RESEARCH FOCUS

Another test for snowball Earth

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The concept of a Neoproterozoic "snowball Earth"–an ice age in the tropics (Kaufman, 1997)–has captured the imagination of the public and scientists alike. The idea of global-scale glaciation, indicated by the abundance of Neoproterozoic glacial deposits (some with low-latitude paleomagnetic signatures), is not new (see Hoffman and Schrag [2002] and Eyles and Januszczak [2004] for developmental perspectives). This idea was given new life by Kirschvink (1992), who suggested that Earth might have been completely glaciated due to unusually high planetary albedo from an equatorial supercontinent. In this scenario, the hydrologic cycle would have been reduced, possibly leading to patchy land glaciers, but sea ice thick enough to prevent photosynthesis in the oceans. Iron concentrations would build up in the ice-covered oceans after oxygen was depleted, and ultimately the ecosystem would crash. Kirschvink termed this scenario "snowball Earth."

A snowball Earth could eventually be thawed when enough carbon dioxide had outgassed from ongoing volcanic processes to create a super-greenhouse (Kirschvink, 1992). Iron formation would precipitate as the ice melted and oxygen re-entered the marine system; iron formation does indeed occur in some Neoproterozoic glacial deposits. Carbonate deposits (termed "cap carbonates"), more typical of warm conditions, overlie Neoproterozoic glacial deposits (Figure 1). Hoffman et al. (1998) tied the cap carbonates to the postglacial greenhouse, where a vigorously reinstated hydrologic and weathering cycle would serve to flush ions from readily available continental debris into the ocean to rapidly precipitate carbonate rocks on top of glacial deposits. The hypothesis was tidy, and had predictive power. Furthermore, it did not escape notice that the diversification of metazoan life occurred just after the "snowball" glaciations–could there be a link?

As such, the snowball Earth hypothesis has met with tremendous interest … and controversy. A major part of this ongoing debate surrounds the scale and severity of Neoproterozoic glaciations: was the Earth completely frozen (snowball) or was there open water at low latitudes (slushball)? If completely frozen, then there would be no room for Pleistocene-style waxing and waning glacial-interglacial cycles: the Earth would be in a frozen state, with little chemical weathering, until the termination of the snowball.

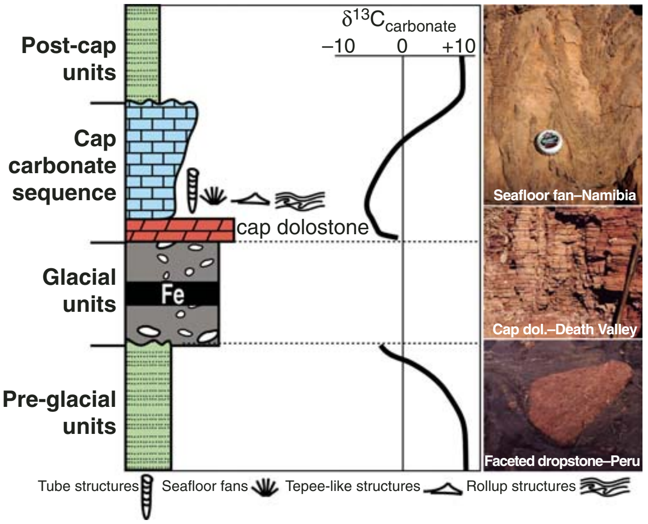

Figure 1. Generalized Neoproterozoic glacial-cap carbonate succession.

A new study from Ruben Rieu et al. (this issue of *Geology*) addresses this debate in a novel way. A consequence of a snowball Earth should be the inhibition of the planet's hydrologic cycle, which might allow for some measure of physical weathering, but should stop virtually all chemical weathering of continental silicates. Through proxies for chemical weathering (the mineralogical index of alteration, MIA, and the chemical index of alteration, CIA), Rieu et al. find variation in continental silicate weathering throughout a Neoproterozoic glaciation, arguing for the waxing and waning of an active hydrologic cycle capable of both physical and chemical weathering. In fact, the CIA and MIA attain similar levels during the ice age and during the deposition of the postglacial cap carbonate. This seems to contradict the snowball Earth hypothesis: it denotes a cyclic, warm, active hydrologic and weathering cycle during the ice age, not unlike what we might predict from a typical Pleistocene glacial/interglacial succession. Such indications of warm, humid interglacials during the ice age are completely at odds with the hydrologic and weathering cycle predicted by the snowball Earth hypothesis.

