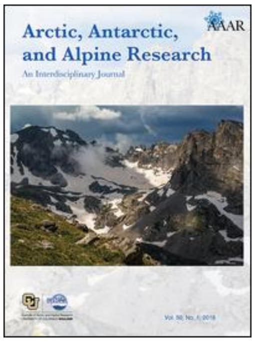

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THE OCCURRENCE OF AN UNUSUAL TYPE OF PISOLITE: THE CUBIC CAVE PEARLS OF CASTLEGUARD CAVE, COLUMBIA ICEFIELDS, ALBERTA, CANADA*

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ABSTRACT

Nests of calcite pisolites ("cave pearls") of approximately spherical form are common features in caves. They grow by accretion of calcium carbonate around rolling nucleii. Nests of cubic pearls are rare. Four nests of cubic pearls are reported, but their development has not been explained.

A nest of cubic pearls in the Second Fissure, Castleguard Cave, is described in this paper. It contains more than 300 individuals in a two-layer orthogonal array. Laboratory analysis of one specimen indicates that it is composed of calcite and grew by accretion to an original spherical nucleus. It is proposed that development of the cubical form resulted from restriction of precipitate supply to the sides and base, a consequence of very regular packing. Very stable growth conditions are required, such as can only be found in certain underground sites.

CAVE PEARLS

Many different types of calcite speleothems are growing in Castleguard Cave today (see Harmon et al., 1983, this symposium). They include nests of pisolites, popularly known as "cave pearls." Although found in only a small minority of caves, these peculiar concretions have been reported from sites worldwide for more than a century.

Cave pearls are formed by the precipitation of concentric, thin calcium carbonate layers around a nucleus, within shallow pools of water that are saturated with respect to the mineral. The nucleus is generally a clast such as a sand grain, mud nodule, fragment of older speleothem, or a gypsum crystal (Gèze, 1965; Hill, 1976; Forti and Pasini, 1977). Bat bones, blue algae, or calcite bubbles have been reported at the centers of a few examples (Coppenole, 1971; Fabre, 1976; Hill, 1976).

The great majority of cave pearls are spherical, or of irregular but still well-rounded form, e.g., ellipsoids. According to Hill (1976), factors affecting pearl shape are the shape of the nuclear fragment, the degree of crowding by other pearls or the walls of the nest (pool), the amount of agitation of the water by falling drops or trickles, the water level, and the axis of rotation of the pearl. Spherical cave pearls usually develop around small and compact nucleii, such as sand grains. Cylindrical or

*A version of this paper was presented orally at a symposium, "Karst and Caves of Castleguard Mountain," at the 8th International Congress of Speleology, Bowling Green, Kentucky, U.S.A., 20 July 1981.

irregular pearls tend to have larger, elongated or irregular, nucleii. The nuclear shape is then reflected in the carbonate coating.

Many authors consider that rotation of pearls by agitation of the water must play an important part in the rounding, especially for smaller (i.e., young) pearls which have a greater surface area/weight ratio (Black, 1952; Gèze, 1965; Hill, 1976). However, agitation may not be essential; large and asymmetrical pearls can continue to grow without rotation by an external force, yet without adhering to the bottom of the pool (Hill, 1976). The force of crystal growth itself is assumed to move the pearl, permitting regular accumulation of precipitate over the entire surface (Emmons, 1928; Davidson and McKinstry, 1939).

The coating mineral is calcite or aragonite. Occasionally, alternating layers of both are found. *C*-axes are perpendicular to the growth surface (Hill, 1976). Pearl diameters range from < 1 mm to 15 cm. It is rare to find one or a few isolated individuals; normally, there are many of similar size, forming a cluster of 10 to 1000 pearls. Often it can be seen that older generations have become incorporated into the bottom or sides of a pool by cementation; a younger cluster of unattached pearls grows upon them.

