Aerobic to anaerobic depositional systems tracts in Archean sediments: Implications for the composition of the early hydrosphere and biosphere

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Deposition of iron-formation is often linked to oxidation of iron along a chemocline that separated shallow oxic from deep anoxic ocean water in the early Precambrian (Klein and Beukes, 1989). However, the basis for this model has been eroded by documentation of mass independent sulfur isotopic fractionation, aparently requiring anoxic conditions, in rocks >2.45Ga (Farquhar et al., 2000) and the discovery of anoxygenic phototrophs capable of oxidising reduced iron (Widdel et al., 1993) implying that iron-formation could have formed in absence of oxygen. This leads to models of a totally anoxic Archean world (Kasting and Siefert, 2002) and a need to revisit evidence for free oxygen at that time.

Archean siliciclastic continental shelf successions, like the 2.95Ga Witwatersrand, often reveal a systematic depositional trend from deep water hematitic iron-formation shallowing upwards through sideritic iron-formation and pyritic carbonaceous shale into green and grey shales. Similar depositional tracts are developed in the 2.52 - 2.64Ga Cambellrand carbonate platform where deep basin hematite and siderite iron-formations are followed by highly carbonaceous pyritic basin to slope carbonates, dark-grey stromatolitic reef and lagoonal carbonates and eventually light-grey carbon-poor intertidal dolomites (Beukes, 1987).

These trends in Archean successions are analogous to aerobic, dysaerobic and anaerobic depositional systems tracts developed in modern sediments through a complex interplay of oxygenated ocean water, primary organic productivity, burial rate and aerobic to anaerobic microbial degradation pathways of organic matter. It is our contention that the presence of these facies in Archean sedimentary strata is best explained if all of these components, including free oxygen and the required microbial respiration processes, were in place in the early ocean.

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Noble gas evidence for gas fractionation in firn

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We present noble gas, oxygen and nitrogen measurements of firn air from two sites. The first set of samples was taken in 1998 at the summit of the Devon Ice Cap in the eastern part of Devon Island (75°N, 82°W, altitude: 1800 m a.s.l.). The second set was taken in 2001 at NGRIP location (North Greenland) (75°N, 42°W, 2960 m a.s.l.).

Noble gas concentrations and main isotopic ratios of He, Ne, Ar, Kr and Xe were analysed. Heavily enriched elemental Ne/Ar ratios are observed with respect to the atmosphere in the so-called "lock-in zone" or "non-diffusive zone" at depths of around 50-70 m. The enrichment in the lock-in zone increases with depth and reaches the maximum value in the deepest samples just above the zone of impermeable ice where no free air could be extracted.

This enrichment can be explained either by 1) fractionation of air expelled from the closing bubbles, or 2) diffusion of neon through the ice in response to the generated overpressure in the newly formed bubbles. Both processes preferentially accumulate neon in the remaining open firn layers. Similarly, elemental ratios of O_2/N_2, O_2/Ar and Ar/N_2 are increasing with depth. The much lower diffusivity of O_2, N_2 and Ar in ice compared to Ne suggests that explanation 1) is of greater importance.