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HOW DOES CONE-IN-CONE MATERIAL BECOME EMPLACED?*

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ABSTRACT. Cone-in-cone calcite sandwiched between the counterparts of an Eocene fish is the basis for a review of the theories concerning the emplacement of such material. Any theory for ordinary bedding plane cone-in-cone that cannot explain this unique fossil fish occurrence satisfactorily must be considered inadequate.

The belief that the specimen here described displays a feature not hitherto reported in any discussion of cone-in-cone is the excuse for still another paper on that much-debated phenomenon. Most articles on cone-in-cone seem to be concerned chiefly with the origin of the conical and associated structures, but here the emphasis is on the origin and emplacement of the cone-in-cone material before the development of the conical structures, which, in the opinion of most observers, are secondary.

On June 25, 1953, accompanied by George Pipiringos, also of the U. S. Geological Survey, I examined the talus slope on the south face of Steamboat Mountain in the northwestern part of the Red Desert, about 30 miles northeast of Rock Springs, Wyoming. Among the mixed igneous and sedimentary debris I found the small piece of rock here figured (pl. 1, figs. 1-4). It very likely came from a layer in the basal part of the Green River formation (Eocene) that crops out in the steep escarpment around the mountain, but, because success in finding the exact bed seemed remote, no effort was made to locate the source stratum. The rock has the imprint of a fossil fish on one side and its counterpart on the other, with 2 centimeters of relatively pure calcite separating them. Whether or not a similar layer of cone-in-cone existed immediately beneath this at the outcrop, with yet another counterpart of the same fish, is, of course, unknown. To find a fossil fish in rock from the Green River formation, which is celebrated for its fine fish remains, is not surprising, but to find the counterpart of the same fish on the opposite face of the rock separated by 2 centimeters of cone-in-cone calcite, is astounding and certainly calls for an explanation. It would seem now that any theory purporting to account for the emplacement of the material in the usual cone-in-cone found in sedimentary strata must also explain satisfactorily how the counterparts of this fish got separated by 2 centimeters of fibrous calcite.

The collector of fossil fishes or fossil leaves knows that well-preserved specimens and their counterparts generally occur along bedding planes and that an appropriate blow of the hammer opens the fossiliferous rock along such a plane of weakness. It is not difficult to imagine the original fish or leaf settling through the water to the bottom of the pool or lake where it flattened out on the sand, silt, or other sediment, and, covered by more deposits, underwent the physical and chemical changes incident to fossilization, leaving its more prominent features clearly impressed on the opposing layers along the bedding plane. Is there any reason to suppose that the Steamboat Mountain fish was not thus embedded and preserved some 40 million years ago?

