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A tectonic-triggered perturbation of the carbon cycle at the Frasnian-Famennian boundary: impact on marine paleoenvironments

L.Riquier , O. Averbuch, N. Tribovillard
UMR 8110 Processus et Bilan des Domaines Sédimentaires & FR 1818, University of Lille 1, France.

Laurent.riquier@ed.univ-lille1.fr, Fax: +33-(0)3-20-43-49-10

The Late Devonian Frasnian-Famennian (F-F) times record one of the biggest five biological crisis that mostly affected marine shallow water organisms especially corals. In many areas, the F-F mass extinction is coeval with the deposition of black organic matter-rich levels: the so-called "Kellwasser horizons" in several epicontinental basins, from shelfal to offshore domains (Schindler, 1990, Buggisch, 1991). The two Kellwasser horizons (Late *rhenana* and *linguiformis* zones of the Late Frasnian) are linked worldwide with two positive excursions of the $\delta^{13}C_{carb}$ signal that are interpreted as the result of enhanced organic-matter burial (Joachimski et al, 1994, 2002). This period is also characerized by a noticeable decrease of detrital input from continental areas to the distal zones. This is highlighted by the decreasing trend of magnetic-susceptibility values in many sections of N. Gondwanan (Central Morocco, Anti-Atlas & Montagne Noire) and S. Laurussian (Harz Moutains & Rhenish Massif) margins. The decrease of this signal, controlled by mainly magnetite mineral abundance and to a lesser extent the paramagnetic minerals contribution of sediments, would result from a global Frasnian sea-level rise. This transgressive phase is punctuated by two major pulses of sea-level rise, corresponding to the two Kellwasser horizons. These peculiar levels, in which increase of productivity-indicator concentrations, such as Ba/Al and Cu/Al (Tribovillard et al., 2004, Riquier et al., 2005) have been recorded, were most probably periods of high oceanic primary productivity. The increase of phytoplanktonic activity seems to be coeval with the onset of dysoxic to anoxic conditions in bottom-water environments, as indicated by positive peak values

of redox paleomarkers, such as U/Th and V/Cr (Tribovillard et al., 2004; Riquier et al., 2005). These oxygen-poor conditions developed during Late Frasnian in both platform and basin settings (Central Morocco, Harz Mountains & Rhenish Massif), and lasted till Early Famennian in the deeper environments (Montagne Noire & Anti-Atlas).

Primary productivity and thus levels of dissolved oxygen in marine domains are usually controlled by nutrient availability in surface waters. For the Late Devonian, it may be postulated that the triggering mechanism for increased nutrient concentration in marine environment was the enhanced weathering intensity under greenhouse conditions (Algeo et al., 1995; Murphy et al., 2000; Averbuch et al., 2005). This mechanism would be the result from the early stage of the Eovariscan orogenesis, associated with vascular plant development. The warm and humid climate has potentially favoured the continental weathering and alteration rates of uplifted zone, enhanced fluvial runoff, and so ensured continued long-term nutrient flux to the oceans during the Late Devonian (Algeo et al., 1995; Racki, 1998; Tribovillard et al., 2004; Averbuch et al., 2005; Riquier et al., 2005). In addition, mountain building might have modified atmospheric circulations, and collision of Laurussia and northwestern Gondwana may have caused a reduction in oceanic water circulations between the Panthalassa and the Paleotethys (Copper, 1986; Averbuch et al., 2005). Reduced circulation slowed the ventilation of deep water. The confinement of epicontinental basin, coupled with highstand sea level and high productivity may have caused the onset of long-term recurrent water stratification and bottom-water anoxia development. These two phenomena could facilitate the release of nutrients (P and N) from decaying organic-matter. The transfer of dissolved P from anoxic bottom water to ocean surface could create a positive feedback loop between P regeneration in bottom water, high surface productivity and anoxia (Ingall and Jahnke, 1997; Murphy et al., 2000). Lastly, silicate alteration, enhanced by large uplifting starting during Frasnian, and the burial of large quantities of organic-matter by the end of Frasnian stimulated CO_2-pumping. The decreased concentration of this greenhouse gas could have resulted in a climate cooling. The latter may have caused a sea-level fall, recorded at the end of the Kellwasser-horizon deposition and a resumption of detrital input, hightlighted by noticeable increase of magnetic susceptibility during the Early Famennian.

Thus, a conjunction of perturbations may have participated actively to the F-F events: the extremely rapid changes in both oxygenation conditions and temperatures are likely to have had drastic repercussions on marine fauna possibly leading to the major F-F crisis.

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