THE PHYSICAL ORIGIN OF CERTAIN CONCRETIONS[1]

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The literature on the subject of concretions is somewhat limited in extent, and consists largely of descriptive rather than theoretical matter. It is safe to say, however, that distinct types present different problems for solution, and have resulted from divers combinations of chemical and physical laws. The forces brought to play in the forming of one kind may have played no part in the creation of another. Types vary to such a degree that a valid classification is difficult to prepare. Certain writers have made general classifications with reference to manner of growth; for instance, Dana[2] employs the terms "centrifugal" and "centripetal" concretions for growths to and from a center respectively. The latter includes principally concretions of a geodal character. In a similar way the terms "excretions" and "incretions" have been used.[3]

There can be no doubt as to the occurrence of these two general types, but it has been supposed, in many cases, that concretions have originated only through chemical phenomena. There are exceptions, however, in which certain forms of rounded nodules have been considered as resultant forms of physical forces. Kindle[4] accounts for certain concretions of the Chemung by pressure of rising gases of organic origin beneath impervious strata in a semi-plastic state. This idea was suggested by observation of Agassiz and Horsford on "raised hemispherical surfaces" in clayey mud near Cambridge.[5] Kindle makes use of this theory to account for a band of undistorted fossils along the vertical and lower horizontal surfaces of certain of

[1] Published by permission of the Director of the U. S. Geological Survey.

[2] J. D. Dana, *Manual of Geology*, 4th ed., p. 98.

[3] J. E. Todd, "Concretions and Their Geological Effects," *Bulletin of the Geological Society of America*, Vol. XIV, p. 361.

[4] E. M. Kindle, "Concretions in Chemung of Southern New York," *American Geology*, June, 1904.

[5] *American Association for the Advancement of Science*, Vol. IV, p. 12.

the Chemung concretions in southern New York. He supposes that the fossils once occupied a definite horizon and have been pushed upward and around the superjacent material which forms the body of the concretion. Kessler and Hamilton,[1] after giving an analysis of a certain gabbro and contained concretions, conclude with the remark: "This similarity in chemical composition seems to denote that the cause which set about the formation of the spheroids was not a chemical phenomenon." The writers refer to the explanation of Vogelsang[2] in the type locality, Corsica; the latter suggested that this concentric arrangement may be due to irregular areas of cooling and contraction. Blake[3] in referring to the concretionary structure in white volcanic lava of Tucson, Arizona, takes the view that concentric structure, in that case, has been formed by deposition around inclusions through action of permeating ground water.

It is apart from the discussion here, however, to deal with the concretionary and spheroidal structure of many eruptive rocks. The present article is intended to consider the origin of certain types of concretions common to sedimentary deposits only, and especially those concentric nodules of argillaceous composition containing, in many instances, noticeable percentages of calcareous and ferruginous constituents, and to show that possibly physical forces have played no little part in the forming of many of the common spherical, elliptical, discoidal, or irregular concretions in shales or clays. In some cases concretions are known to have originated entirely from chemical solution; an instance of this class is found in the well-known "loess kindchen" of the loess deposits. These calcareous nodules are formed often as incrustated deposits around roots and small plant stems. Other occurrences present equal evidences of purely chemical origin. But many of the more or less rounded nodules of concentric structure and smooth surfaces have merely been alluded to as products of an affinity for like to like with no definite explanation as to how or why they were so formed. The theory of attraction or affinity of like to

[1] H. H. Kessler and W. R. Hamilton, "Orbicular Gabbro of Dehesa Co., California," *American Geology*, Vol. XXXIV, pp. 133–40.

[2] *Sitzungsberichte der niederrheinischen Geschichte*, Vol. XIX, p. 185, 1862.

[3] "Origin of Orbicular and Concentric Structure," *Transactions of the American Institute of Mining Engineers*, Vol. XXXVII, p. 39.

segregate to like, subsequent to deposition of beds, is not sufficient to account for many alluminous concretions in clays and shales. Often the composition of inclosing sediments is closely similar to that of the included concretion but is usually variable.

The writer holds that many such concretions are contemporaneous with the strata in which they are contained; that they have resulted through adhesion of particles in overloaded water volumes disturbed by currents.

