Highly negative $\delta^{13}C$ values in organic carbon in the Mt. Roe #2 palaeosol: terrestrial life at 2.765 Ga?

R. Rye

Department of Earth and Planetary Sciences, Harvard University, MA 02138, USA

The $\delta^{13}C$ value of organic carbon at the top of the Archaean Mt. Roe #2 palaeosol is $< -40‰$ PDB. This isotopic composition suggests that methanotrophic organisms lived at or near the top of this soil (Hayes, 1994). There is somewhat equivocal morphological evidence that these organisms were part of a land-based microbial mat. These isotopic and morphological data are the oldest known fossil evidence of life on land.

The Mt. Roe #2 palaeosol is one of two palaeosols developed on basalt flows near the base of the Fortescue Group in the Pilbara region of northwestern Australia (Macfarlane *et al.*, 1994). These are the oldest well-described palaeosols. Lava flows above and below these palaeosols have been dated using the U-Pb zircon method at 2.765 ± 0.010 Ga (Macfarlane *et al*, 1994).

Methanogens and methanotrophs are generally thought to be restricted to the marine environment during the Archaean and Palaeoproterozoic. There is no evidence to suggest that the parent basalt or the Mt. Roe #2 palaeosol were under seawater at any time during weathering. Abundant vesicles in the unweathered basalt and relict vesicles in the palaeosol indicate that the flow was subaerial over the *c.* 1 km strike length that is exposed. Weathering of the basalt was apparently abruptly halted by the emplacement of another vesiculated subaerial basalt flow. There are no marine sediments between the palaeosol and the overlying basalt. We observed no pillow structures in either the parent or the overlying basalt.

The bottom 10–30 cm of the overlying flow contains numerous coherent ripped up pieces of the palaeosol as large as 3 cm in diameter. The mechanical behaviour of the soil when it was covered indicates it was soft and fairly dry.

Several supposed Precambrian palaeosols contain a significant allochthonous component that may have been transported by water. Chemical analyses indicate that the Mt. Roe #2 soil profile almost certainly developed *in situ* on the essentially homogeneous basalt. During *in situ* weathering of homogeneous rocks immobile element ratios (Ti/Al, Ti/Zr, Al/Zr) generally remain constant. The coefficient of variation of the Ti/Al ratios in 67 samples from three complete sections through the palaeosol and parent rock and from several other locations along the palaeosol is 0.064. The coefficient of variation of the Ti/Zr ratios in 13 samples from one complete section is 0.050 (some data from Macfarlane *et al.*, 1994). Thus, there is apparently no significant allochthonous component in the soil.

The top several meters of the Mt. Roe #2 palaeosol are white over nearly its entire strike length exposure of >1 km. Near the southern end of the palaeosol exposure there is a thin (*c.* 50 cm) lens (*c.* 20 m × 20 m) of black material interposed between the normal white palaeosol and the overlying basalt. Petrographic microscopy and EPMA show that the white palaeosol layer and the black palaeosol lens both are nearly pure sericite with a small amount of quartz. In thin section the black palaeosol appears to be made up of palaeosol fragments *c.* 1 mm in diameter. The fragments have no preferred orientation, and probably represent the fragile upper surface of the soil. Some of the palaeosol fragments in the black palaeosol contain sheaves and layers of black material which have the optical properties of graphite. These sheaves and layers are reminiscent of algal/bacterial mat fragments.

The $\delta^{13}C$ values of organic carbon in three samples from the black layer are −41.1‰, −40.8‰, and −40.3‰ PDB. These values are consistent with values found by Hayes (1994) for organic carbon in some late Archaean sediments and suggest that methanotrophic microorganisms colonized the Mt. Roe #2 palaeosol 2.765 ± 0.010 Ga. The methane these organisms needed could have been generated at the base of the mats during the bacterial degradation of organic matter. It might also have been derived from the ambient atmosphere.

The isotopic and morphological observations presented above suggest that methanogens and methanotrophs lived on or near the surface of soils during the Archaean. If there was a methanotrophic and methanogenic microbial land cover during the Archaean, atmospheric oxygen levels could have been extremely low. Land-based methanogens might have provided some of the greenhouse gases needed to make up the difference between the minimum greenhouse gas forcing required to compensate for the fainter sun in the Archaean and Palaeoproterozoic (equivalent to $10^{-0.7}$ atm CO_2) and the maximum forcing due to the carbon dioxide levels allowed by the mineralogy of Archaean and Palaeoproterozoic palaeosols ($10^{-1.7}$ atm CO_2) (Rye *et al.*, 1995).

References

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