Cubical Cave Pearls

Nested pearls of regular cubical form appear to be very rare. Apart from Castleguard Cave, we have reports of just four occurrences. La Clamouse, a cave in southern France, contains many nests of spherical pearls. One pool contains a few hundred cubical pearls, 1 to 5 mm in diameter (Gèze, pers. comm., 1982; Durand de Girard, pers. comm., 1982). In a photograph of a sample of 124 of them, we noted that many, usually those of 1 to 3 mm diameter; displayed the same cubic symmetry as the Castleguard examples. Grotta della Galeria Ferroviaria di Bergeggi in Italy also has one nest in an agitated pool. There is more variation of size (1 to 10 mm), and the form is less regularly cubical; larger examples are well rounded (Gèze, pers. comm., 1982). Ghetzarul de Scarisoara, a Rumanian cave, contains many thousands of tiny cubical pearls (< 1 mm). They are limited to pools in a cold zone where the annual temperature ranges from -2.8 to +0.8°C. Ice forms here in the winter and frost is shattering older speleothems. The pearls are the only growing precipitates, and their genesis is considered to be by some some kind of periglacial process (Gèze, 1969). Several hundred cubical cave pearls, 0.5 to 1.0 cm in diameter, are reported from a cave in Mona Island, off the coast of Puerto Rico (Quinlan, pers. comm., 1982).

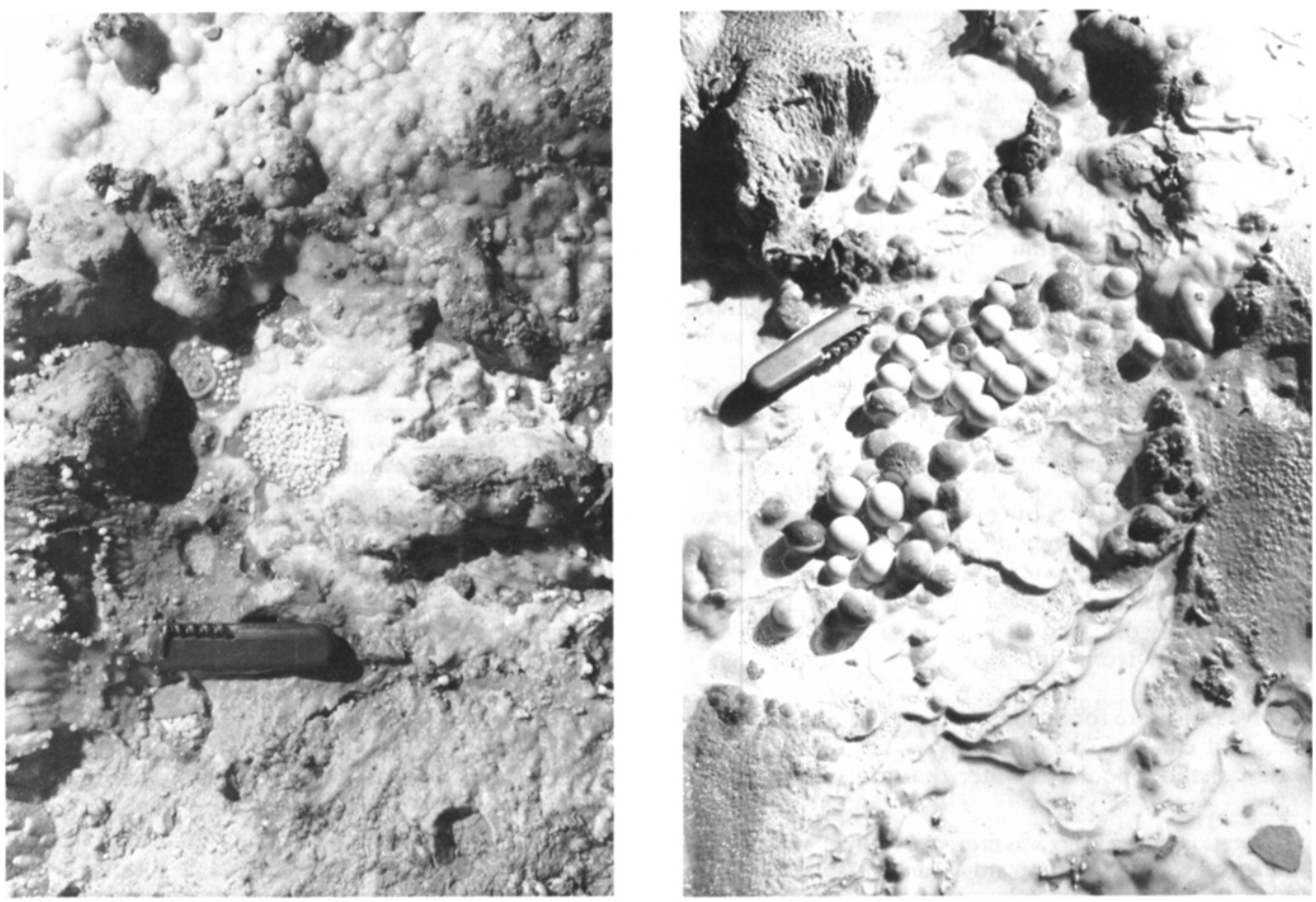

Figure 1. Two nests of spherical (normal) cave pearls in the central grottoes of Castleguard Cave.

