Malachite occurs in sandstones of the upper part of the Wolstenholme Formation in Olrik Fjord. One bright green patch several metres across occurs in an intensely faulted area and here malachite is richly disseminated in the sandstone.

Magnetite is not uncommon in the gneisses and also occurs in cross-cutting pegmatites. At Magnetitbugt, at the top of the sea cliff, it occurs in iron-rich veins and in layers within the gneiss. The magnetite rocks are commonly schists containing amphibole and quartz but some fine-grained, homogeneous, jet black magnetite rocks also occur. Banded ironstone composed of thin magnetite and quartz bands (Bøggild, 1953; Davies *et al.*, 1963) was found only in drift.

Ilmenite-rich river sands occur at North Star Bugt (Ghisler & Thomsen, 1971). Black sands are common in places at the coast in southern Steensby Land and samples containing extremely high heavy mineral concentrations (mainly ilmenite) were collected around Moriussaq. Source rocks are almost certainly the nearby and prominent dolerite sills.

Grey to pink agates occur in volcanic rocks in the lower part of the Wolstenholme Formation on Northumberland Ø and at Siorapaluk in Prudhoe Land. Soapstone suitable for carving exists at several localities along the coast between Kap Atholl and Parker Snow Bugt.

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Late Precambrian trace fossils from the Thule Group, western North Greenland

Peter R. Dawes and Richard G. Bromley

The general 'unfossiliferous' nature of the thick, unmetamorphosed sediments of the Thule Group has been recognised since the last century. During field work in 1971 and 1974 a search was made by P. R. D. for organic remains but the only fossils encountered were stromatolites in some calcareous rocks and the trace fossils described here from thin bedded sandstones. Isotopic age dating of dolerites intruding the Thule Group shows that the Wolstenholme and Dundas Formations are of late Precambrian age and suggests that the younger Narssârssuk Formation is of similar age (Dawes *et al.*, 1973).

Stratigraphical position

The trace fossils occur in the upper part of the Wolstenholme Formation which has a thin-bedded sandstone or quartzite lithology, in places with alternating shales. GGU samples 166103-6 were collected some metres below the contact with the overlying Dundas Formation at Narssaq, north of Olrik Fjord, where some sandstone beds only a few centimetres thick are crowded with the traces. On western Herbert Ø identical structures occupy the same stratigraphical position, occurring in the passage beds to the Dundas Formation. GGU sample 166605, from the south coast of Northumberland Ø, is loose material, the exact position within the Wolstenholme Formation remaining uncertain.

'Rope-like ridges' of the same type as some of the structures described here have been figured by Fernald & Horowitz (1964, fig. 12, p. 32) from sandy shale of the Wolstenholme Formation on Nunatarssuaq at the head of Wolstenholme Fjord.

Morphology

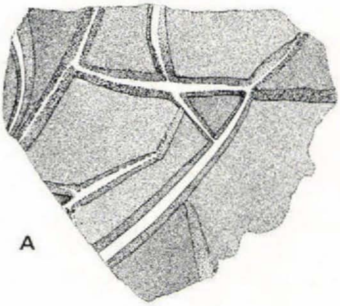
The structures occur on bedding planes of sandstone or quartzite and have the form of vermiform casts in full or partial relief, commonly as hyporeliefs. The Thule Group material covers a spectrum of forms ranging from those resembling, at least in general plan, shrinkage cracks, to others with a biogenic appearance (fig. 10). In cross-section the casts are subcylindrical to flattened cavity fills. Many casts are developed as a series of spindle or pod-like bodies and MMH 13376 and 13379 are entirely composed of bifurcating chains of pod-like bodies, each 2–4 cm in length (fig. 10 D, E). In longitudinal section many have a median ridge of varying width and relief caused by a finer grained filling material than the immediately surrounding sediment (fig. 10 A, C).

There is a marked variation in abundance of the structures on different bedding surfaces. In most exposures the structures form a minor part of the surface area and occur in isolation or as scattered groups. Elsewhere the casts form a tight network and can constitute up to about 60 percent of a bedding plane in hand sample. Many of the sandstones of the Wolstenholme Formation display ripple marks. There seems no obvious morphological difference between structures on 'normal' and on ripple-marked surfaces, although of the present material only MMH 13379 shows ripple marks.