During the seasons of 1906 and 1907 the writer observed concretions so formed under natural conditions in alluvial beds of Present Age. This was in the desert region of the San Juan Basin, New Mexico. Conditions were met with here such as are not common to the present land areas. The Rio Chaco, some 40 miles above its confluence with the Rio San Juan, may be taken as a type locality. Here the bed of the stream is made up of alternating layers of sand and alluvial clay. Water flows along the bed only during the winter and spring months or after extensive rains. The fall of the river is very slight. During the flow, vast amounts of sand and clay, or mud, are transported along by the sluggish stream. The water, disappearing rapidly through evaporation and absorption in this arid region, is forced to deposit its sediments along the way; first the heavy sand grains or tiny pebbles, then the finer sand, then the coarse clayey material, and finally the very fine silt, which is held in suspension, becoming more and more concentrated as the water is soaked up or is evaporated. Often this moving mixture is a mere viscid fluid. After the water ceases to run and dries away, a thin coating of clay is left over the surface of the stream bed. Resting in and on this layer are often to be seen great numbers of round, concentric clay concretions. The accompanying plate indicates the manner in which they are collected into aggregations. These concretions are solid but may easily be broken with the hands. Some show nuclei in the form of small pebbles or angular fragments but many of them appear to be of similar material throughout with no recognizable nuclei. Cross-sections revealed that some of them contain small pebbles and sand grains in certain concentric shells of their makeup. The majority average about 1¼ inches in diameter.

The origin of these concretions is not difficult to explain. In the super-concentrated or overloaded water carrying fine clay particles along a smooth bottom, an adhesion of those particles naturally results. They are pressed together as are finely disseminated particles of butter in the everyday illustration of churning. They may unite with or without a nucleus. A soft nodule will form, grow, and become round by being rotated along its different axes as boys roll snowballs. It will be propelled by the current, gathering as it goes. It will pass over slightly different characters of materials and may gather at intermittent periods; hence different concentric shells will

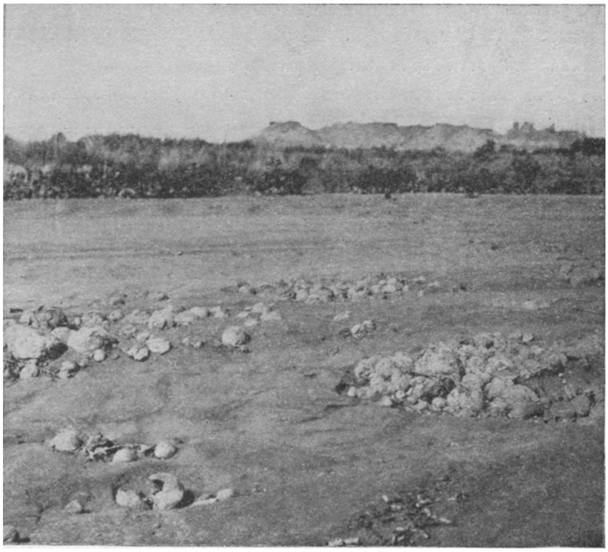

FIG. 1.—Clay balls in the bed of the Rio Chaco, New Mexico.

result. Should it pass over sandy particles or small pebbles, it will gather them up and may later cover them with additional coatings of clay. At eddies or acute bends in the stream the concretions aggregate and may become slightly welded together. There is a limit to their size depending on the strength of current flowage; they grow until the current is no longer able to transport them, then settle to become covered by subsequent deposition. It may occur that the upper or exposed portion while lying on the bottom receives additional material from the depositing sediments, resulting in an orbital form with a partly inclosing shell which, with modifications, is a very common occurrence among concretions from sedimentary clay and shale beds. Or it is quite possible that a concretion formed as above may be subjected to stronger currents or clearer water and be eroded to any imaginable shape with smooth outlines. It may be carried to a distance and incorporated in a sediment of an entirely different character from that in which it had its origin. Its composition as a whole would likely in most instances vary from the material immediately surrounding it.