The central grottoes of the cave contain many nests of regular spherical cave pools, aggregating thousands of individuals. Pearl diameter ranges from 1 to 30 mm, but typically those in a given nest are all very similar in size. There are a few nests of spherical pearls in other parts of the cave. Examples from the Grottoes are shown in Figure 1.

A solitary nest of cubical pearls was discovered by the authors during the 1977 expedition. It is located approximately halfway between the Big Room and the Crutch, in Second Fissure. This part of the cave is beneath glacier ice where air temperature is +2°C (see Atkinson et al., 1983, this symposium). The nest is in one of six or seven small pools upon a ledge of calcite flowstone. The other pools contain spherical pearls and a few isolated cubical individuals. All appear to be fresh and actively growing.

The nest is shown in Figure 2. It is estimated to contain more than 300 individual pearls of very regular size and shape. Diameter ranges between 5 and 7 mm. The form is a cube with rounded edges and corners (Figure 3). Four spherical pearls, 2 to 3 mm in diameter, are nested among the cubical ones.

The distribution pattern is remarkable, reminding us of sugar cubes in a box. The principal cluster is composed of two apparent layers, each an orthogonal array. A separate group of 20 pearls is disposed less regularly at the edge of the pool, and a few individuals are detached around the perimeter of the main cluster. Many pearls in the lower layer are deeply embedded in a general calcite coating upon the floor. It appears that some of these are free to move, while others are cemented in place.

There are ten empty cubical shells, which appear like open boxes. Three clear examples are seen at the top of Figure 2, immediately left of center. In some fashion, the cores of cubes have been removed here.

One cubic pearl was taken for laboratory analysis (Figure 3). The x-ray diffraction pattern revealed a purely calcite crystalline structure. Figure 4 is a scanning electron microscope image of a section taken through the center. The nucleus is seen to be a rounded fragment of calcite, ca. 0.5 mm in diameter. The concentric layers of calcite precipitated upon it show the normal growth of a spherical pearl up to 1.3 mm diameter. Transformation to the edge-rounded cubic form takes place in a regular manner between 1.3 and 2 mm. It is accomplished by a comparative thinning of each growth layer along the protosides and thickening at the corners. Flattening of sides appears first at the center of each, and expands laterally in successive layers. Curvature first disappeared on the base, then on the sides, and a little later on the top. From 2 mm to the final diameter of 6 mm, the edge-rounded cubic form is maintained with great regularity in all growth layers. There is no evidence of hiatuses in growth, disconformities, etc. Calcite deposition in a given layer perpetuates the *c*-axis orientation of the previous one, as described for normal cave calcites by Broughton (1977). While it is difficult to count discernible growth layers, we estimate that there are between 150 and 300, or 0.009 to 0.018 mm per layer.