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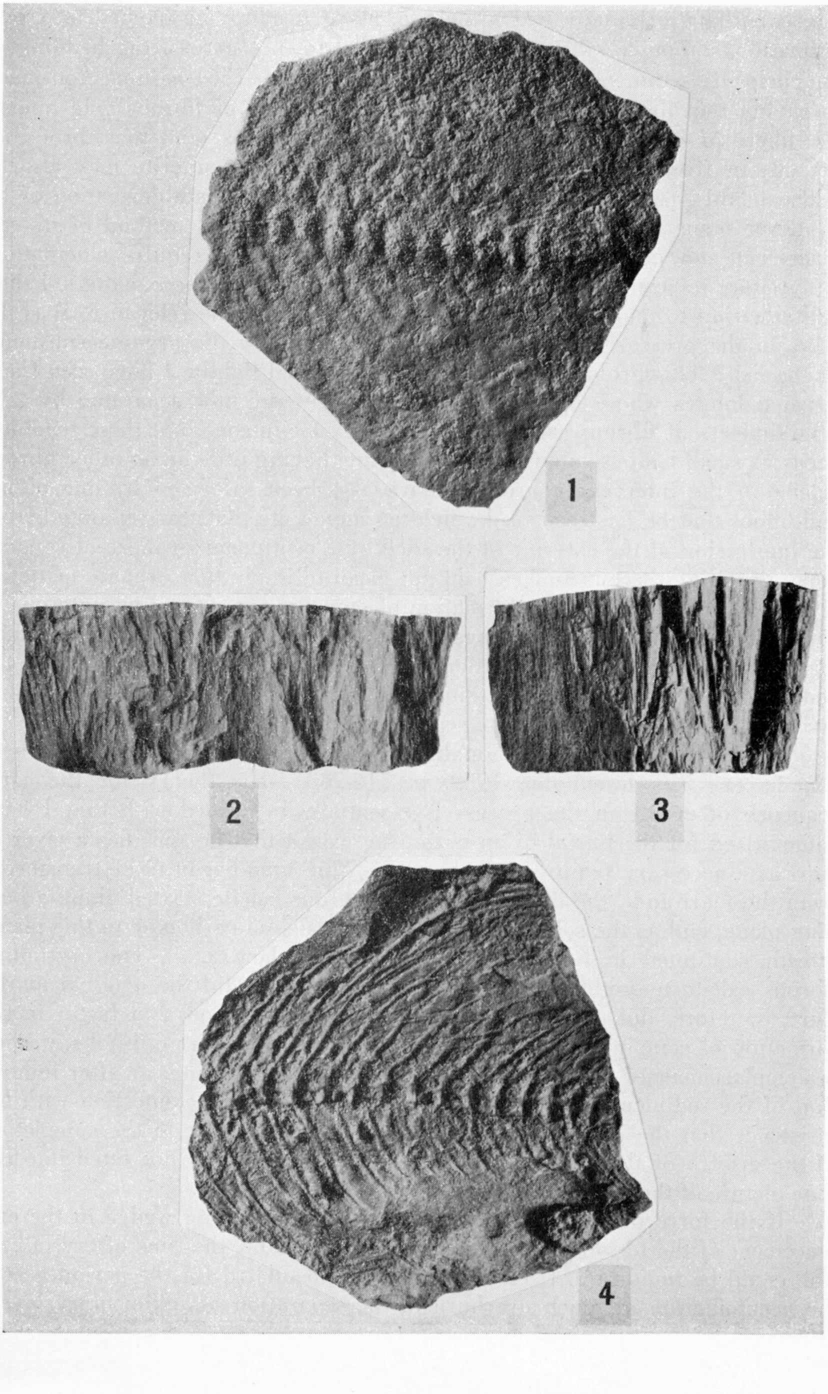
Assuming that the fish was buried in the manner just described, how and when did its counterparts get separated by fibrous calcite? This calcite, which perhaps originally was aragonite, may, in effect, be likened to a vein formation, although its position was parallel to, not across, the bedding of the enclosing sediments. Perhaps Pettijohn (1949, p. 156) assumes too much in saying that the condition is "comparable to those of fibrous vein quartz, the fibers of chrysotile veinlets, fibrous gypsum veins, and the fibrous ice crystals in frost-heaved soils." Fibrous manganiferous siderite may also be added to this list (Hendricks, 1937). Whatever its ultimate derivation or by whatever name the material may be called, the time and method of its emplacement and crystallization along the bedding plane require elucidation.

Before reviewing some of the theories for explaining these matters, I shall call attention to another observation that may have some relevance. Was the lime, in the present instance, attracted to the site by the organic substance of the fish? This probability must not be dismissed lightly. I have seen Cambrian trilobites whose upper and lower surfaces are now separated by 2 to 3 millimeters of fibrous calcite and incipient cone-in-cone, but these trilobites occur as small lenticles along a bedding plane having little or no other fibrous calcite in the intervening areas. I have also been informed by one of my colleagues that he has seen in the field an ammonite that was separated from the impression of the exterior of the shell by a centimeter or more of cone-in-cone. By citing these examples I do not mean to imply that organic matter is always a concomitant of the formation of cone-in-cone, for many outcrops of cone-in-cone do not show or suggest the presence of any apparent organic matter. Perhaps the organic matter, such as a fish or leaf, simply leaves the bedding plane weakest at those sites and, consequently, makes the opposing layers of rock more susceptible to separation there.

W. A. Tarr gave much thought to the investigation and explanation of cone-in-cone (in Twenhofel, 1932, p. 716-733). His theory for the early sequence of events in the process is essentially in accord with that I have summarized for the burial of an organism, except that he specifies a layer of marl as a necessary requirement. Then (p. 726) lime began to be transferred from the marl and "the deposition of the fibrous calcite started along a bedding plane, and as the solutions carried more calcium carbonate to this plane, growth continued in both directions from the plane: . . . The crystalline fibrous calcite undoubtedly occupied less space than did the original marl." Tarr, therefore, did not invoke the force of crystallization as a factor in the formation of cone-in-cone. It should be noted also that Tarr did not say when the emplacement of fibrous calcite occurred—before, during, or after induration of the sediments. His only reference to time was in connection with his insistence that the conical features developed subsequently to the completion of the growth of the fibrous calcite. This "time" also was not fitted into the time picture of the whole.

