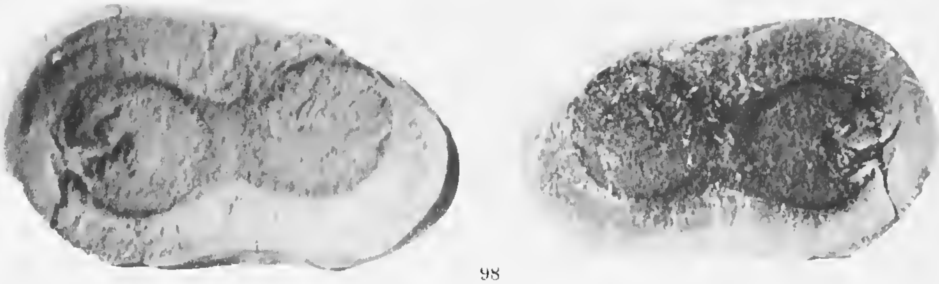
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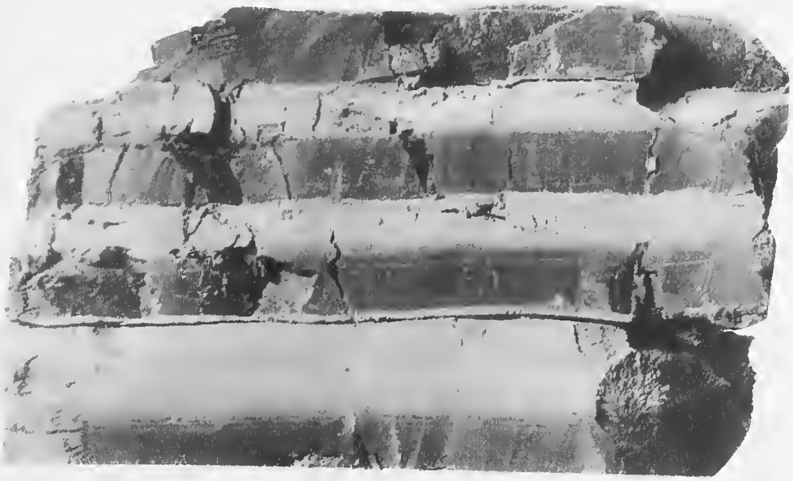
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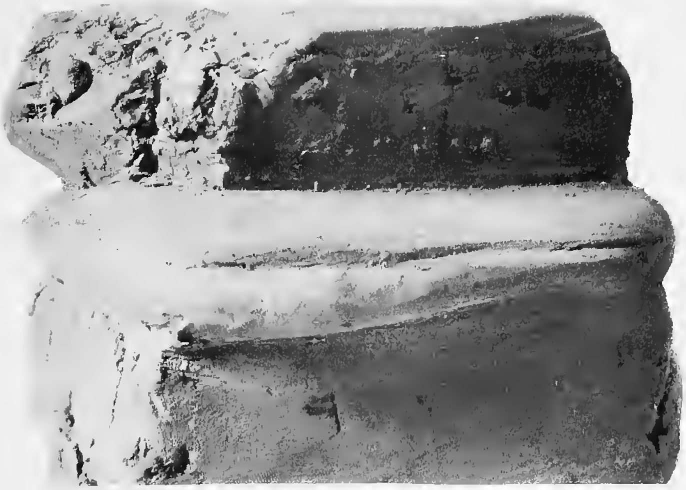

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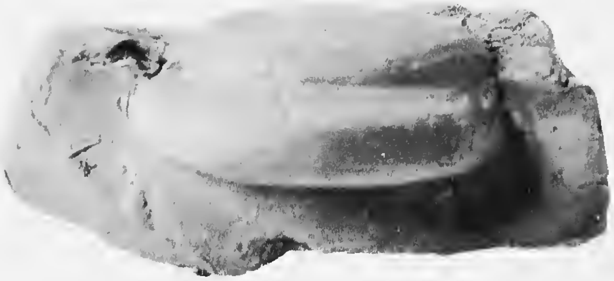

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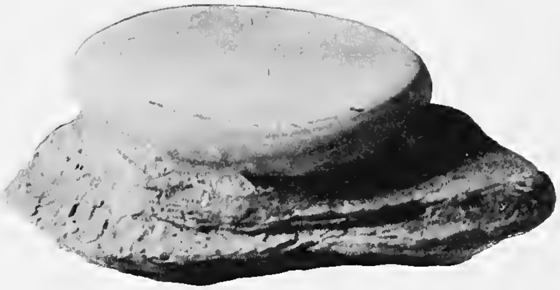

