



Hydrothermal vent microbial communities: a fossil perspective

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Introduction

Stratiform beds of iron oxides (usually haematite) and silica – ‘jaspers’ – are commonly associated with sulphide deposits in volcanic rock sequences in the geological record (e.g. Duhig et al., 1992). They are usually considered as the product of low-temperature, diffuse hydrothermal venting, because of their similarity to seafloor mineral deposits at modern vent sites and on seamounts (Hanert, 1973; Juniper & Fouquet, 1988; Alt, 1988; Stoffers et al., 1993). In contrast some ancient jaspers have been interpreted to have formed in subsurface systems (Hofmann & Farmer, 2000; Trewin & Knoll, 2000). Jaspers often contain abundant filamentous structures, some of which have been identified as fossilized microbial communities (Juniper & Fouquet, 1988; Duhig et al., 1992; Little et al., 1999; Hofmann & Farmer, 2000; Trewin & Knoll, 2000). This paper documents a range of new filamentous fossils in Ordovician to Cretaceous jaspers and discusses their probable biogenic affinities.

Material and methods

The studied jaspers come from the following sites: Ballynoe (6 polished thin sections from one rock sample), Løkken (5 polished thin sections from one rock sample), Alexandrinka (4 polished thin sections from one rock sample), Figueroa (11 polished thin sections from 5 rock samples) and Kambia (2 polished thin sections from one rock sample). The polished thin sections were observed and photographed in transmitted and reflected light. One Figueroa thin section was analysed using Laser Raman spectroscopy for traces of organic matter. Powdered samples from all the jaspers were analysed using X-ray diffraction and a number of the thin

sections were investigated with an electron microprobe instrument.

The Løkken, Alexandrinka, Figueroa and Kambia jaspers are found within volcanic rock sequences closely associated with massive sulphides (ancient hydrothermal vent deposits) and are Ordovician, mid Devonian, early Jurassic and late Cretaceous in age respectively. The Ballynoe jaspers are found as pods in the stratiform Ballynoe barite. This is a lateral equivalent of a massive sulphide deposit contained within early Carboniferous limestones (Mullane & Kinnaird, 1998).

Results

The samples from the Ballynoe, Løkken, Alexandrinka, Figueroa and Kambia jaspers show well preserved filaments (Figs 1 to 3; Little et al., 1999), and all these filaments share a number of characters. They are 1-20 µm in diameter and up to 200 µm long. They are tubular structures coated by sub-micron scale haematite crystals. The thickness of the haematite coatings is variable, with the thickness of the coating increasing with filament diameter. Some of the filaments are hollow, and some are filled with later silica. Organic material could not be detected within the Figueroa filaments by Laser Raman spectroscopy. Most of the filaments have branching structures (Figs 1, 3) forming loose meshes, some of which radiate out from a central mass (Figs 1A, 2A). Some of the branched filaments in the Figueroa jaspers (Fig. 2A) are particularly large and may be the result of false branching of bundled filaments. A significant proportion of the Ballynoe filaments are twisted (Fig. 1B) and one small Figueroa filament has septae (Fig. 2B). All of the filaments are cemented by later silica phases, which can be either quartz (Fig. 2A) or chalcedony

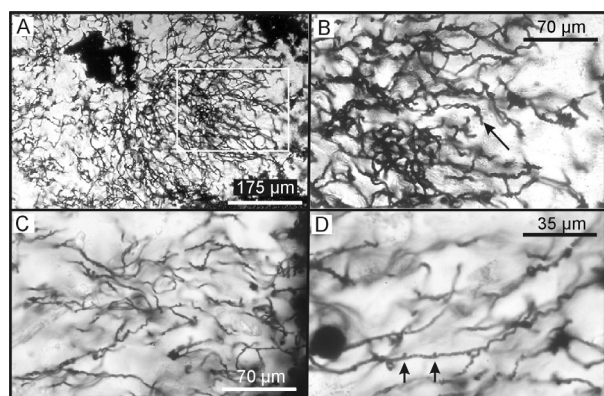


Figure 1. Transmitted light photomicrographs of filamentous haematite microfossils in the Ballynoe jasper, Ireland. **A.** Domain of filaments in quartz matrix showing directed growth. **B.** Detail of white box area in A; black arrow points to twisted filament. **C.** Looser packed branching filaments. **D.** Filaments showing coiling with irregular mineral outgrowths or possibly buds (black arrows). Note the sub-micron scale haematite crystals forming the filaments.

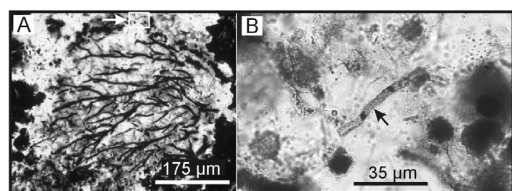


Figure 2. Transmitted light photomicrographs of filamentous microfossils in the Figueroa jasper, California. **A.** Large branching filaments forming a ramifying structure. It is possible this is false branching pattern of bundled filaments. **B.** Detail of white box area in A indicated by white arrow; small filament with septum (black arrow).

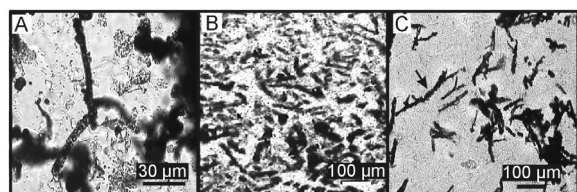


Figure 3. Transmitted light photomicrographs of filamentous microfossils in other Phanerozoic jaspers. **A.** Alexandrinka, Ural mountains, Russia; branching filament. **B.** Løkken, Norway; numerous branching filaments. **C.** Kambia, Cyprus; branching filaments; black arrow shows a filament upon which several chalcedony crystals have nucleated.

