Possible eukaryotic macrofossils in the 1.1 Ga Copper Harbor Formation, Michigan

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Unusual and possibly biogenic cm-scale features have been found on the bedding plane of a siltstone layer within the ca. 1.1 Ga Copper Harbor Formation, the lowermost of the rift-filling sedimentary units of the Midcontinent Rift. The Copper Harbor Formation includes cobble- to boulder-conglomerates, sandstones, siltstones and mudstones, representing alluvial fan, braided stream, and ephemeral lake environments within the axial valley of the Midcontinent Rift (Elmore 1984). Calcified cabbage-sized stromatolites occur at several horizons in the upper part of the Copper Harbor formation; some of these grew on top of a substrate of mud, while others encrusted cobbles and boulders (Elmore, 1094; Planavsky and Bjørnerud, 2006).

The newly discovered features were found in a siltstone layer between two stromatolitic horizons at Horseshoe Harbor, near Copper Harbor, Keweenaw County, Michigan. In plan view, the enigmatic features are circular to slightly elliptical with a diameter of 0.3-1.0 cm (Fig.1). Many have a transecting lenticular element or septum that cuts across them in a 'theta' geometry. These septa lie at random orientations in the ca. 25 x 30 cm bedding plane slab in which more than 50 of the features were found.

In cross section, the features are funnel-shaped, narrowing downward to a blunt tip. In several of the features, the funnel terminates in a mm-scale crystal of calcite (Fig 2). Finer calcite cements the fine-grained material in the interior of the features and also defines the edges of the funnel shapes. Petrographic and XRD analyses indicate that the rest of the interior material is silt-sized quartz and feldspar together with minor clay (halloysite) and iron oxides, the same minerals found in the surrounding rock. SEM imaging of the material inside and outside the features similarly revealed no obvious differences in grain size or texture. Some of the funnel-shaped elements have a crude layering defined by iron oxides, but it is not easily traceable from the enclosing rock. The layering could either be primary or a product of post-depositional pressure dissolution.

These features do not resemble any common sedimentary or diagenetic structures. They are unlikely to be dewatering structures since there is no evidence of 'soft-sediment' distortion of the surrounding layering. Their consistent and unusual shapes make it seem unlikely that they are concretions or similar structures.

A National Academy of Sciences workshop (Knoll, 1999) proposed the following criteria for identifying microbial fossils in Precambrian rocks: 1) *Provenance* [the source and geologic context of the parent rock must be firmly established]; 2) *Age* [the parent rock must be have a reasonably well constrained age]; 3) *Indigenousness* [the features must be embedded in the rock matrix]; 4) *Syngenicity* [the features must have been formed at the same time as the parent rock]; and 5) *Biogenicity* – the features must be definitively biological. The features from the Copper Harbor Formation meet the first four of these criteria; the last, of course, is the most difficult to establish unambiguously.

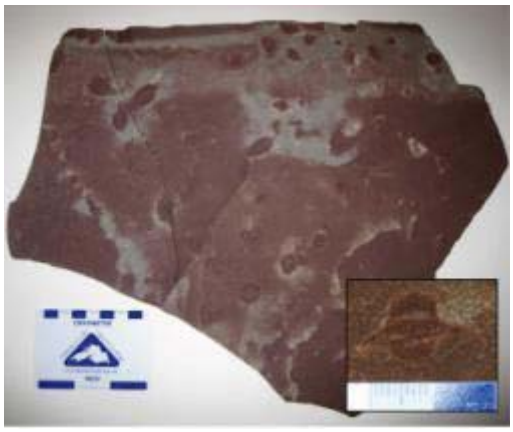

Fig. 1: The siltstone slab with unusual bedding plane features. Lower right: Close-up of one feature, highlighting the transecting element.

Fig. 2: Thin section (cross-polarized light) of one of the features in cross section, showing calcite crystal at terminal end of the funnel (arrow).

If they are biogenic, it seems most likely that the features represent either body or trace fossils of a eukaryotic organism (Andrew Knoll, personal communication, 2010). They are far too large to have been formed by single prokaryotes, and their symmetry and consistent geometry would seem improbable for colonies of individuals.

Eukaryotic organisms were diverse and well-established by Mesoproterozoic time in the marine realm, but there are fewer reports of eukaryotic terrestrial biota (Knoll et al. 2006). Fedonkin and Yochelson (2002) described fossils of colonial eukaryotes on bedding surfaces of freshwater siltstones within the 1.5 Ga Appekunny Fm. of the Belt Series in Montana. In a study of the 1.1-1.2 Ga Torridonian sequence of Scotland, similar both in age and depositional setting to the Copper Harbor Formation, Prave (2002) argued for a diverse terrestrial fluvial and lacustrine ecosystem, based on extensive and well-preserved microbial crusts and evidence for unusually cohesive sandy sediment.

The Copper Harbor stromatolites indicate that in spite of the high-energy sedimentary environment, there was an active lacustrine ecosystem within the valley of the Midcontinent Rift at ca. 1.1 Ga, perhaps seeded via wind transport of dormant reproductive structures (Planavsky and Bjørnerud, 2002). The newly discovered features described here may indicate an even greater degree of biodiversity than previously recognized. The Midcontinent Rift is already renowned for its unparalleled volcanic effusion rates and world-class copper deposits; perhaps it should also be re-examined for clues to the early colonization of the continents by Life.

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