Geophysical Research Abstracts
Vol. 16, EGU2014-3236-1, 2014
EGU General Assembly 2014

Ca, Sr, Mo and U isotopes evidence ocean acidification and deoxygenation during the Late Permian mass extinction

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The most catastrophic extinction event in the history of animal life occurred at the end of the Permian Period, ca. 252 Mya. Ocean acidification and global oceanic euxinia have each been proposed as causes of this biotic crisis, but the magnitude and timing of change in global ocean chemistry remains poorly constrained. Here we use multiple isotope systems - Ca, Sr, Mo and U - measured from well dated Upper Permian- Lower Triassic sedimentary sections to better constrain the magnitude and timing of change in ocean chemistry and the effects of ocean acidification and de-oxygenation through this interval. All the investigated carbonate successions (Turkey, Italy and China) exhibit decreasing δ44/40Ca compositions, from $\sim$-1.4‰ to -2.0‰ in the interval preceding the main extinction. These values remain low during most of the Griesbachian, to finally return to -1.4‰ in the middle Dienerian. The limestone succession from southern Turkey also displays a major decrease in the δ88/86Sr values from 0.45‰ to 0.3‰ before the extinction. These values remain low during the Griesbachian and finally increase to 0.55‰ by the middle Dienerian. The paired negative anomalies on the carbonate δ44/40Ca and δ88/86Sr suggest a decrease in the carbonate precipitation and thus an episode of ocean acidification coincident with the major biotic crisis. The Mo and U isotope records also exhibit significant rapid negative anomalies at the onset of the main extinction interval, suggesting rapid expansion of anoxic and euxinic marine bottom waters during the extinction interval. The rapidity of the isotope excursions in Mo and U suggests substantially reduced residence times of these elements in seawater relative to the modern, consistent with expectations for a time of widespread anoxia. The large C-isotope variability within Lower Triassic rocks, which is similar to that of the Lower-Middle Cambrian, may reflect biologically controlled perturbations of the oceanic carbon cycle. These findings strengthen the evidence for a global ocean acidification event coupled with rapid expansion of anoxic zones as drivers of end-Permian extinction in the oceans.