COMMENTS AND REPLIES

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Comment

No Late Cambrian shoreline ice in Laurentia

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Runkel et al. (2010) propose that Late Cambrian cooling led to shoreline ice development in the upper Mississippi River valley. This cooling then led to latest Cambrian biotic turnover and onset of the Ordovician Diversification. ("Lower"/"Early," "Middle"/"Middle," and "Upper"/"Upper" Cambrian are proposed subsystem/subperiod divisions [Landing, 2007a] and follow the North American Stratigraphic Commission rules.)

Runkel et al. (2010) acknowledge that shoreline ice in the Jordan Formation counters a consensus that the Late Cambrian was part of a long Greenhouse interval. The Late Cambrian tropical latitude of Minnesota (e.g., Runkel et al., 2010) would require drastic cooling to form shoreline ice. However, the coeval "Great American Carbonate Bank" of the Laurentian craton is consistent with warm climates, while increased insolation and heat storage in broad epeiric seas on Laurentia and other tropical continents likely intensified Greenhouse conditions (Landing, 2007b). Runkel et al. (2010) cite evidence of cool-water carbonates, including ooids, to explain this trans-Laurentian carbonate deposition in the Late Cambrian. However, the composition of these ooids and most faunal elements (e.g., trilobites) is calcite, which is consistent with warm conditions (e.g., Zhuravlev and Wood, 1996).

Evaporites occur throughout the Laurentian Upper Cambrian and emphasize Greenhouse conditions. Evaporites are found in older upper Mississippi River valley units (Mount Simon–Wonewoc sandstones; Hagadorn et al., 2002) and the coeval Little Falls Formation, eastern New York (sources in Landing, 2007b). They also form major Upper Cambrian deposits in the equatorial Canadian Arctic (MacLean and Cook, 1999).

Processes other than freshwater ice and freeze-thaw form peritidal-subaerial soft-sediment clasts in sand dunes, salt marsh, beachrock, and intertidal and estuarine mud and peat. Soft-sediment clasts, whether desiccation-produced mud polygons or microbially bound/early cemented beach rock, can be imbricated or moved by waves and currents, or slump into small channels, just like the Minnesota clasts (e.g., Alsharhan and Kendall, 2003; Knight, 2005).

Soft-sediment clasts, whether made firm by clay, organic matrix (possibly stromatolitic in the "pinstripe lamination" of some Minnesota clasts; Runkel et al., 2010), or early cement may remain soft after burial and be deformed. After burial, the soft clasts could be burrowed by trace producers.

Runkel et al. (2010) note that the Jordan sandstone is essentially uncemented with loss of an original cement. Unknown cement/matrix composition (carbonate/evaporitic, cyanobacterial binding?) make conclusions of ice cementation and cold climate speculative.

Without evidence for grounded ice after the Early Cambrian (Landing and MacGabhann, 2010) and subsequent very high eustatic levels (Landing, 2007b), the Late Cambrian ocean likely lacked cold water and a thermocline (Landing, 2007b). Thus, an interpretation of Middle–Late Cambrian extinctions by cold water onlap (Runkel et al., 2010) is unlikely; the role of strong regressive-transgressive couplets and transgressive low oxygen masses should be considered (e.g., Hallam and Wignall, 1999; Zhuravlev and Wood, 1996). The appearance of marginal trilobites (likely dysoxia adapted) after Cambrian extinctions should be compared to Cretaceous faunal replacements at non-glacial times with onlap of hypoxic slope water onto platforms (e.g., Jenkyns, 1991).

Extinction at the *Cordylodus proavus* (conodont) Zone base is not the onset of the Ordovician Radiation (i.e., Runkel et al., 2010). This onset is better dated in the older *Eoconodontus* (conodont) Zone with the appearance and initial diversification of important phylum- and class-level taxa. Rather than driven by extrinsic factors, the Ordovician Radiation and the Cambrian Explosion record community evolution and the origin of more complex marine ecosystems (Landing et al., 2010).

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