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## ADDITIONAL NOTES ON THE GEODES OF THE WARSAW FORMATION

PERCIVAL ROBERTSON AND MARSHALL BROOKS

*The Principia College, Elsah, Illinois*

The geodes which occur in the Warsaw formation were well described by Van Tuyl<sup>1</sup> in 1921. They consist of an outside layer of chalcedony, usually lined with crystalline quartz, and more rarely with dolomite, ankerite, pyrite, or spahlerite, or combinations of these, and much more rarely with chalcopryrite or millerite. Secondary smithsonite, malachite, limonite, hematite stains and kaolin were also reported. The geodes generally have a cavity in the center. This is usually a single chamber, although it may be divided. Quite frequently, however, the size of the opening is so small as to be practically negligible. The minerals Van Tuyl mentions, with the exception of chalcopryrite and malachite, have been identified in this study, and the mineral barite has been added to the list of those discovered.

In considering the origin of geodes Van Tuyl comes to the conclusion that: "The origin of the geodes in the region studied is believed by the writer to be related to the calcareous concretions which originally must have been very

abundant in the beds and which are still preserved at some localities. These nodules, being more soluble than the inclosing rocks, have been in large part removed, thus affording cavities in which the geodes could be formed"<sup>2</sup>, and that "The process of geodization evidently consisted of the inward growth of crystals upon the walls of cavities left by the solution of the imbedded concretions. The growth was necessarily accomplished by deposition from a solution which filled the interior completely. As this solution became depleted in its mineral content, more was introduced by some process of diffusion and a continuous deposition resulted."<sup>3</sup>

It has seemed difficult to understand not so much how circulating water has formed the cavities and later filled them, but why it should select an impervious shale as the zone through which to percolate when soluble limestones lie both below and above it. While there seems to be no doubt that both solution and deposition have produced some crystal lined cavities, there are features of the

geodes found in the Warsaw that have caused the senior author to question this mode of formation and to propose an alternate working hypothesis to account for their production in this particular formation. To what extent this alternate hypothesis succeeds in explaining the formation of geodes in other than the Warsaw formation is beyond the scope of this paper. It appears reasonable to believe that geodes may have been formed in more ways than one.

As a working hypothesis it is suggested that the geodes were syngenetically deposited on the sea bottom as colloidal masses of hydrated silica. It is thought that these hydrosols were probably stiffer than the silica gell postulated by Tarr as the origin of some chert. They were stiff enough or had sufficient surface tension to permit the masses to assume an approximately spherical shape, usually more or less oblate. After being covered by sediments two principal changes occurred in most of them. At some epoch subsequent to their burial the medium surrounding them became drier than the colloidal masses. This caused transfer of moisture from the hydrosol to the surrounding rock. The outside layer of the geode stiffened, producing the characteristic chalcedonic shell. The original silica jell was a negative colloid. This produced a slight difference in potential between it and the surrounding rock which caused a slow loss of electrons from the colloid. When there was a sufficient loss of electrons, a condition suitable to the formation of crystals occurred. Thus there were two principal changes:

1. Loss of water producing a stiffer jell, resulting eventually in precipitation of colloidal chalcedony. (It is presumed that the micro-crystalline structure of the chalcedony is a much later alteration.)
2. Loss of electrons produces a condition favoring deposition of crystalline quartz.

Apparently loss of water usually preceded loss of electrons, as the outer shell is always chalcedonic. Usually the loss of electrons followed, as the interior of most geodes is crystal lined, but in a number of instances the geode contains nothing but chalcedony, and in a few instances there is an alteration from chalcedony to crystalline quartz, then to chalcedony; and in at least one instance

this is followed by the formation of quartz again. This indicates minor changes in environment, causing variations in the rates of loss of moisture and electrons. If the original colloid contained but little moisture the geode produced was nearly solid, but if the jell contained much water the resulting geode was relatively hollow.

In addition to the evidence already mentioned, there are other items that tend to support this hypothesis of geode formation. The shape of the majority of geodes resembles a cauliflower. This botryoidal structure is usually associated with colloidal substances. Such geodes usually have a single hollow in the center, or more rarely several small ones. But some geodes show a starchy fracture on the outside. They resemble somewhat the cracked crusts seen in overbaked loaves of bread. These geodes regularly display one or more flattened surfaces. Geodes showing such a surface, regularly exhibit an internal structure quite distinctly different from the usual cauliflower type. The interior is broken up into many compartments more or less connected, but separated by rather flat partitions consisting of masses of tiny crystals. One gets the impression that while the geode was still a colloidal jelly it was partly crushed and cracked. The cracks on the exterior still show, and the planes of fracture extending through the geode provided nuclei for crystal growth. Still other geodes show indications of more intense pressure as the crusts are crushed in. This probably happened after the solidification was nearly complete. The geode is flattened, the interior cavity collapsed, but the crushed top is well cemented to the balance of the geode.

