Abrupt cessation of North Pacific upwelling with Northern Hemisphere Glaciation recorded by silicon isotopes

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The abrupt cessation of high opaline accumulation marks the initiation of Northern Hemisphere Glaciation in the Subarctic North Pacific at ~2.7 Ma, and the beginning of ice-rafted debris deposition. The decreased opal flux has been linked to a decline in the exposure of nutrient-rich deep water to the surface with an increased stratification of the water column within the subarctic gyre. The restricted nutrient supply is considered to lead to more complete utilization of nutrients with a resulting increase in the $\delta^{15}N$ and $\delta^{30}Si$ values in the marine sediment record. Both Si and N isotopes vary by about half the mass fractionation factor estimated for nutrient uptake across this transition. Whilst nitrogen isotopes from the bulk sediment document a heavy isotope enrichment, there is an inverse correlation with silicon isotopes. This inverse correlation cannot be reconciled with the inferred nutrient utilization signal for the stable isotope variations.

The silicon stable isotope composition of the total diatom export, and thus the underlying sediment, generally does not record a 'utilization' signal in high productivity areas. This is because nutrient supply to surface waters and export of organic material are generally near steady-state conditions, with near complete transfer of the upwelling silicic acid (and isotopic composition) to the opal export from the surface water. Hence, sedimentary silicon isotope variations appear to be predominantly forced by external changes in the supply (and isotopic composition) of nutrients to upwelling waters. The decrease in diatomite $\delta^{30}Si$ values at 2.7 Ma are thus interpreted to reflect a reduced supply of nutrient-rich waters with high $\delta^{30}Si$ values into the surface waters of the North Pacific, rather than a decrease of Si utilization. The increase in $\delta^{15}N$ values from low $\delta^{15}N$ prior to 2.7 Ma may reflect an elimination of diazotrphic N-fixation. The stratification and cooling of the surface waters may have destroyed diatom-diazotroph symbioses, enhancing the effects of water stratification on diatom productivity.

Recorded variations on both glacial-interglacial and longer time-scales can thus be attributed to oceanographic re-organisation. The stable isotope variations of this core illustrate the complex inter-dependencies between productivity, ocean circulation and nutrient dynamics and their effects on proxies for nutrient utilization.