The following are analyses of a typical clay and inclosed concretion from the Champlain clays of the Connecticut Valley.[1]

DARK CLAY LAYER		INCLOSED CONCRETION	
Silica	51.90	Silica	42.93
Iron oxide	8.81	Iron oxide	13.66
Alumina	20.43	Alumina	25.49
Lime	.97	Lime	3.07
Magnesia	1.27	Magnesia	2.09
Manganese oxide	.94	Manganese oxide	1.10
Carbon dioxide	.30	Carbon dioxide	18

It will be observed that the silica and carbon dioxide of the concretion are somewhat lower than that of the clay, while the remaining constituents are higher. While the percentage of lime is 2.10 per cent. greater than in the clay, yet it is not in sufficient amount to justify the term "lime-concretion." The quantity of lime present in this type may vary from a small amount to more than 50 per cent.[2] From the presence of a high percentage of lime it does not follow that this constituent has been the prime factor in the origin of the concretion. Concretions of the character under discussion often show structure made up of very fine material such as would have resulted had they been formed from the adhering of minute particles. Clay and shale concretions have been known to contain gravels, coarse sand grains, or small organic relics as nuclei. Some show small pebbles and coarse sand grains in the form of interior concentric shells.[3] Similar structure has been pointed out as occurring among the concretions which form in the bed of the Rio Chaco.

[1] J. M. A. Sheldon, *The Champlain Clays of the Connecticut Valley.*

[2] C. B. Adams, "Concretions," *Second Annual Report on Geology of the State of Vermont*, pp. 111–18.

[3] "Champlain Clays," *loc. cit.*

Unfortunately the writer has no quantitative analysis of the specimens from the Chaco. They effervesce, however, in the presence of acids. One would expect them to contain a high percentage of soluble materials as is common to ordinary concretions. The last material laid down physically in the water volume is necessarily of a very fine character; furthermore, the water itself, being rapidly concentrated to the point of super-saturation, is forced to throw down its minerals in solution at the same time the concretions are being formed. If the water gains its clayey substances from ferruginous beds, iron oxides will prevail in the last stages of the concentrated solution. If calcareous, then lime will be prevalent in the fine silt at the time when conditions are favorable for the forming of concretions. The same will hold true in the case of other soluble minerals. It is reasonable to suppose that, in accordance with the theory of physical origin, most concretions of this class would be calcareous, since lime is most common. Hence it is seen that while the composition of a concretion so formed depends on chemical relationship, yet the concretionary process is itself a physical one.

Concretions often show flattened or discoid shapes with the greater axes parallel to the bedding planes of the containing strata. Writers have suggested that this is due to there being less resistance to growth in the horizontal than in the vertical planes. In some cases the strata seem to have been pushed away by the enlarging concretion. Such a flattening, however, may have been due entirely to pressure and the strata pushed back around the concretion through resistance to that pressure. There would also be a tendency toward development of cleavage in the concretion at right angles to the pressure and these planes might easily be confused with planes of stratification, the two in normal instances being parallel.

So far as the writer knows, attention was first called by Dr. George P. Merrill[1] to the balling tendency of mud under artificial conditions. He cites the phenomenon of concretionary balls having been formed in mud flowing quietly from the mouth of an iron pipe; the instance was that of pumping sediment from the bottom of the Potomac a few years ago for the purpose of deepening the channel and filling the so-called Potomac flats on the river front at Washington City.

[1] G. P. Merrill, *Rocks, Rock Weathering, and Soils*, p. 37.

Dr. Merrill states that this occurrence shows in an interesting way the manner in which certain concretions are formed.

Another example of the balling tendency of clay particles thickly suspended in current water is shown in the washing of brown iron ores in Alabama.[1] The clay in the log washers often adheres into balls or concretions and it is necessary to remove these by hand before the ore is sent to the furnaces. There may be serious loss of the finer ore particles due to the balls picking them up and carrying them to the waste dump. These mechanical illustrations of the balling tendency of clay are closely similar to those observed to occur under natural conditions in the bed of the Rio Chaco.

Is it not reasonable to suppose that causes which are now effective in producing concretionary structure have been in operation during past ages of the earth's history?[2]

[1] W. B. Phillips, "Iron Making in Alabama," *Alabama Geological Survey.*

[2] Since preparing the above article, the writer has been informed by Mr. Frank L. Hess that mud concretions have been observed by him along the Cuyama River and other localities in California and by Mr. H. S. Gale along a small tributary to White River, near Meeker, Colorado. No doubt the occurrence is familiar to most geologists.

In the Umpqua shales (marine Eocene) of Oregon, Mr. Chester W. Washburne reports having found concretions containing a concentric layer of marine shells; they were in such a position as to indicate that the concretions had been formed by a union of particles due to rolling.