(Fig. 3C). The fact that filaments often cross quartz and chalcedony crystal boundaries proves that the silica post-dates haematite filament formation.

The jasper filaments documented here are similar to those described by Duhig et al. (1992) from Australian Cambrian jaspers (actually Ordovician according to Paulick & McPhie, 1999). These Australian filaments are hollow tubes, 1–30 µm in diameter, formed of haematite crystals

and are cemented by chalcedony and quartz. They form meshes and some of the smaller examples have internal septae. Alt et al. (1992) have also reported iron oxide filaments of the same size and shape cemented by quartz in drill core samples of Jurassic age ocean crust from the western Pacific. Juniper & Fouquet (1988) described Cretaceous and Eocene silica-cemented, iron-rich filaments from jaspers in Cyprus, California and the Philippines.

The fossil filaments documented here are also very like those found in modern hydrothermal vent deposits and iron oxide deposits on seamounts (Hanert, 1973; Juniper & Fouquet, 1988; Alt, 1988; Stoffers et al., 1993; Iizasa et al., 1998). Those from the seamounts are particularly like the fossil filaments being hollow tubes of iron oxides (as Fe oxyhydroxide) with branching and twisted morphologies (e.g. Alt, 1988). Identical filaments have recently been identified on sediment-free basaltic lava flows from the rift valley of Knipovich Ridge at 76°47' N (Thorseth et al., 2001). These filaments are 1–2 µm in diameter and have either branching or twisted morphologies. They are variably encrusted with Fe oxyhydroxide and silica (Fig. 4).

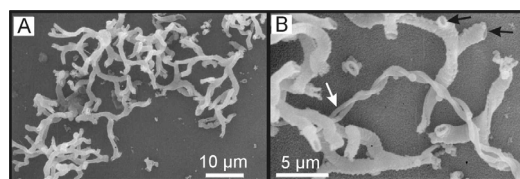


Figure 4. Scanning electron micrographs of filamentous structures from Knipovich Ridge. **A.** Mat of branching filaments. **B.** Detail of branched and twisted (centre) filaments; white arrow indicates where two strands of the twisted filament have separated; black arrows show the hollow tubular nature of the branched filaments.

Discussion

It is becoming evident that filamentous structures are ubiquitous in both modern and ancient jaspers. The important question is what do these filaments represent? Are they microbial in origin? And, if so, what sort of bacteria formed them? Do they merely represent complex abiogenic crystal forms? The latter is quite possible, as the hydrothermal vent environment is one where extreme temperature and chemical gradients can promote rapid crystal growth. Indeed, García-Ruiz (1998) has grown complex barium carbonate crystals (including twisted and hollow forms) similar in size and shape to the iron oxide filaments reported here in silica-rich alkaline brines. However, these synthetic crystals differ from the jasper filaments being formed of barium carbonate and not iron oxides, and having variable not constant diameters (see discussion in Hofmann & Farmer, 2000). Some of the more complex features of the jasper filaments are difficult to explain as being the result of abiogenic crystal growth, for example the septae crossing the whole width of a filament (Fig. 2B), and the separation and merging of strands of the twisted filaments (Figs 1B, 4B). It seems most likely, therefore, that the jasper filaments have a biogenic origin.

Because of the size of the filaments, bacteria seem the most obvious, but by no means the only, candidate causative organisms.

Accepting that the jasper filaments do indeed have a microbial origin how is it that they are now represented as hollow tubes of iron oxides without a core of organic material? Juniper & Fouquet (1988) offer a convincing model of mineralization whereby filamentous bacterial cells act as nucleation sites for iron oxides. As corroboration they were able to stain a few modern silica filaments for microbial DNA. The formation of iron oxide crusts on the cell surface may be a purely passive process, or the result of metabolic reactions (e.g. iron oxidation) of the microbes themselves (Konhauser, 2000). The iron coated filament meshes then serve as a scaffolding for silica precipitation and at some point the original organic material of filaments decays away to leave hollow tubes. The features seen in the fossils and modern filaments discussed in this paper are in full agreement with this model.

Can the fossil jasper filaments be identified further? Unfortunately we only have the gross morphology to work with and in the microbial realm cell morphology is a poor guide to identification (see Reysenbach & Cady, 2001 for discussion). However, the twisted and branching filaments in the Ballynoe jasper (Fig. 1B) and on the Knipovich Ridge (Fig. 4B) are similar to the stalks of the iron-oxidizing bacterium *Gallionella* (Hanert, 1973). This similarity has been noted for other twisted filaments in fossil jaspers (Hofmann & Farmer, 2000) and modern iron oxide deposits (Alt, 1988). Intriguingly, Thorseth et al. (2001) were unable to detect *Gallionella* by PCR-DGGE in the Knipovich Ridge samples, possibly because of the low number of cells present. The identity of the larger branching filaments in the Figueroa jasper is more speculative and therefore assigning metabolic processes to these microfossils (e.g. sulphide oxidation, iron oxidation etc.) is premature.

There is a potential to use the jasper filaments identified here and in other papers as biomarkers for low temperature hydrothermal systems and possibly also iron oxidation metabolic activity. Although the oldest known specimens are Ordovician in age, it will surely be possible to find similar examples in older jasper deposits and use these as evidence of more ancient hydrothermal vent communities. This is particularly likely, as very ancient filaments related to hydrothermal activity have been described by Rasmussen (2000). He found pyrite filaments in chert in a 3.235 billion year old massive sulphide deposit and suggests that these are fossil filamentous microbes, possibly thermophilic anaerobes utilizing sulphur compounds.

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