Pliocene warmth: ocean gateways and polar oceans

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Paleoceanographic time series from numerous sediment cores retrieved in the Atlantic and Pacific Oceans and in the Caribbean Sea show that the Panamanian Seaway closure had a major impact on ocean circulation beginning at 4.6 Ma. The Gulf Stream intensified and introduced warm and saline water masses to high northern latitudes**,** which led to Pliocene warmth at 4.6 Ma. The world during the Pliocene warm interval was globally warmer than the past interglacial maxima and was characterized by a Northern Hemisphere without major ice shields. Since 2.7 Ma, the cycle between ice ages and warm interglacials has dominated the climate on Earth. Our understanding of the Pliocene warm period and the ice age cycles is that subtle variations in Earth's orbit and rotation are amplified by internal feedbacks, yielding dramatic climate change over hundreds to thousands of years. The time interval between 4.5 and 3.1 Myr was dominated by a pronounced long-term minimum in the amplitude of the 41 kyr cycle in the obliquity of Earth's rotation which would have failed to produce particularly cold northern hemisphere summers, the key requirement posited by Milankovitch for the onset of major northern hemisphere glaciations. During this time interval, there may have been several aborted shifts toward glaciation, for example between 4.1 - 3.9 Myr and 3.5 - 3.3 Myr. During late Pliocene and early Pleistocene, a high amplitude in the obliquity cycle resulted in periods of low tilt angle, which, in turn, would have yielded periods with cold summers in the Northern Hemisphere. Thus, it has been suggested that the progressive increase in the amplitude of the obliquity cycle tipped the scale between 3.1 - 2.7 Myr, allowing for long-term expansion of Northern Hemisphere ice. In short, our long-held view of the temperature requirement of glaciation is largely consistent with the timing of the onset of Northern Hemisphere Glaciation.In addition, atmospheric carbon dioxide appears to represent the key internal feedback to explain Pliocene warmth, being more abundant during the Pliocene thermal maximum (≥400ppm) than during warm interglacial periods (280-300ppm) and scarce during ice ages (180-200ppm). However, it is not conclusively explained what caused atmospheric carbon dioxide to change. Carbon dioxide is sequestered in the ocean interior by the photosynthetic production of organic carbon that subsequently sinks out of the low latitude surface ocean before being converted back to carbon dioxide. However, rapid vertical mixing in warmer polar ocean regions such as the Antarctic and the Subarctic North Pacific allows this deeply sequestered carbon dioxide to escape back into the atmosphere through the polar ocean surface. Measurements of the N isotopes and biogeochemical properties in sediment cores indicate that vertical stratification of the polar ocean reduced this polar CO_2 leak during cold times, has provided a satisfyingly simple physical explanation for this cooling-induced stratification. This hypothesis has been recognized as the critical piece in the Plio/Pleistocene CO_2 puzzle.

High-resolution chemostratigraphy of the 2.46 Ga Joffre banded iron formation, Western Australia: implications for the hydrosphere-atmosphere-lithosphere in the early Palaeoproterozoic

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Here we present new geochemical data of a 355 m long drill core from the single largest banded iron formation (BIF) known, the 2460 Ma [1] Joffre BIF, Western Australia. By directly preceding the 2.45-2.32 Great Oxygenation Event (GOE), this BIF was deposited prior to one of the most important periods in Earth history. The Joffre BIF consists predominantly of chert-hematite-riebeckite microbands (<1mm) alternating with chert-Fe dolomite-siderite-crocidolite mesobands (>1cm) and denser magnetite-hematite mesobands, respectively. The precursors of these mineral phases were laid down on a large stable and clastic-starved continental shelf [2]. Very fine-grained occasionally oolitic, bands of potassium-rich greenalite and stilpnomelane occur throughout, documenting input of tuffaceous material from evolved volcanic sources, similarly to the Woongarra rhyolite, in the vicinity of the depository. Preliminary geochemical results show that K_2O and Ba are strongly correlated to immobile elements such as Al_2O_3, TiO_2, Zr, La, Nb, Hf and various trace metals such as V, Cr, Ni and Co, suggesting minimum degree of K- and Ba-mobilisation. Relative to the profound Cr enrichment in the overlying Weeli Wolli BIF [3], very low Cr content (3-10 ppm) are found within Joffre BIF which indicate that the atmospheric O_2 and the oxidative weathering of continental pyrite was suppressed at the time. In contrast to the underlying Dales Gorge BIF, elevated values are found of P_2O_5 (up to 2.4 wt.%), B (up to 33 ppm), Li (up to 9 ppm) and Au (up to 8.4 ppm). Since none of these elements are hosted within the tuffaceous material they likely were sourced from elevated submarine hydrothermal activities related to the emplacement of the 2449 +/- 3 Ma large, bimodal igneous province of Weeli Wolly-Woongarra Formations [4].

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[2] Morris (1993) Precambrian Research **60**, 243-286
[3] Konhauser et al. (2011) Nature **478**, 369-373
[4] Barley et al. (1997) Nature **385**, 55-58