The coupled biological and geochemical evolution of the Earth surface

D. E. Canfield

Institute of Biology, Odense University, Campusvej 55, Odense M, 5230, Denmark

The history of life on Earth and the history of ocean and atmospheric chemistry are intimately linked (e.g. Cloud, 1972). Biological innovations such as the evolution of anoxygenic and oxygenic photosynthesis provided for the oxidation of the primordial, chemically reducing, Earth surface environment. As sulphate, oxygen, and oxidized iron accumulated, organisms evolved a variety of heterotrophic and autotrophic metabolisms that could use these oxidized compounds as electron acceptors. Thus, biological evolution was both responsible for, and responded to, profound changes in the chemistry of the Earth surface.

The geological community has reconstructed the history of metabolic innovations mainly from the stable isotopic compositions of biologically active carbon and sulphur species and from direct indicators of Earth surface oxidation (e.g. palaeosol chemistry) (Des Marais *et al.*, 1992; Hayes *et al.*, 1992; Canfield and Teske, 1996; Holland and Beukus, 1990). Supporting information has come from microfossil studies where the early appearance of cyanobacteria, for example, is possibly revealed (Schopf and Packard, 1987). Microfossil evidence by itself, however, is too sparse and too ambiguous to reconstruct an adequate history of major biological innovations.

Over the past few decades biologists have constructed the evolutionary relationships among organisms from sequence similarities in the 16s and 18s subunits of the ribosomal RNA molecule (Woese, 1987). From these relationships a new tree of life has emerged. This tree of life demonstrates the dominance of prokaryotic organisms, with plants and animals occupying just twig within the Domain of the Eukaryotes. Furthermore, this new tree provides, in principle, a window into the relative timing of significant metabolic advancements such as, for example: 1) the evolution of photosynthetic pathways, 2) the evolution and subsequent diversification of sulphate reduction, and 3) the emergence of aerobic metabolisms. Of further significance is the identification of evolutionary events which were likely spurred by major changes in the chemistry of the Earth surface; the evolutionary radiation of plants, animals and fungi near the crown of the Eukarya is one such event, and the near synchronous emergence of cyanobacteria, purple bacteria, and gram positives within the Bacteria is another.

This new tree of life has been the backbone of evolutionary discussions within biological community for nearly a decade, but has not pervaded discussions within the geological and geochemical communities. The most exciting advances in our understanding of the coupled evolution of life and the Earth surface environment will likely come from a complete integration of molecular phylogenies with geochemical indicators of Earth surface change.

In my talk I will review some of the key principles behind the construction of the rRNA-based tree of life, and I will also provide a quick guided tour through the tree. I will discuss how these genetic-based phylogenies might be linked with geochemical information to provide insights into, for example, the evolution of the sulphur cycle.

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