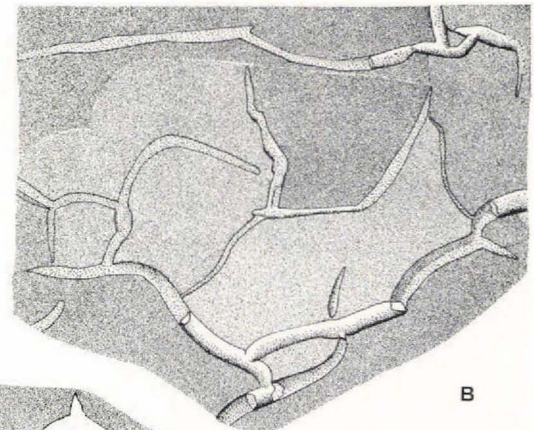
Discussion

Curvilinear to sinuous structures similar in general appearance to the Thule Group examples occur widely in arenaceous and other rocks in many geological systems. Due to the scarcity of organic life in Precambrian times, the structures probably have aroused most interest in Proterozoic rocks. The structures have been variously explained as organic (worm tube infillings, burrows, algae, sponges) and inorganic (desiccation crack infillings).

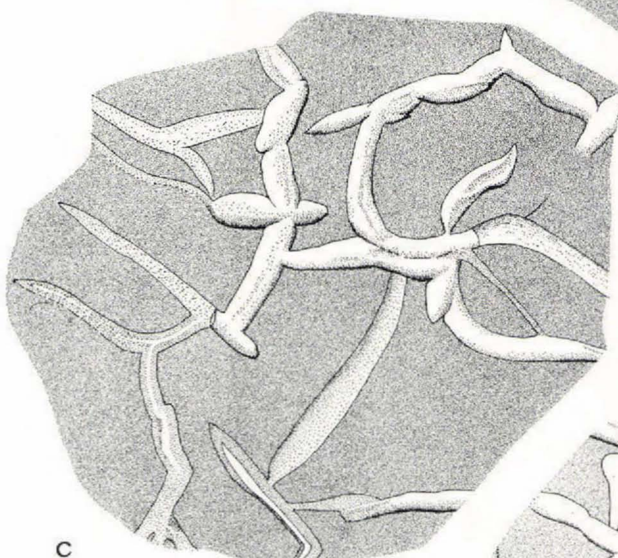
Structures described by Endo (1933) from Precambrian quartzites of Manchuria appear to fall within the range of variation of the Thule Group structures. Endo (1933) interpreted these structures as algae and designated them as *Manchuriophycus yamamotoi*. Rather different structures, curved and restricted to troughs between ripple mark



