Sedimentology and stratigraphy

Banded iron formations (BIFs) reviewed (*December 2017*)

2.1 billion years old boulder of banded ironstone. (Credit: André Karwath)

During most of the last hundred years every car body, ship, bridge, skyscraper frame and rebar rod in concrete had its origins in vividly striped red rocks from vast open-pit mines. Comprising mainly iron oxides with some silica, these banded iron formations occur in profitable tonnages on every continent. But such reserves are confined mainly to sedimentary sequences dating from about 2.8 to 1.9 billion years ago. They are not the only commercial iron formations, but dominate supplies from estimated reserves of around 10^5 billion tons. From a non-commercial standpoint they are among the most revealing kinds of sediment as regards the Earth system and its evolution. All scientific aspects of BIFs and similar Fe-rich sediments are reviewed in a recent volume of *Earth Science Reviews*. (Konhauser, K.O. and 12 others 2017. Iron formations: a global record of Neoarchaean to Palaeoproterozoic environmental history. *Earth Science Reviews*, v. **172**, p. 140-177; doi: 10.1016/j.earscirev.2017.06.012).

The chemical, mineral and isotopic compositions of BIFs form a detailed repository of the changing composition of seawater during a crucial period for the evolution of Earth and life – the transition from an anoxic surface environment to one in which water and air contained a persistent proportion of oxygen, known as the Great Oxidation Event (GOE). Paradoxically, BIFs are highly oxidized rocks, the bulk of which formed when other rocks show evidence for vanishingly small amounts of oxygen in the surface environment. The paradox began to be resolved when it was realized that ocean-ridge basaltic volcanism and sea-floor hydrothermal activity would have released vast amounts of soluble, reduced iron-2 into anoxic seawater, in the upper parts of which the first photosynthetic organisms evolved. Evidence for the presence of such cyanobacteria first appears around 3.5 billion years ago, in the form of carbonates whose structure suggests they accumulated from growth of microbial mats. Oxygen generated by photosynthesis in iron-rich water immediately acts to oxidize soluble iron-2 to iron-3 to yield highly insoluble iron oxides and hydroxides and thus deposits of BIFs. While oceans were iron-rich, formation of ironstones consumed ecologically available oxygen completely.

Other biological processes seem to have been involved in ironstone formation, such as photosynthesis by other bacteria that used dissolved iron-2 instead of water as a reductant for CO_2, to release iron-3 instead of oxygen. That would immediately combine with OH^- ions in water to precipitate iron hydroxides. Konhauser and colleagues cogently piece together the complex links in chemistry and biology that emerged in the mid- to late Archaean to form a linkage between carbon- and iron cycles, which themselves influenced the evolution of other, less abundant elements in seawater from top to bottom. The GOE is at the centre. The direct evidence for it lies in the sudden appearance of ancient red soils at about 2.4 billion years, along with the disappearance of grains of sulfides and uranium oxides – both readily oxidized to soluble products – from riverine sandstones, which signifies significant oxygen in the atmosphere. Yet chemical changes in Precambrian marine sediments perhaps indicate that oxygen began to rise in ocean water as early as 3 billion years ago. That suggests that for half a billion years biogenic and abiogenic processes in the oceans were scavenging oxygen as fast as it could be produced so that only tiny amounts, if any, escaped into the atmosphere. Among other possible factors, oceanic methane emissions from methanogen bacteria may have consumed any atmospheric oxygen – today methane lasts only for about 9 years before reaction with oxygen forms CO_2. If and when methanogens declined free oxygen would have been more likely to survive in the atmosphere.

The theme running through the review is that of changing and linked interactions between life and the inorganic world, mantle, lithosphere, hydrosphere and atmosphere that involved all available chemical elements. The dominant chemical process, as it is today, was the equilibrium between oxidation and reduction – the loss and gain of electrons among possible chemical reactions and in metabolic processes. Ironstones were formed more commonly between 3 to 2 Ga than at any time before or since, and form a substantial part of that periods sedimentary record. Their net product and that of the protracted organic-inorganic balancing act – oxygenation of the hydrosphere and atmosphere – opened the way for eukaryote organisms, their reproduction by way of the splitting and recombination of nuclear DNA and their evolutionary diversification into the animal and plant life that we know today and of which we are a part. It is possible that even a subtly different set of global processes and interactions set in motion during early evolution of a planet apparently like Earth may have led to different and even unimaginable biological outcomes in later times. The optimism of exobiologists should be tempered by this detailed review.