

## ***Sedimentology and stratigraphy***

### **Inglorious mudstones (*August 2000*)**

Because they succumb to erosion easily, mudrocks do not outcrop well, except on the coast or in arid lands. Often they show little if any stratification that field workers can distinguish from the partings imparted by compaction and dewatering, which make shales from them. Yet they are repositories of a great deal of information. In hand specimen their two main components, silt-sized quartz grains (<62 microns) and clay minerals (>4 microns) only become distinguishable by chewing! They are irresolvable using optical microscopes, and detailed work needs scanning electron microscopy.

Silt to clay proportions in mudrocks are variable. Silt is generally taken as an indicator of suspended debris from land masses and their proximity to where the mud accumulated. The more clay, the further muds were from exposed continents, or so sedimentologists used to assume. That approach has taken a hard knock from some recent detailed work on Devonian mudrocks (Schieber, J. *et al.*, 2000. [Diagenetic origin of quartz silt in mudstones and implications for silica cycling](#). *Nature*, v. **406** 31 August 2000, p 981-985; doi: 10.1038/35023143).

Jurgen Schieber of the University of Texas (Arlington), Dave Krinsley of the University of Oregon and Lee Riciputi of the Oak Ridge National Laboratory in Tennessee used scanning electron microscopy, [cathodoluminescence](#) and ion-probe techniques to discriminate between detrital quartz grains and those formed by precipitation of silica from pore water in the original muds. Those grains that do not luminesce probably formed by silica solution and reprecipitation, and the Devonian mudrocks contain mainly non-luminescent quartz grains. Oxygen isotope ratios from individual grains confirm this *in situ* origin. The researchers had no reason to suspect that their Devonian samples would give such results, and assumptions based on silt to clay ratios from any mudrock are now in doubt.

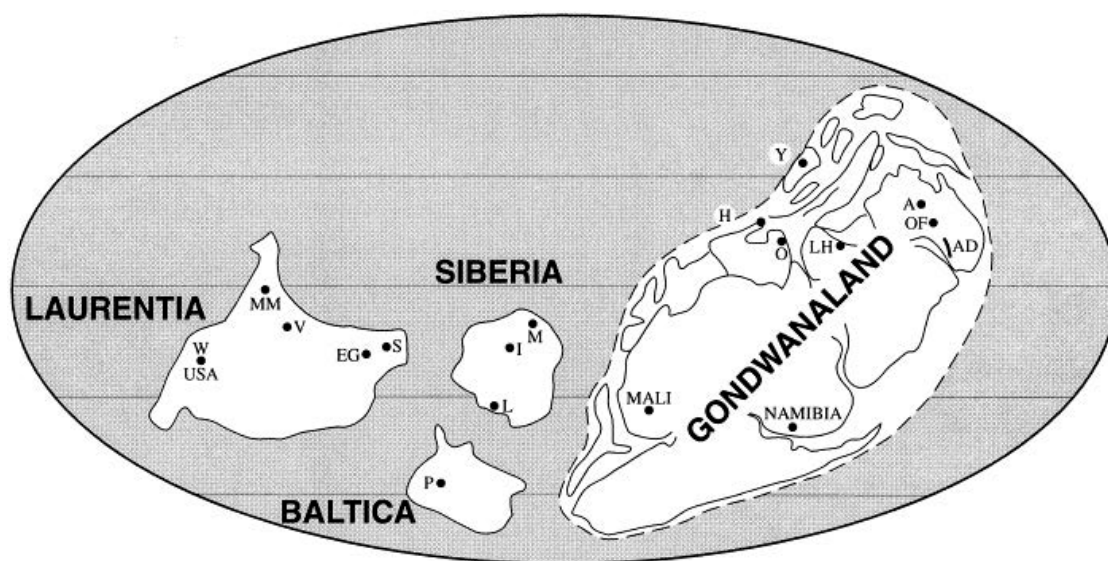
Worse still, silt in ocean-floor muds, cores of which form the linchpin for Pleistocene climate studies, has been a rough and ready way of estimating wind speeds as climate shifted from glacial to interglacial conditions. These silts could be precipitates too, and the variations in their proportions may stem from changes in the delivery of dissolved silica from land to the oceans.

