Extensive marine anoxia during the Tonian Period revealed by uranium isotopes in marine carbonates

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The Tonian Period is a critical time interval that bridges the Mesoproterozoic 'boring billion' and the Cryogenian 'freezing millions' as well as the subsequent Ediacaran rise of morphologically complex animals. Understanding the global marine redox conditions during the Tonian Period is central to understanding the role of O_2 in the evolution of early animals. To provide a quantitative estimate on the global marine O_2 levels in the Tonian oceans, we measured 155 Tonian carbonate samples for uranium isotopic compositions ($\delta^{238}U_{carb}$). Our $\delta^{238}U_{carb}$ data is characterized by highly negative values throughout the sampled succession. The extremely low uranium concentrations (<0.2 ppm) and the lack of systematic covariations between $\delta^{238}U_{carb}$ values and established diagenetic indicators suggest that the measured $\delta^{238}U_{carb}$ values closely reflects the isotopic compositions of Tonian seawater. U isotope mass balance models indicate that a significant proportion (>50%) of the Tonian seafloor was overlain by anoxic water. Combined with recent $\delta^{238}U_{carb}$ studies from the Cryogenian[1] and the Ediacaran[2–5] periods, we find there were no significant changes in the proportion of oxic to anoxic waters in the deep ocean until the middle Ediacaran Shuram negative $\delta^{13}C_{carb}$ excursion. Integrated with paleontological data, our study suggests that extensive global marine anoxia until the middle Ediacaran period was a key factor delaying the rise and diversification of large, mobile, and morphologically complex animals.

[1] Lau et al. (2017) EPSL 458, 282–292. [2] Zhang et al. (2018) Sci. Adv. 4(6), eaan8983. [3] Wei et al. (2018) Geology 46 (7), 587-590. [4] Tostevin et al. (2019) EPSL 506, 104–112. [5] Zhang et al. (2019) Geobiology, in review.