Proterozoic ocean chemistry and the evolution of complex life

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This presentation will review evidence from biomarker geochemistry that may link the pattern of early eukaryote evolution to the history of oxygen concentrations in Proterozoic oceans. Lower concentrations of molecular oxygen may have played a key role in the low rate of change of eukaryotic shapes and forms in the Proterozoic relative to the Phanerozoic.

The modern oceans are virtually completely oxygenated. However, oceans in Earth's distant past were fundamentally different. In the first half of its history, ~4.5–2.3 billion years (Ga) ago, Earth's oceans and atmosphere contained little or no free oxygen. Geochemical evidence indicates that oxygen concentrations rose to $>10^{-5}$ times the present level around 2.45–2.32 Ga concurrent with a cessation of deposition of banded iron formations. However, iron formations reappeared in the sedimentary record about 2.1 Ga ago and continued until about 1.8 Ga, potentially indicating that pO_2 had dropped again to pre-2.45 Ga levels (Canfield, 2005). In the following billion years, atmospheric oxygen levels increased, but evidence from iron chemistry and sulfur and molybdenum isotopes in sedimentary rocks suggests that the deep oceans remained vastly anoxic and became additionally sulfidic. Biomarkers detected in sedimentary rocks from a 1.6 Ga marine basin in northern Australia are consistent with this scenario. The molecular fossils indicate a stratified and sulfidic sea that harbored a unique ecosystem of green and purple sulfur bacteria but was hostile to eukaryotic algae (Brocks et al., 2005).

The first simple fossils of eukaryotes occur in the geological record before 1.8 Ga. However, eukaryotic diversity, complexity and abundance remained low well into the Neoproterozoic (1.0–0.54 Ga) when oceans may eventually have became more fully oxygenated. The first convincing evidence for animals, at this stage still mere clusters of cells, occurs at 0.6 Ga. An elucidation of molecular fossils of eukaryotes from the period 1.8–0.54 Ga yields a picture that is consistent with these evolutionary transitions.

References

Canfield, D.E., 2005. *Annu. Rev. Earth Planet. Sci.* **33**, 1–36.

Brocks, J.J., Love, G.D., Summons, R.E., Knoll, A.H., Logan, G.A., Bowden, S.A., 2005. *Nature* **437**, 866–870.

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Nanoscale characterization of the 'critical zone' of naturally weathered feldspars by FIB and TEM

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Introduction: exploring the critcal zone at the nanoscale. Information on weathering mechanisms is recorded by grain surface topography and the microstructure and chemical composition of the grain immediately beneath the surface and any overlying reaction products. Here we describe a method that enables investigation of this ~1–2 μm thick 'critical zone' in unprecedented detail. We have studied naturally weathered alkali feldspar grains that were hand-picked from ~1 kyr old soils formed on river terraces in Glen Feshie (NE Scotland) and ~10 kyr old soils overlying the Shap Granite (NW England). A focused Ga^+ ion beam (FIB) microscope was used to cut ~100 nm thick cross-sections from outer surfaces of these grains for high resolution imaging and chemical analysis by transmission electron microscopy (TEM).

Topography and crystallinity of feldspar surfaces. Diffraction-contrast images of cross-sections of the Shap grains show that the size, shape and location of nanoscale etch pits is controlled by the magnitude and distribution of elastic strain associated with exsolution microtextures. These feldspars are completely crystalline up to the weathered grain surface. If amorphous layers, comparable to those formed during laboratory silicate dissolution, are present they must be <~2–3 nm thick. Surfaces of the Glen Feshie grains are less pitted and are overlain by silicate weathering products that are typically amorphous but contain smectite crystallites.

Evidence for microbial weathering. We have also investigated the role of microbes in weathering by cross-sectioning fungal and algal remains on grain surfaces. The Ga^+ ion beam destroys biological details, but the microbe-feldspar interface is preserved intact. There is little evidence for biological enhancement of feldspar weathering, although the close association of fungal hyphae with smectite in the Glen Feshie samples indicates that microbes may assist in crystallization of weathering products.

Summary: future applications of the FIB-TEM technique. The FIB-TEM technique has tremendous promise for revealing the nanoscale properties of weathering that occur at mineral surfaces.

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