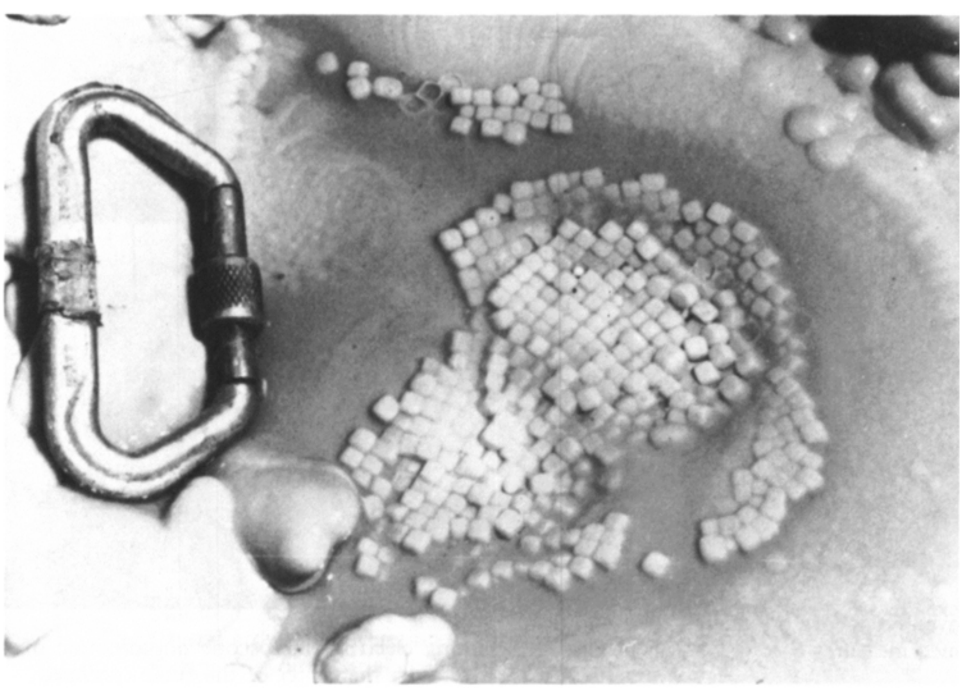

FIGURE 2. The nest of cubical cave pearls in Second Fissure. The carabiner is approximately 10 cm in length.

GENESIS OF THE CUBIC PEARLS

The uniform size and morphology of the Castleguard pearls strongly suggests that all have grown simultaneously from nucleii of similar size. Their restriction to one of a group of pools that are fed from the same dripping source indicates that the cubic form cannot be a consequence of the chemical composition of the source water. Furthermore, the x-ray diffraction results exclude an explanation based upon peculiar crystalography.

The cross section (Figure 4) gives useful genetic hints. Flattening of the faces cannot be attributed to any erosional process because there is no rupture or discordance in the depositional sequence. It shows very clearly that the early growth of the pearl was spherical but that differential thickening towards the corners led to evolution of the edge-rounded cubic form which proved to be stable. Ninety-five percent of the volume of growth of the sample specimen is an edge-rounded cube. We have to determine what factors may have caused the differential thickening of corners, or flattening of sides, in such a regular manner.

Hill (1976) mentions that where pearls in a pool are not rotated, growth layers are generally thinner at the base. We see two possible explanations for this phenomenon: (1) basal crystal growth is retarded by the weight of the pearl; (2) constricted space at the base limits the rate of circulation of water (and, thus, the renewal of Ca^{2+} and HCO_3^- ions) there. This basal thinning appears in our cross section (Figure 4) at 1.3 mm diameter. Similar thinning of the two sides exposed in the cross section appears at 1.5 mm diameter. We suggest that thinning of sides, which eventually produced flat faces, was a consequence of the pearl touching orthogonally disposed neighbors. This suggests that the critical thinning mechanism is (2) above, restriction of the renewal of supersaturated water.

We propose the following scenario:

(1) Precipitation of calcite started forming regular pearls around a few hundred nucleii clustered at the center of a bowl-shaped pool. The nucleii were all of similar diameter, 0.4 to 0.6 mm.

Water was supplied to the pool as trickling films, rather than the direct overhead drips seen at many spherical pool sites. As a consequence, the water was calm, its measure of agitation being insufficient to roll pearls after they had attained diameters ca. 1.0 mm. This calm water condition is a requirement for most of the pearl growth thereafter.

(2) The pearls grew at similar rates, maintaining similar sizes. At diameters of 1.3 to 1.5 mm, they contacted neighbors, inducing the first flat facets at the sides. Basal flattening was a consequence of lack of rolling.