A

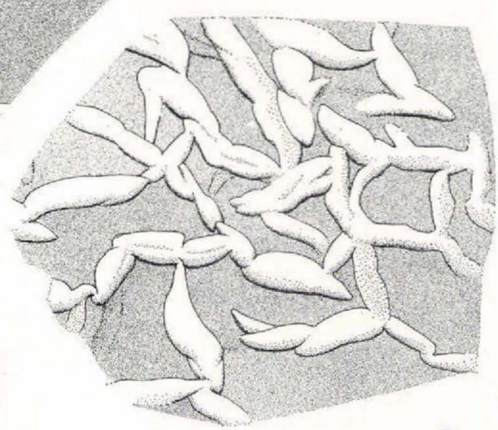


B

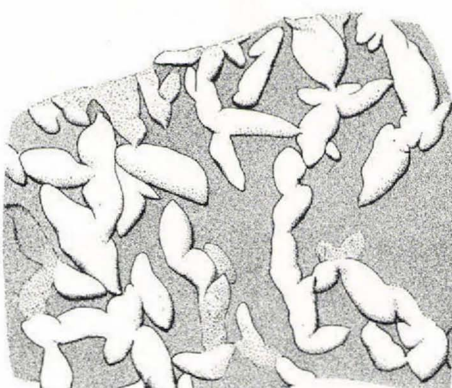


C

5 cm



D



E

crests, were described as algae by Yabe (1939) under the name *Manchuriophycus sawadai* from the Precambrian of north-eastern China. Lee (1939) supported a biogenic interpretation for the Chinese structures but considered them to represent worm burrows. Häntzschel (1949) reviewed these and other occurrences recorded in the literature, including Triassic examples from Germany and East Greenland, and reinterpreted them as mudcracks. He attempted to explain the curvilinear form of the structures by comparison with recent tidal mudflats, where incomplete drying out of a clay drape over rippled sands can produce curved cracks in inter-ripple troughs.

The East Greenland structures, described by Stauber (1942, figs 45, 46, p. 296–297) as inorganic structures, were derived from the Malmros Klint Member of the Fleming Fjord Formation (Triassic) of Scoresby Land and Jameson Land. Field photographs of Jameson Land examples were recently presented by Perch-Nielsen *et al.* (1974, pl. 16) and interpreted as mudcraks influenced by ripple marks. However, on other beds in the Malmros Klint Member, and in the Thule Group material, the sinuous structures can occur without ripple marks, while at many horizons in the Malmros Klint Member fully symmetrical, polygonal mudcracks occur in ripple marked bedding planes. Thus, in these settings, the sinuosity cannot be attributed to interference by ripple marks.

Other Proterozoic vermiform structures, similar to the range of forms shown by the Thule Group material include: annelid burrows from quartzite from Montana (Fenton & Fenton, 1937); burrows of a "small unknown organism" in the Ajibik Quartzite of Michigan (Faul, 1950); "fossil relics of tapering, branching tubes" (Frarey & McLaren, 1963); the metazoan relic *Rhysonetron* (Hofmann, 1967) and "casts of vermiform organism" (Young, 1967) in various Huronian quartzites of Ontario; and the worm-shaped organic casts in quartzite from north-eastern Finland (Lauerma & Piispanen, 1967). Similar structures elsewhere have been interpreted as sinusoidal shrinkage crack infillings (Wheeler & Quinlan, 1951; Barnes & Smith, 1964). Glaessner (1969) noted that curved, sinuous and branching desiccation cracks can be produced experimentally and considered this sufficient evidence to group together many of the forms mentioned above, including *Manchuriophycus* and *Rhysonetron,* as "shrinkage crack infillings resembling trace fossils". Donaldson (1967) considered that many features of vermiform Precambrian structures "may be simulated by algal mats subjected to subaerial desiccation" while "clay-rolls" and certain "mud flakes" can also present a similar appearance, as shown by Trusheim (1929) and Voigt (1972).

The range in form shown by vermiform structures cited in the literature leaves little doubt that similar-looking structures on the bedding surfaces of Precambrian and younger rocks are polygenetic.

Thus, in order to explain the spectrum of forms represented by the Thule Group material it may be necessary to invoke a multiple origin.

The cross-section of the sample most like a shrinkage crack (fig. 10A) is unknown. In all others it is subcircular and does not resemble the cross-section of a normal

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Fig. 10. Vermiform structures from the Thule Group, North Greenland, showing range form most resembling dessication cracks (A) to biogenic traces (D & E). *A*. MMH 13378 from GGU sample 166106, lower surface; *B*: MMH 13377 from GGU sample 166105, upper surface; *C*: MMH 13375 from GGU 166103, lower surface; *D*: MMH 13376 from sample 166104, lower(?) surface; *E*: MMH 13379 from GGU sample 166605, lower surface.

shrinkage crack. Furthermore, in places there are clear overlapping relationships between casts (fig. 10D, E), a phenomenon difficult to reconcile with desiccation crack infillings. We therefore consider all these forms to be burrows of animals, despite the resemblance in general plan of two of them (fig. 10 B, C) to a system of desiccation cracks. In some cases it is not impossible that a burrowing animal could have worked within an earlier, infilled shrinkage crack network. The lobed or pod-like form of the structures in fig. 10 D, E, and locally in fig. 10 C are unquestionably biogenic.

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