Geophysical Research Abstracts,
Vol. 11, EGU2009-5186, 2009
EGU General Assembly 2009

13 years of OPALEO: half-way towards calibration of opal as a paleoproductivity proxy?

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About a decade ago, the OPALEO community has evaluated the advantages and difficulties of using the mass accumulation rate of biogenic silica (opal MAR) in marine sediments, as a proxy for paleoproductivity (Ragueneau et al., 2000). On the one hand, diatoms play a major role in carbon export, biogenic silica is relatively well preserved compared to carbon and siliceous sediments are found everywhere, especially around Antarctica which plays such an important role in the biological pump and where carbonate sediments are virtually absent. On the other hand, spatial and temporal variations in silica dissolution and preservation as well as in the Si-C decoupling, from surface waters down to the sediments, drastically complicate the deciphering of the siliceous sediment archive. Is there any hope?

Several recommendations arose from the OPALEO workshops, which proved valid for many other proxies beyond opal MAR: the need for a better understanding of the cycling of the tracers, or the life cycles of the organisms that make the archives, in the modern ocean; the need for a multi-proxy approach, for a closer collaboration between experimental and modeling work and the complementarity between the conducted work at regional and global scale. In this paper, I will present our approach to address the question raised above, illustrating how these recommendations made our community make real progress on this path towards proxy calibration. I will also show that on this path, many questions have been addressed which have impacts for our understanding of the modern ocean and in particular, concerning the role of diatoms in the biological pump or the transfer of Si from land to ocean.

We started by addressing the processes controlling opal early diagenesis in the sediments, combining direct measurements of silica dissolution properties and early diagenetic modeling. Beyond detailed results concerning a kinetic versus thermodynamic control of opal dissolution, these studies pointed out the importance of a better characterization of the quality of the biogenic silica reaching the sediment-water interface. This made us conduct a series of original experiments on diatoms as single cells, being more or less silicified, more or less degraded. On diatoms incorporated inside aggregates and fecal pellets as well. These experiments suggested in turn that biogenic opal may be constituted of different phases and we are exploring today the origin of these phases because their existence may have profound implications for our paleoceanographic interpretations. Do they have a purely siliceous origin or are they related to a variable strength of Si-C interactions inside diatoms? We are now studying these Si-C interactions inside diatoms, from their origin during silicification to their implications for the dissolution of silica and the degradation of diatom-carbon.

In a very parallel manner, we started our studies on Si and C decoupling in the sediments and very rapidly, ended up in trying to understand the origin of the spatial variations encountered in the sediments of various biogeochemical provinces. For this aspect of proxy calibration, we combined process studies and the construction of a global data base of Si and C fluxes, from surface waters down to the accumulation in sediments. This global analysis showed that sedimentary signals find their origin in surface waters and in fact, spatial variations in Si:C ratios observed during production are carried out relatively unchanged down to the sediments. The Si:C ratio is increasing by two orders of magnitude between production and accumulation (only one order of magnitude on continental margins) but in such a homogeneous manner that spatial variations seem well preserved. This homogeneity is remarkable, given the many different characteristics of the biogeochemical provinces studied. This is particularly true when we realize that grazers, both in the water column and at the sediment-water interface, seem to play a major role in this decoupling.

Following a brief overview of progress at these two fronts, silica dissolution/preservation and Si-C interactions, I will derive information on the carbon biological pump, present and past. Indeed, we have been combined recently these studies to propose a silica-based reconstruction of the efficiency of the carbon biological pump in today's ocean and results will be discussed in terms of the role of diatoms in the biological pump, the importance of seasonality and the need to explore further the complexity of the ecological/biogeochemical processes controlling the way carbon is being exported to the deep, beyond POC that can be captured in sediment traps. This study has also paleoceanographic implications and to eventually come back to the OPALEO perspective, I will also try to combine these recent information to understand better the question of glacial/interglacial variations in the strength of the biological pump in the Southern Ocean as seen from siliceous geochemical and micropaleontological signals.