Persistent global marine anoxia in the early Silurian

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The lower Silurian Rhuddanian Stage directly follows both the Hirnantian glaciation and end-Ordovician mass extinction. The E1-NC174 core from the Murzuq Basin, Libya, records a continuous black shale sequence from the lower to upper Rhuddanian (*Akidograptus ascensus-Parakidograptus acuminatus* to *Coronograptus cyphus* global graptolite biozones, lasting approximately 3 million years). Using iron speciation analyses we have empirically confirmed previous inferences that this shale sequence was deposited under a consistently anoxic water column. Pyrite to highly reactive iron ratios further demonstrate that bottom-waters were locally euxinic throughout this interval.

To evaluate the global extent of reducing depositional environments through this interval we measured the uranium and molybdenum stable isotope compositions of this euxinic shale sequence. Both $\delta^{238}U$ and $\delta^{98}Mo$ values exhibit low variance, and Mo isotope values are anomalously light. We make a case that the low variance in the $\delta^{98}Mo$ values is indacative of Mo being quantitatively reduced under the locally euxinic conditions represented by the Rhuddanian black shales of the Murzuq Basin. These consistently low isotope values are interpreted as recording roughly 3 million years of persistently reducing global marine conditions in the early Silurian. Although there is fractionation during U removal into anoxic evironments, the shale $\delta^{238}U$ values are also consistent with widespread anoxia. Isotope mass balance modeling suggests that, at minimum, oxygen minimum zones during this interval were greatly expanded and largely euxinic.