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THE ORIGIN OF THE GEODES OF THE KEOKUK BEDS.

By Francis M. Van Tuyl.

The presence of great numbers of geodes of varying size and degree of development in the Keokuk beds of the Central Mississippi Valley has long been known to geologists, but their origin has been, from the earliest times, a disputed question, and, although there has been considerable speculation upon the subject, no theory of their formation has been, as yet, widely held.

The geodes attain their greatest development in the Upper Keokuk, that division of the Keokuk beds formerly known as the Geode bed or Geode shales. But geodes also occur locally in the Lower Keokuk or Keokuk limestone.

The rocks in which the geodes appear vary in composition from an argillaceous shale, through carcareous shale, to an impure magnesian limestone. Such material constitutes almost entirely the strata of the Upper Keokuk; in the Lower Keokuk it appears only in the form of layers interbedded with bluish, fossiliferous crystalline limestone.

In size the geodes range from about 1-16 of an inch up to 30 inches in diameter. Well developed geodes, however, of either extreme are very rarely found.

Mineralogically the geodes are almost invariably siliceous, but a few carcareous geodes and geodic calcareous nodules have been found. The siliceous types are characterized, without exception, by an outer shell of chalcedony and this is usually followed by crystalline quartz, but calcite sometimes succeeds the chalcedony. In some instances, however, the interior is lined with botryoidal chalcedony and no crystalline calcite nor quartz appears. These chalcedonic types frequently bear small cubes of pyrite and one specimen was found which contained sphalerite partly decomposed to smithsonite. This geode bore, also, a slight incrustation of gypsum. The quartz geodes are often solid, but when they are hollow the quartz crystals of the interior may be studded with crystals of calcite, dolomite, ankerite, sphalerite, pyrite, or magnetite, and occasionally they are stained with the powder of limonite or hematite. Sometimes an incrustation of aragonite or gypsum is found. Moreover, hollow siliceous geodes from the vicinity of Niota. Ill., are often filled with a black bitumen, and those from the more shaly portions of the Upper Keokuk, particularly at Keokuk, Ia., and Warsaw, Ill., commonly contain kaolin in the form of a flocculent white powder.

Calcite geodes and geodic calcareous nodules with, or without, siliceous shells are much less common. A few calcite geodes have been found to bear small sphenoids of chalcopyrite. The geodic calcareous nodules, however, are characterized, in general, by calcite of two periods of growth and frequently contain crystals of pyrite.

Furthermore, calcareous nodules without geodic cavities and sometimes inclosed with siliceous shells identical with those on perfect geodes are sometimes found in the Upper Keokuk. These have exactly the same relationship to the containing rock as the geodes and have analagous shapes.

The most popular conception as to the origin of the geodes is that they were formed when the rocks were in a heated condition and that their genesis is related to that of the "niggerhead" boulders of the region. Those entertaining this view believe that there were once molten masses containing gas in the rocks and that the expansion of this gas, followed by infiltration of mineral matter, gave rise to the geodes.

Still another idea, and one even more preposterous, is that the geodes are of meteoric origin.

Of the theories which must be considered more seriously, that adopted by Dana[3] in his Manual of Geology is probably the most unique. In referring to the geodes from the Keokuk beds, he says:

> "They have been supposed to occupy the centers of sponges that were at some time hollowed out by siliceous solutions, like the hollowed corals of Florida, and then lined with crystals by deposition from the same or some other mineral solution."

This theory has had many followers and Wallace[5] has even gone so far as to coin a generic name for the sponge whose solution is supposed to have afforded the cavities in which the geodes were developed. To this genus, called Biopalla, eight species were referred upon the basis of difference in size, shape, and surface markings of the geodes. The sponge hypothesis, however, is not now widely held and the investigations of the writer convince him that Wallace's conclusions are not in accord with the facts. No evidence of sponges capable of giving rise to geodes has ever been found in the Keokuk beds. A few depauperate specimens have been collected from the lower limestone member of the formation, but these are not of the shape of geodes and have nothing in common with them.

Moreover, the geodes vary widely in size and shape, a fact which argues strongly against any theory which pre-supposes an organic origin. Many specimens are nodular and irregularities of the greatest variety characterize their exterior form. It may safely be said that no two of them assume exactly the same proportions. Furthermore, evidence of the symmetry so characteristic of organisms is noticeably lacking.

