Reports

Carbonaceous "Snowflakes" and the Origin of Life

Abstract. The possibility that the intricate "organized elements" found in some carbonaceous chondrites are to be interpreted, not as microfossils of once-living cells, but as organic-chemical analogues of similarly intricate snow crystals is raised; tests and implications are discussed.

Claus and Nagy (*1*) have exhibited photomicrographs of "organized elements" of one to three tens of microns diameter, found abundantly within some minerals of carbonaceous chondrites. These are neither contaminants of their sample, nor recognizable as any known forms. Their associates, with other chemists (*2*), have demonstrated that in these chondrites organic compounds of considerable complexity, for example long-chain paraffins and even quasi-nucleotides, can be found, and the charring, fluorescence, and differential staining of the "organized elements" make it likely that some of the microscopic structures are themselves chemically of complex organic composition. In this note the correctness of all these statements, which indeed are strongly supported by the careful work of the discoverers, is assumed, though characterization is by no means complete. Are these organized elements, whose morphology is reminiscent of algal cells of some sort, indeed the microfossils of once-living cells, unfamiliar because extraterrestrial?

It is the intention of this report to suggest an alternative interpretation. Not all of the organized elements are of intricate form. Many are spherical, or clustered spheroidal granules, made polyhedral by packing. Such elements might very reasonably be expected in many circumstances, even inorganic. The regular spheres of the casein globules in milk, on a much smaller scale, to be sure, may stand as models for such objects. S. W. Fox (*3*) has produced, for example, various bubbles and capsules of a similar sort by heating his complex organic mixes of high polypeptide content. There is a long history of other "artifacts." Let me put it by extension, then, that in environments of suitable water and ion content and temperature, even the most complex of the bristled, polyhedral, and encapsulated forms observed can grow in time from nonliving mixes of organic polymers of varied kind, provided that the sterility of the environment prevents their being consumed as free energy sources by living cells, and its reducing nature prevents their oxidative breakdown. Before this possibility is rejected as absurd, the reader is urged to examine photographs of snowflakes (*4*), whose wonderful dendritic and platelike forms, on a similar scale of size, are surely the result of nothing more complex than the growth of crystals of nearly pure water from the vapor phase, perhaps nucleated, and perhaps in the presence of some acoustic means of information transfer from one arm to another (*5*).

The point is that any complexities of form resolvable on a micron scale represent relatively so few constraints on the extraordinarily numerous possible configurations of molecules that their thermodynamic significance is relatively small (*6*). Even small free energy sources, without participation of anything like the molecular complexity of genetic polymers, are therefore capable of producing "spontaneously" micron-sized regularities, beyond any clear limitation. Since the composition and chemical origins of the "organized elements" of Claus are surely much more complex than those of the familiar snowflake, it appears plausible that their gross morphology also may have become more complex, without involving the molecular specificity, the self-duplication, or the mutability of living processes. Any intricate "organized elements" on this view are then not fossils at all but mere carbonaceous "snowflakes." (The term is of course used only metaphorically; it is not implied that they are of water, or even that they are microcrystalline.)

This interpretation is open to test. If it is true, the "elements" should show a wider variability than is characteristic of life, visible perhaps even on the microscopic level, and surely on the molecular level. A low content of any specific polymer, and a low level of optical activity among all the asymmetric monomers present, are both to be expected. The importance of widespread experiment with appropriate constituents in appropriate environments to try to simulate the "snowflakes" is evident. Possibly similar terrestrial paleoenvironments may be found and examined.

It does not at all follow, however, that the "organized elements" lose significance if they are but snowflakes of a sort. On the contrary, if this interpretation were verified, it would strongly suggest that such micron-scale order is a probable precursor of living systems. The prebiotic environment would be marked by such unliving microscopic order, as it is surely marked by unliving molecular complexity and by high free-energy content. Just as when the famous typewriting ape is set at work to produce *Hamlet*, he is most likely to fill whole libraries with jargon versions of many other plays first, so the environment which is eventually to produce life first becomes rich with the simulacra of life *on various levels of size*. It may well be that spatial association between self-replicating molecular species and complex pseudo-crystalline aggregates of the "snowflake" type play an essential role in closing the evolutionary gap between an early genelike life (*7*) and the cells of the present day.

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Type manuscripts double-spaced and submit one ribbon copy and one carbon copy.

Limit the report proper to the equivalent of 1200 words. This space includes that occupied by illustrative material as well as by the references and notes.

Limit illustrative material to *one* 2-column figure (that is, a figure whose width equals two columns of text) or to *one* 2-column table or to *two* 1-column illustrations, which may consist of two figures or two tables or one of each.

For further details see "Suggestions to contributors" [*Science* **125**, 16 (1957)].

References

1. G. Claus and B. Nagy, *Nature* **192**, 594 (1961); *ibid.*, in press.
2. S. K. Vaughn and M. Calvin, *Proceedings of the 1st Space Science Symposium (Nice)* (North-Holland Publ. Co., Amsterdam, 1960), p. 1171; B. Nagy, W. Meinschein, D. Hennessy, *Ann. N.Y. Acad. Sci.* **93**, 25 (1961); ———, *ibid.*, in press.
3. S. W. Fox, *Science* **132**, 200 (1960); oral presentation at AAAS meeting, Denver, 1961.
4. U. Nakaya, *Snow Crystals* (Harvard Univ. Press, Cambridge, Mass., 1954).
5. D. McLachlan, *Proc. Natl. Acad. Sci. U.S.* **43**, 143 (1957).
6. P. R. Porcino, "The entropy of intricate organic patterns," M.S. thesis, Cornell University, Ithaca (1951).
7. H. Blum, *Am. Scientist* **49**, 474 (1961).