**See also:** Kemp, A. 2000. Probing the memory of mud. *Nature*, v. **406**, p 951-953; DOI: 10.1038/35023211

### **Unravelling Neoproterozoic environments (*September 2000*)**

The latest Precambrian or Neoproterozoic, from 1000 to 544 Ma ago, and especially from 700 Ma to the start of the Cambrian, is the most important episode in the history of biological evolution. That is the episode during which remains of large, soft-bodied animals (the Ediacaran fauna) first appear and at whose end animals able to secrete hard parts burst onto the scene. It marks the preparation for the beginning of life as we know it best; the Cambrian Explosion. This period is remarkable also by its huge climatic upheavals that twice turned Earth into a planetary snowball, when ice masses extended to tropical latitudes. As

if these unprecedented and never repeated big freezes were not sufficient to focus geologists' undivided attention on the late-Neoproterozoic, seawater became for a time so depleted in oxygen that soluble ferrous iron entered shelf areas to precipitate out as banded iron formations, which had vanished around 2.2 Ga when oxygen first entered the oceans in any amounts. Neoproterozoic world events opened with all continental lithosphere known to be around at the time consolidated in the mother of all continents, literally called Rodinia from the Russian for motherland. Rodinia broke up with the as yet unexplained break out of Laurentia from close to its heart. A massive round of sea-floor spreading saw tiles from the Rodinian mosaic reassembled as the core of the Gondwana supercontinent beginning around 650 Ma ago. Gondwana played a massive role in subsequent tectonics until it too broke up in the Mesozoic. These were interesting times, relative to which the Phanerozoic seems somewhat tame, except for its tangible record of life's ups and downs.



Continents of the Late Neoproterozoic

But there is a problem; with magmatic activity sparsely distributed in Neoproterozoic space and time, and a lack of rapidly changing biomarkers, division of events through time and, more important, correlating events from place to place has proved difficult, except in a barely useful and often mistaken way. Geological accounts of the late-Precambrian have been permissive and provocative, to say the least. That seems likely to change rapidly. Frustration centred on the time problem set against the undoubted drama of events had spurred the development other means of stratigraphic division and correlation.

The geologically instantaneous mixing of isotopes affected by global processes forms the basis for identifying large events that fractionate them in stratigraphic sections everywhere. That has been the biggest contribution of the oxygen-isotope data in seafloor sediment cores for the Neogene, in which fluctuating volumes of land ice shifted the proportion of  $^{16}\text{O}$  to  $^{18}\text{O}$  in ocean water, so that features in  $\delta^{18}\text{O}$  records become means of fine-tuned correlation world-wide for climate shifts. Carbon isotopes play a similar role in charting changes in global bio-productivity and burial of dead matter and carbonate hard parts. Strontium serves to detect changing balances between supply of dissolved material from oceanic magmatism and from erosion of  $^{87}\text{Sr}$ -enriched continental crust. Sulphur isotopes also help chart supply and demand among organic and inorganic processes. Such chemo-

stratigraphic methods were recognised as a lifeline for resolving Precambrian evolution in the late 1980s. A decade on, painstaking work has begun to bear fruit, as covered by a Special Issue of the 100<sup>th</sup> volume of *Precambrian Research* (v. **100(1)**, 2000). Andrew Knoll of the Botanical Museum, Harvard, USA summarises progress (Knoll, A.H., 2000. [Learning to tell Neoproterozoic time](#). *Precambrian Research*, v. **100**, p. 3-20; doi: 10.1016/S0301-9268(99)00067-4), but details of the chemo-stratigraphic approach and what the prominent isotopic markers might mean appear in a paper of monographic proportions from a team at the Department of Earth and Planetary Sciences, Macquarie University, Australia (Walter, M.R. et al., 2000. [Dating the 840-544 Ma Neoproterozoic interval by isotopes of strontium, carbon and sulphur in seawater, and some interpretative models](#). *Precambrian Research*, v. **100**, p. 371-433; doi: 10.1016/S0301-9268(99)00082-0)