Quite a different theory to account for the Keokuk geodes is that proposed by Benge[2]. His assumption is that, following the deposition of the Coal Measure strata of the region, water surcharged with carbonic acid migrated down into the Keokuk beds, and that solution and re-deposition of the limestone took place. It is his thought that during the process of re-deposiion bubbles of carbon dioxide were included, and that after the hardening of the limestone the cavities resulting furnished conditions favorable to the formation of geodes. Unfortunately this ingenious theory will not account for the occurrence of geodes in shale, and it is certain that such a process has not operated in the limestone.

Mooers[2] has further attempted to outline the origin of geodes, using as a basis the occurrence of wads of grass inclosed in clay balls along the beds of certain creeks in the region. It was his thought that the decay of this included

grass would furnish hollow balls, which in the presence of water bearing silica in solution might develop into geodes.

Professor Shaler[4] has also contributed to the literature on geodes His studies were based on geodes, known to be of fossil origin, which occur in the Knobstone shales of Kentucky. His conclusion is that these geodes are spheroidal veins and that they have been formed by a process of vein building at the junction of the plates of crinoids.

More recently Bassler[1] has published on the formation of geodes. He, too, limited his study to the geodes of the Knobstone group of Indiana and Kentucky. He agrees that these geodes are of fossil origin but his ideas concerning the details of their method of formation are somewhat at variance with those of Shaler. He attributes the same method of origin to the Keokuk geodes, although he admits he has been unable to secure a full set of these geodes to illustrate this method of formation. I quote from his article:

> "Returning to the suggestion in Dana's Manual of geology that the Keokuk geodes are hollowed out sponges lined with crystals, it seems more reasonable, in view of the absence of such sponges in that formation and the presence of numerous specimens indicating the origin described above, that the latter is nearer the truth."

This generalization has no facts to substantiate it. Specimens which are in any way related to fossils are extremely rare. Several thousand geodes were examined from the Keokuk beds yet only two showed evidence of fossil remains. These came from fossiliferous portions of the Upper Keokuk and the relationship was such as to indicate clearly that the fossil fragments had been merely accidently enveloped by the siliceous shell when it was formed. It should also be recalled at this point that the typical geodiferous phase of the Keokuk beds is non-fossiliferous, and that the most productive layers are utterly devoid of life remains.

The writer's investigation of the geodes of the Keokuk beds has led him to conclude that they are closely related to the calcareous nodules which occur in the strata at some localities. Such masses consist at times of almost pure calcium carbonate, but frequently a considerable amount of argillaceous material is intermixed. These nodules have exactly the same relationship to the containing rocks as the geodes and possess analagous shapes. They were obviously formed on the sea bottom while the beds were being deposited since lines of stratification are very rarely found passing through them and no evidence of expansion is encountered.

Between well formed geodes and such nodular masses a fairly complete gradation has been found. Starting with rounded calcareous nodules a whole series of intermediate specimens consisting of solid nodules inclosed with siliceous shells identical with those of perfect geodes, and of inclosed nodules bearing geodic cavities in their centers, to ordinary geodes may be found.

The steps involved in the formation of the geodes, therefore, must have been as follows: (1) the growth of the nodules by the segregation of calcareous material on the sea bottom; (2) the development of siliceous shells upon these nodules; (3) the removal of the enveloped nodules by solution; (4) the deposition of mineral matter upon the inner walls of the empty siliceous shells.

The solution of the nodules evidently took place when the Keokuk beds were above ground water level, but the deposition of the minerals which now line

the interiors of the geodes must have proceeded in the belt of cementation. Most of these minerals are believed to have been deposited during the interval which just preceded the Pennsylvanian inundation but some are unquestionably much younger than this.

The minerals now found lining the geodes were derived from the rocks immediately adjacent. Circulation could not have been great enough to introduce appreciable amounts of material from other formations, nor is it necessary to attribute an exotic origin to the minerals. Shale and impure limestone may contain any number of different mineral particles and the mineral species of the geodes merely represent the segregation of material through the medium of aqueous solutions from such disseminated particles.

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