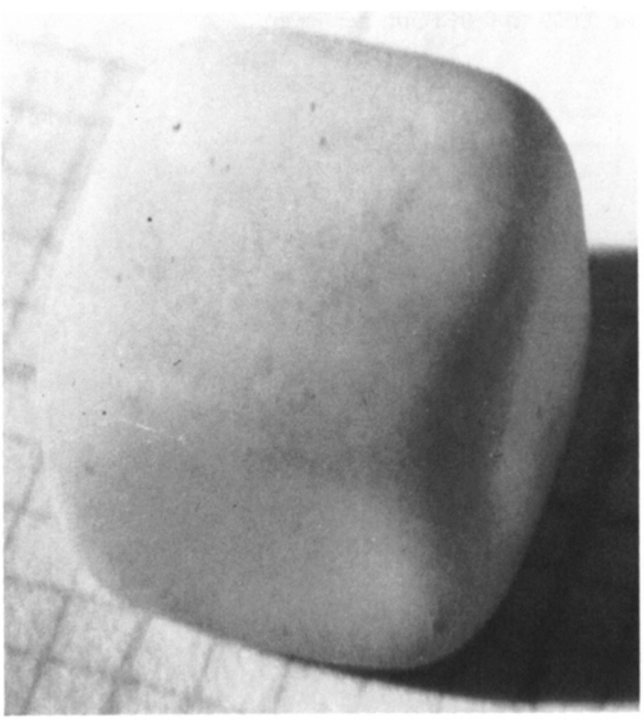

FIGURE 3. The cubic specimen removed for laboratory analysis. Grid scale is 1 mm. The specimen measures 6 × 6.2 × 6.5 mm.

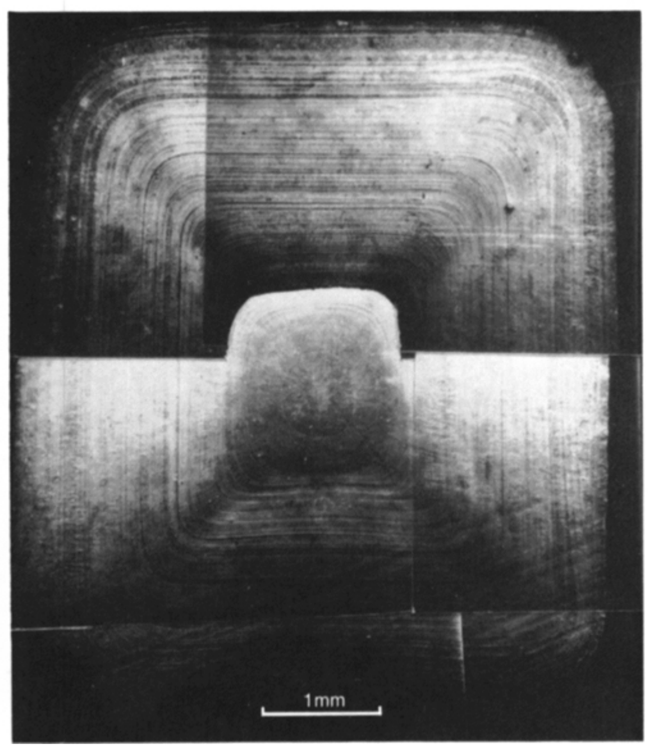

FIGURE 4. Scanning electron microscope photomosaic of a vertical section through the center of the cubic specimen.

(3) At this time, distribution of pearls in the pool must have been an orthogonal array, so that each had four neighbors in a layer (Figure 5a). The expected packing array for coalescent spheres is hexagonal, which would create a pearl with six facets on the sides (Figure 5b). As has been shown, cubic pearls are very rare (five cases reported), and hexagonal pearls are unknown.

The differential growth continued and the flat faces extended, until only rounded edges remained. In our specimen, this was attained at 2 mm.

(5) Growth of the pearls from ca. 2 mm to their modern diameters of 5 to 7 mm occurred with strict maintenance of the orthogonal array until close to the end. Pearls thus remained detached from each other and the bottom of the pool, and were systematically displaced outwards from its center by growth of their neighbors. For example, an orthogonal array of 400 pearls, each 1 mm in diameter, occupies 4 cm^2. Grown to 6 mm, the array is 144 cm^2. Pearls at the margins move outwards an average of 5 cm to accomplish this expansion. The floor must remain a smooth, regular surface, implying that calcite deposition occurs mainly on the pearl. As the array expanded onto the curved sides of the Castleguard pool, its regularity began to break down, angular gaps appearing between adjoining faces as seen in Figure 2. The tops of the pearls in the upper layer have no contact with other pearls. Curvature disappeared a little more gradually, flattening appearently being dictated by the flatness of the four bounding sides. The pearls grow slightly faster in that direction so that the nucleii are no longer at the precise center.

(6) When the pearls were very close to their present dimension, there were significant disturbances of the pool, which had two major consequences. First, the water was sufficiently agitated to displace some of the pearls. The few cubes noted in adjoining nests of spherical pearls were probably ejected. Disturbance continues; comparison of photographs taken in 1979 and 1980 reveals that one spherical pearl (an immigrant) was displaced. Second, the agitation appears to have accelerated the rate of calcite deposition upon the pool floor. Exterior shells of calcite built up around individuals; expulsion of the pearl left the empty shells noted in Figure 2. Other pearls became cemented to the floor. We believe that these recent disturbing events are most probably the introduction of an occasional overhead drip, caused by a surcharge of seepage film flow on the cave roof.