19 January 1962

Toxicity of Plankton to Cristispira Inhabiting the Crystalline Style of a Mollusk

Abstract. The crystalline style of *Saxidomus giganteus* supports a large population of *Cristispira* spp. which swim freely in it except near the functional end which impinges on the gastric shield. Here the style is frayed and mixed with ground food material, while amylolytic enzymes and an oxidase are released. Glucosone appears to result from oxidase activity. This proved toxic to cristispira in fairly high dilution. Several tests of the toxicity of extracts of plankton, which forms the food of *Saxidomus*, were made. In every case such extracts proved toxic.

I have previously reported (*1*) that dense populations of an undetermined species of *Cristispira* occur in the crystalline style of *Saxidomus giganteus* Deshayes and that, while the organisms swim freely in that environment in all directions, none, or extremely few, are ever found within a few millimeters of the functional end of the style, which, during feeding, is projected from the diverticulum of the stomach in which it is secreted and rotated against the gastric shield. The cristispira appear to be sensitive to some external adverse influence when they reach this point which causes them to retreat from it. Surmises were discussed as to what this influence might be.

It is well known that the grinding and stirring action of the crystalline style against the gastric shield is accompanied by softening and eventual solution of its material with simultaneous freeing of polysaccharide-splitting enzymes. I have shown that the style material contains a peroxidase which, in association with a substance, or substances, derived from the food material of the mollusk during the grinding process, establishes an oxidizing system (*2*). I suggested that something resulting from oxidation of food material might be responsible for the repulse of cristispira at the head of the style.

A culture of actively swimming cristispira is readily obtained by steeping pieces of styles, which have had their grinding ends, with food material attached, removed, and have been thoroughly washed, in sea water at a temperature not exceeding 5°C for some hours, the style material completely dissolving. Support for the foregoing surmise was obtained by adding to such a culture a few of the severed anterior ends of styles with accumulations of ground food material attached, which resulted in the death of all the cristispira present in a few hours at 5°C. The only means of judging of the death of the organisms in these, and other experiments to be described, has been by the complete cessation of motility, but, since this is usually quickly followed by their disintegration, it seems to be a reliable criterion.

The only substance which has been recognized as probably resulting from the oxidizing activity of the crystalline style system is glucosone, obtained by reacting it with glucose (*2*). Since this substance has been shown to be toxic to many animals (*3*) it seemed of interest to determine whether it were so in relation to cristispira. It was found that addition of 0.5 percent of glucosone to an active culture kept at 5°C killed the organisms completely in 1 hour. It therefore seemed possible that glucosone might be responsible for the repulse of cristispira at the end of the style. However, the production of glucosone under the united action of foodstuff and style has been found to operate only in the presence of glucose as substrate, and there is no evidence of the breakdown of the complex polysaccharides of the food organisms to the hexose stage by style activity. There is some divergence of opinion about this even in application to more simple polysaccharides. Yonge (*4*) found that, among those he studied (including pectin, glycogen, starch, lactose, maltose, raffinose, sucrose, and cellulose), only starch and glycogen were degraded to the hexose stage by the style of *Ostrea edulis*. On the other hand Lavine, in the cases of *Mya arenaria* and *Mactra solidissima* (*5*), and Newell, in those of *Ostrea edulis* and *Mytilus edulis* (*6*), found that the style enzymes degraded cellulose, and the former found glucose in the digest after several days. Newell failed to detect either glucose or glucosone after 25 hours. Possibly digestion was not carried far enough in this case and, even had glucose been derived, no oxidation to glucosone was to have been anticipated in the absence of the component of the food material which is essential to promote the oxidase reaction of the style (*2*).

It would elucidate the situation if it could be determined whether the substance toxic to cristispira occurs in the plankton organisms of which the food material of the mollusk consists before it had been submitted to the action of the style enzymes, but this could be accomplished only if cristispira could be maintained in culture in something other than a solution of style material. This has not been found possible. Nevertheless, a number of samples of plankton have been examined from this standpoint. The results do no more than confirm those previously obtained with food material collected and ground on the styles, but they bring out two points of collateral interest. Plankton was collected in the usual manner over, or in the neighborhood of, saxidomus beds. The material was washed free from coarse components and the remainder filtered through paper, washed, and finely ground. Fractions of the resulting pulp were extracted with as small volumes of sea water as practicable, and again filtered. For tests, samples of the clear, usually colorless, filtrates were added to standard volumes of cristispira cultures; the mixtures were maintained at low temperature (5°C, or lower) for varying periods, and examined at measured intervals for vitality. Checks, with volumes of sea water corresponding to those of plankton extracts in the tests, were maintained under the same conditions and examined at the same intervals.

The results brought out two definite points. (i) All plankton extracts were toxic to cristispira sooner or later, while corresponding checks remained fully active. The periods for complete killing varied considerably in various tests. Quantitative comparisons were not possible, but, with equal volumes of culture and extract, the period was usually between 60 and 90 minutes. (ii) The biological constitution of the plankton was a matter of indifference. This varied very greatly through the period during which the tests were conducted, in some cases phytoplankton predominating, in