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Stable isotopes, trace elements, and tiny fossils: Reconstructing a Mesoproterozoic ecosystem via the integration of isotope geochemistry, redox proxies, and eukaryotic fossils

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The Mesoproterozoic Roper Group of Australia is one of the oldest geological units that contains fossils which can be confidently assigned to the eukaryotic clade. Here, we report eukaryotic acritarchs from the Wyworrie and Amungee members of the Velkerri Formation. We use nano-EA IRMS to measure $\delta^{13}C$ of individual acritarch microfossils (n=147) along with bulk rock $\delta^{13}C$, $\delta^{15}N$, and $\delta^{15}N_{org}$ to obtain a view of water column conditions and paleoecology. Our work integrates geological, geochemical, and paleontological data sets to gain clarity on oceanographic and ecological conditions during the early stages of eukaryote evolution.

In the Amungee Member total organic carbon content (TOC) is elevated and redox proxy data are consistent with euxinic conditions. Here, all fossil $\delta^{13}C$ values are 6-7‰ higher than bulk $\delta^{13}C$. We suggest that Amungee eukaryotes were phototrophs confined to near the oxic surface where the $\delta^{13}C$ of dissolved inorganic carbon (DIC) was elevated because of an efficient biological pump in a water column that was redox stratified. In the Wyworrie Member TOC is low and redox proxies show oxygenated conditions through the water column. Here fossil $\delta^{13}C$ values broadly bracket bulk rock $\delta^{13}C$, and are considerably lower than in the Amungee Member. These data suggest that eukaryotes were not confined to the surface and were therefore accessed a wider range in the $\delta^{13}C$ of DIC through the whole water column or utilized a diversity of carbon substrates with a wider $\delta^{13}C$ range.

$\delta^{15}N$ data are consistent with a redox-active nitrogen cycle and oxygenated surface conditions throughout Velkerri deposition. While bulk rock $\delta^{15}N$ data are relatively consistent, organic $\delta^{15}N$ of extracted macerates increases in Wyworrie Member, consistent with more oxidizing conditions. We also document a tight correlation between fossil occurrence and kaolinite, which we hypothesize is due to taphonomic conditions controlled by redox shifts, themselves potentially driven by relative sea level change. Our data indicate that acritarch organisms were living solely in oxygenated portions of the water column, support the view that oxygen-requiring eukaryotes were an important part of marine ecosystems during the Mesoproterozoic, and bolster the hypothesis that coeval protosterol biomarkers were synthesized by eukaryotes.