If the force of crystallization was the active, opening wedge in the emplacement of the fibrous calcite along a bedding plane, the time of crystallization could be important. If crystallization be postulated for the period before the accumulation of much overburden, the separation of sedimentary layers

PLATE 1



by that method might be readily possible, but if much overburden had accumulated, crystallization, although powerful, probably could not lift all of this weight and would merely cause differential compaction for a short distance within the adjacent sedimentary layers. Most well-developed bedding plane cone-in-cone shows the largest cones with broadest bases on the upper side of the emplacement. The upper surface of these bases may show that some of the cupped conelets have slipped with respect to one another. I have never observed this feature on the under side of cone-in-cone. Does the offsetting of these conelets mean that during or after emplacement of the calcite the yielding was in the sediments above rather than in those below the original bedding plane?

Another theory for cone-in-cone along a bedding plane, but not assuming a marly layer, hints that external structural stresses may have caused spaces to open up along weak bedding planes, thus permitting lime solutions to enter and crystallize. It seems difficult to disprove that this may perhaps apply to some occurrences. Tarr (Twenhofel, 1932, p. 722), however, reported that the Comanchean of Kansas has a more or less lenticular cone-in-cone layer spread over an area 25 by 40 miles in extent. This layer is so characteristic of a given stratigraphic horizon that Twenhofel and Tester (1926) considered it useful, discretion implied, for correlation purposes. How external stresses could have operated to produce the opportunity for cone-in-cone calcification over such an extensive area and at the same general level requires a strenuous exercise of imagination to visualize.

The theories considered thus far have assumed the presence of a bedding plane with adjacent sedimentary layers already in place. Suppose, on the other hand, we assume that the floor of a pool or lake, whose waters are charged with lime, is receiving limy sediments, granular or stromatolitic. Is it possible that the accumulation of sediment may grow upward at such an even rate and so homogeneously that the upper surface of a 2-cm thickness of fine lime should preserve a faint but still recognizable counterpart of all the inequalities of the lower surface, including the outline of the skeletal remains of a fish? I do not know that such a possibility has ever been demonstrated, tested, or proved on the scale comparable to that of the specimen here being considered. In any event the development of fibrous calcite from the amorphous lime would still require explanation.

Figs. 1-4, top, side, and bottom views, respectively, of a cone-in-cone specimen from the south face of Steamboat Moutain, 30 miles northeast of Rock Springs, Wyo. Natural size. Photos by Nelson W. Shupe.

Figs. 1, 4, are counterparts of an Eocene fish, separated by 2 centimeters of cone-in-cone calcite, shown in figures 2, 3. Fig. 3 shows the broadest-based cones toward the upper surface. Near the upper left but not clearly depicted is a small patch of the stairwaylike annulations or drag marks commonly seen in weathered cone-in-cone. The direction of the broad-based cones and the ascending arrangement of the "steps" of the drag marks serve to orient the usual specimens of cone-in-cone. For example, the specimen illustrated by Twenhofel (1932, fig. 101B) appears to be upside up, but that by Shaub (1937, fig.4) to be upside down.

Still another theory for cone-in-cone was proposed by Shaub (1937), and was based on analogy with the formation of conical cups in alluvial material along the floodplain of the Connecticut River. According to this theory, "cone-in-cone originates as the result of contraction, settling, or volume shrinkage during dewatering of highly saturated, porous, fine-grained sediments of any kind (such as silts, marls, finely comminuted organic materials, including certain kinds of coals, . . . fine-grained sand, hydrated silica, precipitated calcium carbonate, etc.) deposited under a loosely packed condition." Although Shaub here pointed out a striking analogy so far as the end products are concerned, I cannot accept the conclusion that, therefore, the processes leading to those ends are identical. Too often I have noted that in nature, art, and industry, identical or almost identical-looking products may result from application of quite different methods.

In the presentation of this discussion I have raised questions to which I have volunteered no answers. The reason is plain. I do not know the answers. The subject is like the many-headed hydra whose slaying was a problem because no sooner was a head lopped off than two others came up in its place. Nevertheless, I recommend this fossil fish and its counterpart as food for thought to researchers on cone-in-cone.

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