Are the 3,800-Myr-old Isua objects microfossils, limonite-stained fluid inclusions, or neither?

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Bridgwater et al. issued a ‘cautionary note’ concerning several reports published by Pflug and co-workers describing objects called yeast-like microfossils (Isuaphera isua Pflug) from a metamorphosed quartzite of the 3,800-Myr-old Isua supracrustal belt of south-west Greenland; Bridgwater et al. believe that the objects described by Pflug et al. are ‘indistinguishable from limonite-stained fluid inclusions’ and hence are non-biogenic. I show here that the objects are neither limonite-stained fluid inclusions nor microfossils, but are limonite-stained cavities from the otherwise complete dissolution by weathering of ferruginous dolomite grains in these rocks. Several supporting arguments presented by both sides are believed to be invalid, and others are ambiguous. In view of the extensive research on the earliest life forms, and their significance to evolution, to early geochemical cycles and to the origin of the atmosphere and some ore deposits, the exact nature of the Isua objects, and particularly the validity of the evidence either for or against a biological origin, are of considerable importance. A careful evaluation of the evidence from Isua is particularly pertinent, as bona fide Precambrian fossils are also found in chemically similar (but much younger) silica-rich environments.

I have examined the following sections of the original rock in question (no. 2377); 2377-1-D from J. W. Schopf, UCLA; and 2377, 2377-G3, and 2377-G5, and a small piece of the rock itself, from H. D. Pflug. The objects vary only in abundance among the four sections.

A brief description of the ‘fossil-like’ objects is necessary, because some of those described by Bridgwater et al. are not of the same type as are those described by Pflug et al. The latter are irregularly ovoid features, 10–40 μm in length, which are distinguishable from the embedding quartz on the basis of two features: (1) the walls of the ovides are coated and hence outlined by a granular substance having a relatively high index of refraction (n much greater than that of quartz); some ovides are partly filled by this substance; and (2) this substance is dark yellowish brown.

Bridgwater et al., however, described two quite different ‘categories’ of ‘fossil-like’ objects. One is yellowish to reddish brown (here called brown objects), and corresponds exactly to the objects described by Pflug. The other are ‘... clear, spherical to ellipsoidal objects (Fig. 1b), occur only within quartz grains (rather than at grain boundaries); these structures are comparable to fluid inclusions ...’ (here called clear objects). They are always closely associated with the brown objects (Fig. 1b, c), but in all the many photomicrographs of Isuaphera isua presented by Pflug et al., not a single clear object is seen. Although they did not so state explicitly, the context indicates that Bridgwater et al. believed that the brown objects are the exact equivalents of the clear objects, but as a consequence of occurrence on grain boundaries, the brown objects have become iron stained. I hope to show first that this equivalence of the evidence is indeed correct, but then to show that neither brown nor clear objects are, or were, fluid inclusions or microfossils.

Not being a palaeontologist, I am not qualified to discuss the various morphological features within the objects that are described by Pflug et al. as biogenic structures, except to note that at least some of the Isua objects each appear to my untrained eye to be extremely similar to at least one or more of a series of previously described (and more generally accepted) Precambrian microfossils. As a result of my petrographic examination, however, I present the following observations that are pertinent to the origin of the Isua objects and may also have some applicability to samples from other localities.

(1) Deformation of the host material: the bulk of the evidence presented by Bridgwater et al. to negate a biological origin for the brown objects is based on the premise that such fossils could not be preserved in rocks that had undergone such an extensive series of high-grade metamorphic and tectonic events. The amount of deformation in any compositionally banded metamorphic rock will vary widely with the nature of the assemblage; quartzites are among the most resistant bands and frequently form boudins, and hence should be the most resistant to the destruction of any fossils (macro or micro). The quartz in sample 2377 does show some preferred orientation, from an unknown stage in the metamorphic history. This was best seen by a simple optical integration procedure: view in crossed polars with the 104 plate, at very low magnification and grossly defocused. During rotation of the stage, an overall change from bluish to yellowish is readily visible.

(2) Distribution of the objects: most of the clear and brown objects occur in a very small fraction of each section, in scattered clusters or bands of larger quartz grains (100–500 μm in diameter). These particular bands have little or no actinolite (Figs 1a, 2).

(3) Nature of the clear objects: I find most of the clear objects to be crystals of one or more silicate minerals and not fluid inclusions (Fig. 1c). They are ovoid single crystals (some are slightly greenish) having an index of refraction n much greater than quartz and moderate to high birefringence, and in polished sections they are more reflective than the host quartz. The clear objects that are not crystals of silicate minerals are ovoid, single crystals of a rhombohedral carbonate mineral, presumably ferruginous dolomite. Some of these, in turn, have one or more
small (~1–2 μm) fluid (?) inclusions attached to the interface with the host quartz; these inclusions may be high-pressure gas, as the fluid inclusions show stain birefringence and/or decrystallization to form pits where they are cut by the polished surface. Identification as dolomite was based on optic sign, on estimates of the birefringence and the indices of refraction relative to those of quartz, and on solution in HCl under the microscope, accompanied by very slow effervescence of three small grains that were at the surface. The presence of dolomite in contact with quartz places limits on the maximum pressure-temperature combination of the metamorphism. These two minerals react to form diopside plus CO₂ at 2,000 bars at ~520°C (ref. 11); each 20°C above 520°C increases the pressure another 1,000 bar. I do not know why these few grains have not reacted, whereas other presumed grains have reacted to form actinolite.

