Goldschmidt 2026 Abstract
https://doi.org/10.46427/gold2026.36398

# Formation of Early Eukaryotic Microfossil-Bearing Iron Carbonate Nodules in the Neoproterozoic Chuar Group

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Vase-shaped microfossils (VSMs) are globally distributed eukaryotic microfossils that appear in the late Tonian. VSMs rarely occur with other eukaryotic microfossils and are most commonly found in (silicified) carbonates – lithologies that form in peritidal settings and generally preserve only prokaryotic microbiotas for most of the Proterozoic. This suggests that VSMs may have occupied different habitats than most other early eukaryotes.

Here, we investigate the mineralogy and petrology of carbonate nodules within the late Tonian (~741–729 Ma) upper Walcott Member of the Chuar Group to gain a better understanding of VSM paleoenvironment. VSMs are found in high abundance in black shale-hosted, organic-rich iron carbonate nodules which contain minor quartz, gypsum, pyrite, iron oxide, and aluminosilicate clays. The principal fabric within nodules is sub-mm-scale spherulites, a common fabric today associated with microbial mats in tidal flat and terrestrial hypersaline and/or hyperalkaline environments. Spherulites contain acicular crystals with square or pointed terminations, arranged around a locus of amorphous organics or VSMs. Other fabric elements include mm-scale continuous and discontinuous laminations of organic matter and rhombic cements within the matrix and VSM test interiors. VSM tests are preserved as silica, iron carbonate, iron oxide, or pyrite casts and may contain a mix of these minerals. In some samples, VSMs have poorly preserved fragments of their original organic test. Stable carbon ($\delta^{13}C$) isotope values in nodule samples (-6.5 to -12.4‰) are generally more negative than Walcott Member bedded carbonates (~2 to -5‰).

We propose that VSMs were preserved in a restricted marginal marine environment, where they may have lived or were deposited from a more marginal setting. These results complement chemostratigraphic and sedimentological evidence for drier conditions during upper Chuar Group deposition. VSMs may have been among the first eukaryotes able to tolerate the hypersaline and evaporative conditions common at the interface of marine and terrestrial environments.