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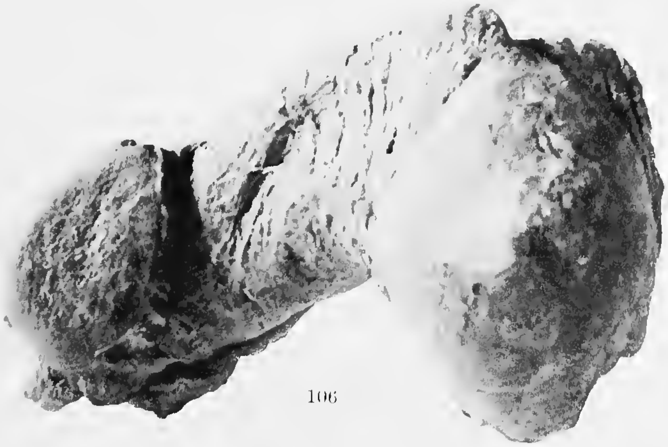

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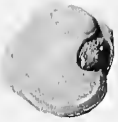

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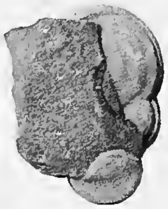

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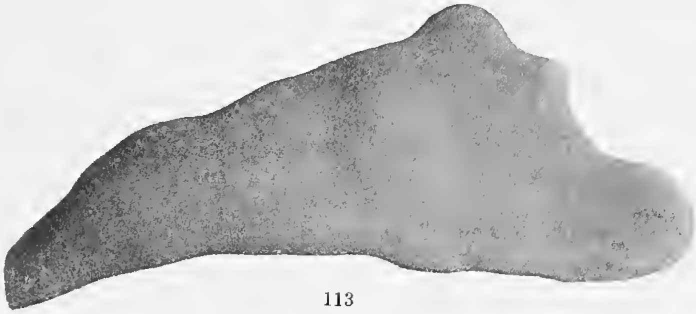

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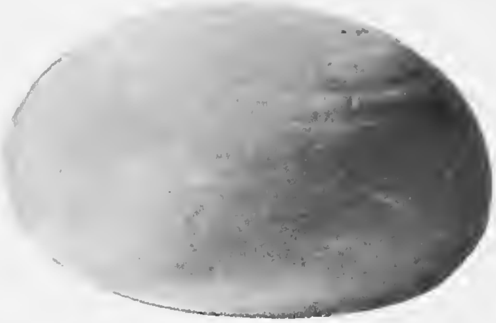

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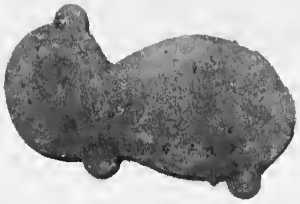
HELIOGRAPH, HART & VON ARX, N. Y.

PLATE XIV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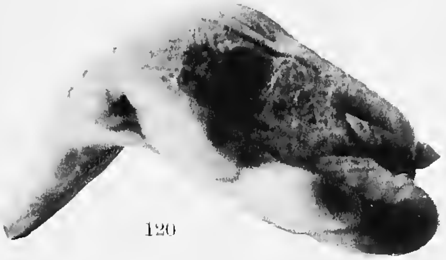
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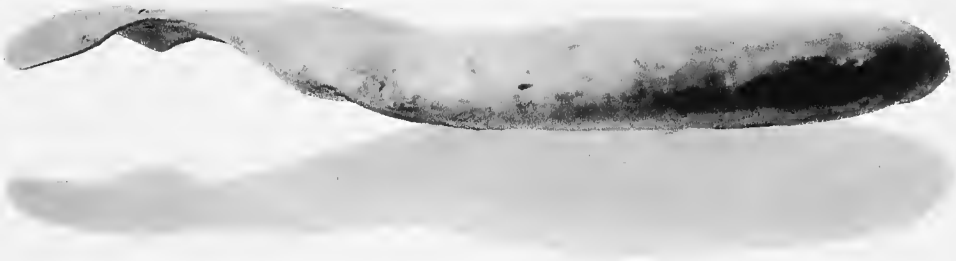
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123

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