The genetic mechanism we have proposed for the cubic pearls should impress upon nonspecialist readers the remarkable stability of all conditions that may occur in relict caves. We do not know the age of the pearls, but suppose that their growth to present dimension required at least several centuries. Although the air temperature measured at the site at the end of winter is very close to the freezing point (+2°C), there is no evidence of frost shatter in the locality, and the growth mechanism suggested does not require freezing, such as Gèze (1969) has suggested might play a role in the Rumanian example.

One principal point remains at issue: that is how a regular, double-layer, orthogonal array of spherical pearls is obtained at the start. It is an essential condition for our hypothesis. Possibly, this was the consequence of one or a few freezing events.

When calm water freezes, a thin ice film first appears

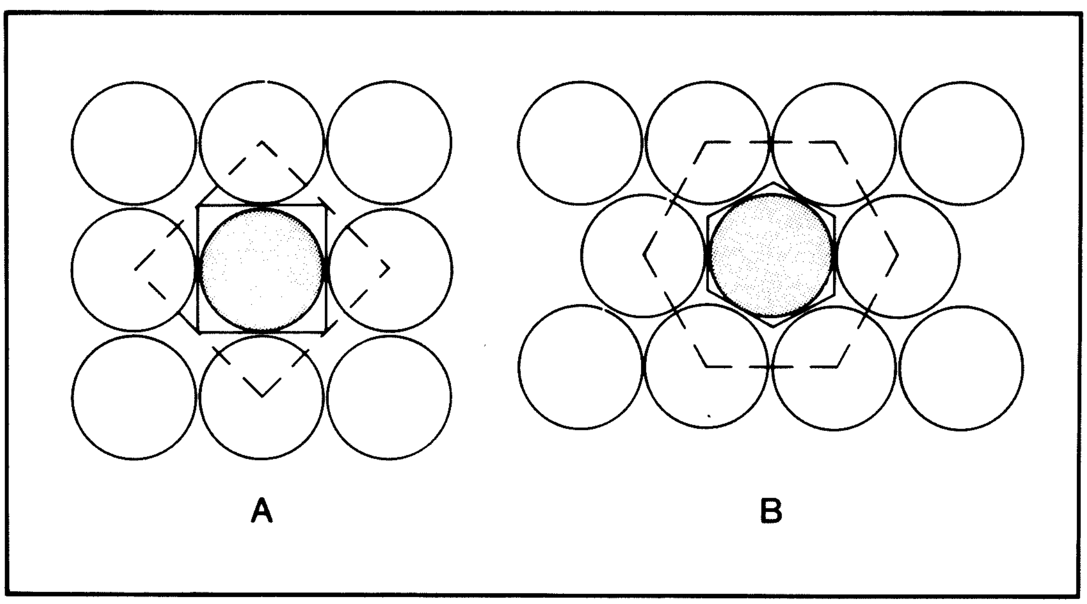

FIGURE 5. A: An orthogonal array (or packing pattern) of spheres. B: An hexagonal array of spheres. Crystal growth by accretion to the central sphere where growth rate is restricted by lateral contact is shown. For discussion, see text.

at the surface, with c-axes perpendicular to it. As it thickens, crystals grow downwards in a columnar manner and later ice accretes laterally to the columns. We suggest that regularly distributed ice columns penetrated an initially irregular array of small spherical pearls and displaced them into the orthogonal pattern as freezing accretion continued. For example, in a single layer, hexagonal array of spheres (the optimal packing pattern), the pore volume available for water is only 39.5% of the total volume of the layer. This increases to 47.6% with the adoption of an orthogonal array; thus, uniform expansion of columns upon freezing should tend to favor rearrangement into the orthogonal pattern. This suggestion is hypothetical. It has not been tested experimentally.

ACKNOWLEDGMENTS

Professor Bernard Gèze and Dr. J. F. Quinlan informed us of other sites of cubic cave pearls. M. Durand de Girard supplied photographs of La Clamouse cubic pearls. The x-ray diffraction was obtained from Jean Renault at I.N.R.S.-Pétrole, Québec, and the cross section at the Department of Geology, McMaster University. Dr. T. C. Atkinson provided useful discussion. Derek Ford revised our text and we are especially grateful to him for our participation in Castleguard expeditions.

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