The phenomenon most difficult to explain on the basis of percolating water is the presence of pairs or groups of geodes which show definite flattening on their mutual planes of contact. Such pairs of geodes show chalcedony surfaces practically in contact, with only minor amounts of shale separating them, and the contact surfaces are definitely flattened. It is difficult to see why percolating water would not have removed the very thin partitions between two such cavities, thereby forming one large one; but two colloidal masses in contact

would probably behave somewhat as two soap bubbles do when brought together and form a flat surface of contact.

Some geodes contain numerous totally free doubly terminated crystals within them. These are moderately common in Jersey County, Illinois. While no statistical record has been kept, one such geode may be found among several hundred of those encountered in the field. If the percolating waters were as dilute as most students seem to believe, it is difficult to ascribe to them specific gravities or viscosities high enough to support a crystal so it would be free to grow equally in all directions. A stiff colloidal medium would be ideal for the growth of such crystals.

If one speculates on the shape that a spherical mass of colloidal hydrated silica would assume under the conditions postulated for the formation of these geodes, he comes to the conclusion that the shape would in all probability be a function of the stiffness of the jelly. The less water in the original colloid the stiffer it would be, although it is not implied that there is a perfect linear relationship between stiffness and degree of hydration. Stiff jells containing little water could probably retain a nearly perfect sphericity. Somewhat less viscous jells would find it difficult to maintain this shape even under their own weight and would become more oblate. As the water is removed, such geodes would have a relatively larger hollow space than the stiffer ones. On this basis it would be expected that some quite solid geodes could be nearly spherical in form, but that more hollow ones would generally show vertical shortening or oblateness. There is no reason why many very stiff and therefore solid geodes should not be flattened, but it would be surprising if many hollow geodes approached perfect sphericity.

If, however, the original colloid was very hydrous, as the water was removed the geodes would probably be subject to extreme flattening or even collapse. This would reduce the actual volume of the central cavity. Hence one would not expect to find many very flat geodes with large internal cavities, or with a high degree of hollowness.

This latter statement may not apply strictly to the smaller geodes where surface tension may be a greater force in shaping the geode than its own weight, or the pressure of the overlying mud. It would be hard to say at just what size the line should be drawn and probably experimental work would be needed to determine it.

To provide a quantitative check on the plausibility of this hypothetical consideration, a study was made of the shape of the geodes compared to their degree of hollowness. To determine the shape, or really the departure from sphericity, the longest and shortest axes were measured. The longest axis is regularly one of the horizontal ones as the geodes are found in situ and the shortest axis is the vertical one. The ratio of the shortest axis to longest one has been designated as the "degree of flattening." To determine the degree of hollowness of the geode, the surrounding shale was first removed, then the specific gravity of the unbroken geode was determined. Thus the degree of hollowness may be computed. A geode having a specific gravity of 2.14+ is 20 per cent hollow, etc. Two distribution graphs, showing "degree of flattening" and "degree of hollowness" were constructed, one for 120 geodes from the vicinity of Elsayh, in Jersey County, Illinois, and another for 250 geodes from the type locality at Warsaw, Illinois. The results are shown in tables I and II.

TABLE 1.—Relationship between roundness and hollowness for 116 geodes collected in Mill Creek, Jersey Co., Illinois.

Degree of roundness (1.0 is spherical)							
1.0	0.9	0.8	0.7	0.6	0.5	0.4	
0	3	8	7	5	0		0-5% hollow
2	6	5	13	2	3		5-10% hollow
2	8	7	11	6	0		10-15% hollow
1	3	4	4	3	1		15-20% hollow
0	1	1	4	1	0		20-25% hollow
0	0	2	2	0	0		25-35% hollow

TABLE 2.—Relationship between roundness and hollowness for 232 geodes collected at Warsaw, Illinois.

Degree of roundness (1.0 is spherical)								
1.0	0.9	0.8	0.7	0.6	0.5	0.4	0.3	
8	40	53	31	12	7	6		0-5% hollow
3	11	14	4	8	1	0		5-10% hollow
2	3	8	3	3	0	0		10-15% hollow
0	2	4	4	1	1	0		15-20% hollow
0	2	2	0	0	0	0		20-25% hollow
0	1	1	2	1	0	0		25-30% hollow

The data appears to justify the correctness of the speculation. The geodes of higher density and therefore less degree of hollowness have shapes ranging from nearly perfectly spherical to very flat forms with the vertical axis less than half the longest one; but those with lower density and greater degree of hollowness have much more restricted forms. They are neither as spherical nor as flat as the more nearly solid geodes.

It may be of interest to add that all of the primary minerals identified in the Warsaw geodes when in a colloidal state are negative, as is silica, so it is conceivable that they were present in the original mass in a colloidal state, subject to the same changes as the silica and deposited subsequently to the silica, either due to their greater solubility or lesser concentration, or both.

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<sup>1</sup> Van Tuyl, Francis M., The Stratigraphy of the Mississippian Formation of Iowa, Iowa Geological Survey Annual Report, Vol. XXX, 1921 and 1922.

<sup>2</sup> *Ibid.*, p. 344.

<sup>3</sup> *Ibid.*, p. 346.

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