

## Paleoproductivity reconstruction: The on-going quest for a quantitative geochemical tracer

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The export of organic carbon from surface to deep water is one of the key aspects of the global carbon cycle controlling atmospheric CO<sub>2</sub> and the earth's radiation balance. A full understanding of the influence of greenhouse warming on secular changes in global climate thus requires the accurate reconstruction of this variable from the sedimentary record.

The residual organic carbon that is buried after reaching the seafloor is inadequate for this purpose, because of poor and variable preservation. Instead, indirect methods, which use geochemical or micropaleontological parameters that can be related to primary production, have been explored. In general, the main advantage of these tracers is better preservation of the productivity signal; the main drawback is that other processes, which may or may not be related to productivity, also affect this signal. One can attempt to mitigate this problem by combining different tracers of productivity that are influenced by different secondary processes, but we have yet to obtain a fully constrained system using this approach and it is becoming increasingly clear that one cannot expect to find a simple method of paleoproductivity reconstruction that would be universally applicable. Instead, different proxies will have different domains of applicability and it behooves us to clearly understand and define the limits of these domains. I will briefly review recent developments that have changed our views on the applicability of two geochemical tracers, sedimentary biogenic Ba accumulation rates and ex.<sup>231</sup>Pa/ex.<sup>230</sup>Th, which were initially viewed as very promising and broadly applicable. As we gained a better understanding of their geochemistry, this initial optimism has given way to a more cautious approach towards their use for paleoproductivity reconstruction. While it is now clear that they cannot be used indiscriminately, however, they could still provide useful quantitative information under a more restricted set of environmental conditions.

## Modelling the Cenozoic evolution of atmospheric CO<sub>2</sub>

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In recent years, paleolevels of atmospheric CO<sub>2</sub> during the Cenozoic have been estimated from various proxy records, such as the <sup>13</sup>C isotopic composition of marine organic matter (Pagani et al., 1999), the seawater pH recorded in boron isotopes (Pearson and Palmer, 2000; Lemarchand et al., 2000) and the stomatal density/index of fossil leaves (Royer et al., 2001). These proxy-based reconstructions provide Cenozoic evolutions of atmospheric CO<sub>2</sub> between two extreme scenarios: (1) CO<sub>2</sub> decreased from very high levels (2000-4000 ppmv) in the Paleocene-Eocene to present or lower than present values in the Miocene-Pliocene, (2) CO<sub>2</sub> remained relatively constant throughout the Cenozoic.

Here we present a coupled model of the carbon and boron cycles. This model includes four carbon reservoirs (ocean-atmosphere, shelf/continental carbonates, pelagic carbonates and crustal organic carbon) for which carbon content and isotopic composition are calculated. A budget is also established for ocean alkalinity, ocean boron and its isotopes. A sub-model of the ocean-atmosphere system allows a redistribution of carbon and alkalinity among the atmosphere, the surface and deep ocean reservoirs. This sub-model calculates explicitly carbonate chemistry, pH, calcite and aragonite lysocline depths, as well as discrimination of carbon and boron isotopes in physical, chemical or biological processes. Surface temperature is related to atmospheric pCO<sub>2</sub> through a simple parametric law.

Various weathering rate laws or scenarios of spreading rates through time are tested with this model. Organic carbon deposition is derived from the δ<sup>13</sup>C of ancient seawater. It is shown that it is possible to produce simulations which are broadly consistent with a variety of proxy records, such as calcite compensation depth, <sup>13</sup>C isotopic fractionation of marine biology and boron isotopes changes through the Cenozoic. Interestingly, in such reconstructions, Miocene levels of atmospheric CO<sub>2</sub> tend to be smaller than today.

### References

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