(4) Nature of actual fluid inclusions present: only a relatively few isolated true fluid inclusions were found. These are at most only a few micrometres in length (Fig. 3); they are irregular or faceted but not void; they consist of two isotropic phases (liquid and a gas bubble, which is frequently in motion); n is much less than quartz; and at a polished surface, they would be represented only by holes. None was found in the size range (and shape) of the clear or brown objects. Hence I suggest that the two clear objects illustrated by Bridgwater et al. in their Fig. 1b, which they called fluid inclusions, may be silicate or carbonate crystals rather than fluid.

(5) Distribution of objects relative to quartz grain boundaries: the specific nature of the occurrence of the objects—on grain boundaries or within single quartz crystals—is critical to the interpretation of many of the data obtained, and is surprisingly difficult to determine unambiguously. Pfug et al. stated that some of his brown objects were actually within single crystals of quartz, whereas Bridgwater et al. stated that the brown objects “...show a marked concentration at quartz grain boundaries...”. The importance of this distinction lies in the fact that if a brown object was actually enclosed within a single crystal of quartz, both deformation and chemical metamorphism of the surrounding rocks would be of no consequence to its preservation unless that quartz crystal were deformed and recrystallized. A close analogy is the preservation of the spiral growth patterns in some metamorphic garnets 13. However, the apparent occurrence of some brown objects within quartz crystals is only apparent, as shown by the next observation.

(6) Solubility of the brown material: I gently crushed ~100 mg of sample 2377 to ~1 mm, immersed it in 1.55 p.p.m. index oil, and picked out ~50 grains, each containing one or more typical brown objects. After removal of the oil, I covered these grains with dilute HCl (20 vol.% concentrated HCl, 80 vol.% H₂O) at 22°C. All the brown objects (~250) and brown grain boundaries (Fig. 4) lost their brown colour completely within 30 min, leaving cavities partly or completely filled by clear or slightly yellowish acid. Organic materials in sediments, particularly old sediments, are generally considered to be relatively immune to attack by HCl, and this insolubility, even in hot, concentrated HCl (10%) is commonly used as the basis for a laboratory technique for concentration of the organic matter 13. Because the brown objects were readily soluble in cold dilute HCl, and because a yellow solution remained in the cavities, I conclude that the brown material in the objects I have examined is not organic and is probably limonite. Even more important to other studies of possible Precambrian organic matter is the fact that these brown objects were not completely enclosed within single quartz crystals, even though they appeared to be. From the fact that clear objects, of both carbonate and silicate types,
trapping primary gas, and no such bubbles are found in the clear objects.

They also found brown objects with rhombohedral, obviously crystalline shapes (see their Fig. 1e). These may well represent former carbonate crystals. The exact mechanisms whereby soft microfossils become preserved in crystalline silica are obscure, but there seems to be no doubt that such structures are preserved in younger rocks, though the reading of the record is fraught with difficulties. However, I see no difficulty in the presumption that the cavity representing a microfossil within a quartz crystal could become faceted and hence could represent merely an intermediate stage in its destruction. Similarly, I see no difficulty in the presumption that actinolite needles could have grown in such a way that they appear to penetrate the brown objects, regardless of their origin.

Pflug et al. stated that the brown material is more resistant than quartz to attack by hot vapours of HCl and HF; this is to be expected for limonite, as iron chlorides and fluorides are not volatile as SiF₄ is.

Pflug et al. reported that brown objects (supposedly within single quartz grains) showed weak fluorescence, and extensive optical, IR absorption and Raman spectral studies by Pflug et al. showed a series of organic components in the brown objects. I suggest that these data may stem from natural organic contamination during weathering, or even from migration of the indigenous, 3,800-Myr-old organic matter reported to exist in these rocks. The extremely weak spectra expected from major limonite could easily be lost in the very strong signals expected from trace organics. The 'multilaminar sheaths' (that is, multiple layers of brown material on the walls) reported and illustrated by Pflug et al. may represent several stages of deposition of limonite. The several brown objects that also contain liquid and vapour in the central cavity (ref. 1, Fig. 1f; ref. 5, Plate 2, Figs 4 and 8) may well be cavities formed by weathering of dolomite grains that have since been partly resealed by precipitation of silica (the highly variable gas–liquid ratio ratio suggests that this sealing is poor).

Many Phanerozoic fossils have been infilled with calcite or other minerals, and subsequently leached, but these occur in permeable, polycrystalline rocks, not within single crystals.

Even though I conclude that the Isua objects are not microfossils, I am confident that organic material, and even morphologically recognizable fossils, if actually trapped within single crystals, should be able to withstand rather high grade metamorphism. The ability of organic matter to persist is evident from the fact that coalification of organic matter does not proceed as far in a given set of conditions if the gaseous products cannot escape as it does if gaseous products can escape. I also conclude that incipient weathering (and in these samples, even complete dissolution of dolomite grains) can take place through seemingly tight grain boundaries and even through invisible fractures in apparently 'unweathered' rocks. The most important conclusion, however, is that considerable caution is called for in the study of Precambrian microfossils.

I thank Professors Pflug, Bridgwater, Schopf, Klein and Strother for their cooperation and discussions, and for access to samples from Isua.

Received 17 February; accepted 10 August 1981.