Advances in Neoproterozoic biostratigraphy spark new correlations and insight in evolution of life

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Our understanding of the evolution of life is fundamentally based upon the geologic time scale and the law of Faunal Succession (Smith, 1917), developed through countless observations of the fossil record for times when visible evidence of life is abundant. Indeed, the Neoproterozoic Eon (younger than 541 ± 0.13 Ma; Bowring et al., 2007) is defined by stacked zones of fossil assemblages with short stratigraphic ranges, calibrated with extensive geochronologic data (Gradstein et al., 2012). However, life on Earth reaches back another 3 billion years. The Precambrian record contains abundant microfossils, but their stratigraphic ranges are commonly unknown or seem long due to poor preservation and/or lack of geochronologic constraints. Biostratigraphic divisions have been proposed for Neoproterozoic strata (541–1000 Ma; e.g., Knoll, 2000; Hill and Walter, 2000), yet time-calibrated lithostratigraphic marker units and carbon-isotope anomalies indicating global “events,” including Snowball Earth glaciations and their aftermath, have thus far been more useful (Fig. 1; Hoffman et al., 1998; Condon et al., 2005; Knoll et al., 2006; Macdonald et al., 2010; Rooney et al., 2014). Stratigraphic successions predating Snowball Earth glaciations (older than ca. 720 Ma) are becoming more of a focus, with questions addressing ocean-atmosphere-lithosphere conditions leading to the most severe climate changes in Earth’s history, and eukaryotic diversification and innovation (e.g., biomineralization) (Porter and Knoll, 2000; Johnston et al., 2010; Macdonald et al., 2010; Bosak et al., 2011; Porter, 2011; Rooney et al., 2014). Strauss et al.’s (2014, p. 659) article in this issue of Geology contributes to our understanding of the Neoproterozoic Earth system by integrating high-resolution microfossil assemblage, carbon-isotope, and geochronologic data. The new results present the promise of moving from Proterozoic morphclass correlations with broad stratigraphic ranges and poor age control, to Phanerozoic-style species-level assemblage-zone correlation constrained by precise radiometric dates.

Vase-shaped microfossils (VSMs) appear in the rock record at ca. 740 Ma (Karlrstrom et al., 2000; Dehler et al., 2010; Strauss et al., 2014). These teardrop-shaped, originally organic-walled forms (tens to hundreds of micrometers in diameter) commonly occur in carbonate or silica concretions, bedded black chert, and organic-rich shale and carbonates. VSMs share the greatest number of affinities with modern testate amoebeae (heterotrophic protists), indicating that food-web complexity was advanced by middle Neoproterozoic time (Porter et al., 2003). VSMs have been reported from many paleocontinents (Porter and Knoll, 2000, and references therein), and this cosmopolitan distribution suggests the potential utility as index fossils to subdivide the earlier Neoproterozoic. Strauss et al. discovered VSMs in the Callison Lake dolostone in the Mount Harper Group, Yukon, Canada, and provide time-calibration of these fossils through Re-Os geochronology on organic-rich shale interbedded with carbonate that preserve a large negative shift in carbon-isotope values. Hundreds of VSMs were identified in thin sections from silicified shale near the top of the Callison Lake dolostone, and a subset contains diagnostic characters allowing species-level comparison to VSMs in the upper Chuar Group of Grand Canyon, Arizona (USA; Porter et al., 2003). Re-Os geochronology of organic-rich mudrocks provides a time calibration for these strata, which lack interbedded volcanic rocks suitable for U-Pb dating on zircon. The Re-Os age of 739.9 ± 6.1 Ma was derived from samples stratigraphically below the Mount Harper Volcanic Complex, dated at 717.4 ± 0.1 Ma with chemical abrasion–isotope dilution–thermal ionization mass spectrometry (CA-ID-TIMS) on zircon, and is correlative with the Coates Lake Group in the Mackenzie Mountains, with a Re-Os age of 732.2 ± 3.9 Ma (Rooney et al., 2014), illustrating how Re-Os geochronology can provide precise ages that are consistent with U-Pb geochronology (e.g., Selby and Creaser, 2003). Importantly, the age from the Callison Lake dolostone is within error of the U-Pb zircon age on a reworked tuff in the VSM-bearing black shale of the upper Chuar Group (742 ± 6 Ma; Karlstrom et al., 2000).

In both the Grand Canyon and northwestern Canada, the ca. 740 Ma VSM-bearing interval coincides with a downturn in carbonate and organic carbon-isotope values (Dehler et al., 2005; Rooney et al., 2014; Strauss et al., 2014). VSMs occur in other western Laurentian successions, including the top of the Beck Spring Dolomite of the middle Pahrump Group, Death Valley, California (USA; Horodyski, 1993), and the Red Pine Shale of the Uinta Mountain Group of Utah (USA; Dehler et al., 2007). Both occurrences also coincide with relatively low carbon-isotope values (Strauss et al., 2014, their figure 4) and are known from U-Pb detrital zircon ages to be younger than ca. 780 (Dehler et al., 2010; Mahon et al., 2014). Strauss et al. report poorly preserved VSMs from the base of the Callison Lake dolostone, also coincident with a downturn in carbon-isotope values at the base of a positive excursion (their figure 4). This discovery emphasizes that the first appearance of VSMs predates 740 Ma, perhaps by millions to tens of millions.

Figure 1. A Neoproterozoic time scale showing biostratigraphic, carbon-isotope, and geochronologic constraints with an emphasis on future possible subdivisions within the middle Neoproterozoic (data from Butterfield et al., 1994; Knoll, 2000; Knoll et al., 2006; Hill and Walter, 2000; Porter and Knoll, 2000; Karlstrom et al., 2000; Dehler et al., 2005; Macdonald et al., 2010; Halverson, 2006; 2010; Cohen et al., 2013). OA—Ornamented acritarchs; DS O—Diverse soft-bodied organisms; WCM—Weakly calcified metazoans; C. buickii—Cerebrosphaera buickii; VSM—Vase-shaped microfossils; Mpz—Meso-proterozoic; Pz—Paleozoic; GSSP—Global Boundary Stratotype Section and Point of the International Commission on Stratigraphy; GSSA—Global Standard Stratigraphic Age.
of years. Interestingly, VSMs were recently found in the upper Horse Thief Springs Formation (less than 780 Ma) of the middle Pahrump Group in Death Valley (Fig. 2), coinciding with what appears to be the base of the same positive carbon-isotope excursion (their figure 4).


Continued research may well result in further subdivision of the Neoproterozoic time scale within the 720 Ma to 811 Ma time window (Fig. 1). New techniques and careful examination of previously unexplored Neoproterozoic successions in Laurentia thus demonstrate the promise of the application of the Law of Faunal Succession to the Precambrian rock record, enhancement of our understanding of biotic evolution.

REFERENCES CITED