The debate does not stop here. Modelers point out that the ice-albedo feedback is too simple and does not account for enough parameters to be considered realistic (e.g., Poulsen, 2003), while others counter that the models, with their roots in modern climate, are inappropriate for the non-actualistic conditions of Neoproterozoic time (Schrag and Hoffman, 2001). The case for iron formation may be somewhat overstated; where abundant, it seems to have formed in association with rift deposits (Young, 2002), and new data demonstrate the oceans may have been largely anoxic throughout much of the Neoproterozoic, not just during glaciation (Canfield et al., 2007). Many different hypotheses are available to explain the cap carbonates (e.g., Grotzinger and Knoll, 1995; Hoffman et al., 1998; Kennedy et al., 2001; Ridgwell et al., 2003; and Shields, 2005). Finally, the case for global ecosystem crash has not withstood careful scrutiny (Corsetti et al., 2003; Corsetti et al., 2006); biomarkers indicating a "healthy" photosynthesis-based ecosystem have been noted from within glacial deposits (Olcott et al., 2005), and post-glacial diversity trends appear sufficiently disconnected from the glaciations to preclude a cause and effect (e.g., Grey et al., 2003). Nevertheless, the snowball Earth hypothesis has reinvigorated interest in the Neoproterozoic and spurred on many scientific investigations in a way that only a truly provocative and innovative hypothesis can, regardless of the current lack of consensus.

Much–one might even say most–of the geochemical work surrounding snowball Earth has focused on postglacial cap carbonates. The new study by Rieu et al. reminds us that there is a lot to learn from glacial deposits themselves, which remain a relatively untapped resource with respect to novel analyses. Furthermore, preglacial rocks should provide a target to help us understand the processes that initiated the Neoproterozoic glaciations in the first place.

Geology, April 2007; v. 35; no. 4; p. 383–384; doi: 10.1130/Focus042007.1; 1 figure.

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ERRATUM

Porosity of the upper edifice of Axial Seamount

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Figure 3 in van Gilbert et al. was printed incorrectly. The correct figure is provided here.

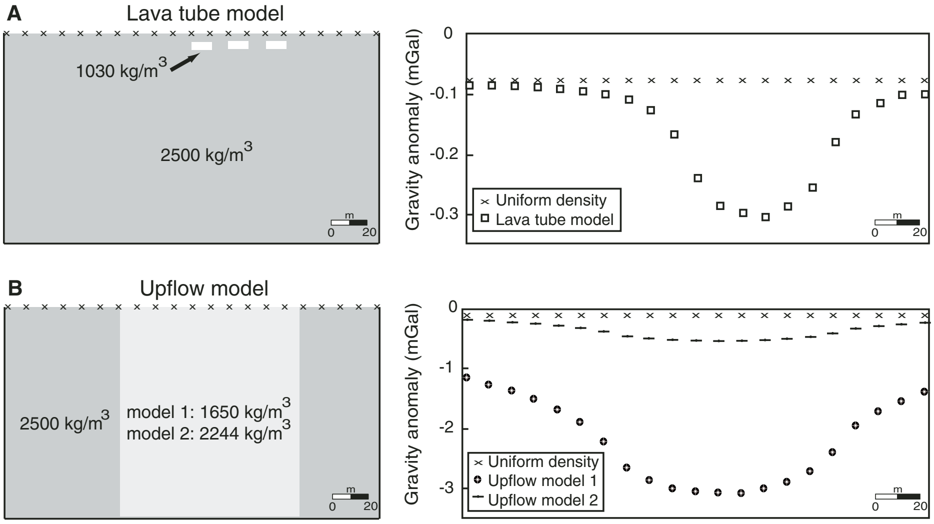

Figure 3. Left panels show model geometries and densities; symbols (x) indicate locations of synthetic gravity stations. Right panels show calculated gravity signal for uniform density crust (x) and effects relative to background low-density crust of (A) seawater-filled cavities near seafloor (0.25 mGal anomaly) and (B) upflow zones of two different densities (3 and 0.2 mGal anomalies for models 1 and 2, respectively). See text for detailed explanation of model geometries and density choices.