Chemostratigraphy seems to resolve the question of how many late-Precambrian icehouse conditions of global significance. Though some have speculated on as many as 5 or 6 from occurrences of glaciogenic rocks, only two match with isotopic signals, one (Sturtian) around 700 Ma and one around 600 Ma (Marinoan). Both have associated negative  $\delta^{13}\text{C}$  excursions in carbonates to the level of mantle carbon, which suggest that life was reduced to a minimum by 'Snowball Earth' conditions. Associated shifts in the proportion of isotopically heavy sulphur are different. Sturtian glaciation matches with an increase in  $\delta^{34}\text{S}$ , a likely product of ocean anoxia, the involvement of light  $^{32}\text{S}$  in bacterial reduction of sulphate to sulphide ions, and the burial of iron sulphide at sources of ferrous iron around sea-floor hydrothermal systems. The anoxia was sufficiently extreme for  $\text{Fe}^{2+}$  to dissolve and mix throughout the ocean water column, so that precipitation as ferric oxy-hydroxides burgeoned in shelf seas to form BIFs a little younger than the glaciogenic rocks. Marinoan glaciation, though equally catastrophic for bioproductivity, did not fully deplete the oceans of oxygen. Massive peaks of  $\delta^{13}\text{C}$  prior to glaciations suggest that intense precipitation of carbonates in the limestones so common in the run-up to frigidity, plus burial of abundant dead organic matter in the case of the Marinoan, dramatically drew down  $\text{CO}_2$  from the atmosphere. Life's recovery after the Sturtian, together with organic burial, boosted oxygen levels, as too following the 600 Ma Marinoan. Possibly the delivery of huge amounts of glacially ground rock flour added nutrients that helped fuel this biological pump, and an increase in  $^{87}\text{Sr}/^{86}\text{Sr}$  after the Marinoan could reflect such fertilization. There is much more in the paper that will fuel advances in ideas of the co-linkage of glaciation and biological evolution - essentially adaptive radiation by the few eukaryotes that survived anoxia and other stresses - and the evidence for large increases in oxygen production that are prerequisites for the origin of large, oxygen-demanding animals in the Ediacaran fauna. What came as complete surprise to me, a non-specialist, was clear evidence from several well-studied sections for the largest negative  $\delta^{13}\text{C}$  excursion in geological history only 2 Ma before the Cambrian Explosion, which took less than a million years to develop.. Other isotopic trends seem to indicate a brief but highly intense global warming that snuffed the Ediacaran animals from the fossil record. The unique depletion in heavy carbon points strongly to the seabed belching teratonnes of methane in unstable gas hydrate, a product of double selection of  $^{12}\text{C}$  by photosynthesizing plankton and methanogen bacteria metabolizing dead planktonic matter within ocean-floor sediments.

Isotopically, the late-Neoproterozoic was chaotic. Carbon in particular records ups and downs with amplitudes and frequencies that dwarf those of the far-better recorded Phanerozoic, even in later glacial epochs and mass extinctions. It was two evolutionary

developments that probably damped down excursions in carbon isotopes in later times: the stirring of deep-ocean muds by burrowing animals to promote more rapid oxidation of buried organic matter; the increased efficiency of CO<sub>2</sub> drawdown by organisms that secreted carbonate hard parts. Perhaps Precambrian events were not so dramatic after all, equally disturbing events being smudged in the Phanerozoic by the rapid adaptive radiation following the Cambrian Explosion.

My prediction is that this issue of *Precambrian Research* will become the starting post for a major shift of research into Neoproterozoic and earlier Precambrian sedimentary piles, after two decades of getting things straight in the Mesozoic and Cenozoic. I feel confident in that, because the stories of Snowball Earth and near extinction of all oxygen demanding life around 700, 600 and now 545 Ma are ones that will, as The Daily Mirror might say, run and run.