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Devonian mass extinctions: cumulative or cataclysmic?

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The Late Devonian Mass Extinction is the least understood of the 'Big 5' extinctions in virtually every aspect: timing, effects and causes - and there is little knowledge of the coupling of events on land and in the ocean. At one extreme, the marine crisis is viewed as a rapid, cataclysmic event at the Frasnian/Famennian boundary (the "Kellwasser Event") followed by another crisis 13 Myr later (the "Hangenberg Event"). Alternatively, these Late and end-Devonian extinctions are viewed as a cumulative series of minor events, drawn out over the entire Devonian. Our project aims to resolve these through study of the spectacular Devonian sedimentary succession in northern Spain that is both remarkably complete and laterally extensive, providing a transect across an entire Devonian marine shelf from deep marine to near terrestrial environments. We present initial results from Piedrasecha, north of Léon. We analysed 47 samples spanning the Frasnian Nocedo Formation, and the Famennian-Tournasian (Carboniferous) Fueyo, Ermita and Baleas Formations. Combined geochemical and palynological analyses reveal:

1) $\delta^{13}C_{org}$ values are stable around -26‰ through the Frasnian and Famennian prior to a 2‰ negative shift associated with the onset of black mudstones at the base of the Baleas Formation (latest Famennian). This is likely a muted expression of the Hangenberg Event negative $\delta^{13}C_{org}$ excursion.

2) Redox proxies (Th/U, Mo/Al, V/Al and U/Al) indicate bottom waters remained oxygenated until the latest Famennian, when weakly dysoxic (at worst) conditions developed. There is no obvious expression of Kellwasser Event anoxia in this offshore setting, and only a weak manifestation of Hangenberg oxygen restriction.

3) An order of magnitude shift in productivity proxy values (Ba/Al, Ni/Al, Zn/Al and P/Al) in the latest Famennian suggests that the Hangenberg Event is associated with increased primary productivity.

4) Mercury is enriched in the upper Frasnian Nocedo Formation where it withstands normalisation

to TOC (Hg/TOC values reach 388 ppb/wt%, similar to those reported for the Upper Kellwasser Horizon elsewhere). This mercury might derive from large igneous province volcanism and is potentially a chemostratigraphic marker for the Kellwasser Event, though we require better stratigraphic control to evaluate this. Significant Hg enrichments (up to 160 ppb) in the latest Famennian Baleas Formation do not withstand normalisation, as TOC reaches 4.7 wt% at this level. The succession is thermally mature and since TOC drops with thermal maturity, Hg/TOC values might be elevated in comparison to original values.

5) Palynomorph assemblages are dominated by simple spores and *Geminospora*. The latter derives from the Mid-Late Devonian forest tree *Archaeopteris*. This suggests a rather homogenous vegetation typical of Late Devonian settings where successive extinctions stripped out diversity from terrestrial floras. However, it may be that in this distal section we are sampling spores that have been winnowed during transport. Work on other sections will enable us to test this.

We have sampled 14 further sections providing a complete Devonian succession and with >500 samples in preparation we hope to resolve whether the Late and end-Devonian crises were the result of cumulative stresses, or were indeed cataclysmic events.