Comment on: A Complex microbiota from snowball Earth times: Microfossils from the Neoproterozoic Kingston Peak Formation, Death Valley, USA
by Frank A. Corsetti, Stanley M. Awramik, and David Pierce,
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Corsetti et al. (1) report that nearly identical assemblages of diverse microfossils occur in strata beneath and within glaciomarine diamictites of the lower Kingston Peak Formation, a Neoproterozoic sedimentary sequence in eastern California believed to have been deposited within 5-10 degrees of the Equator (1). They conclude that the lack of any perceptible biotic change is inconsistent with global sea-ice cover postulated in the snowball Earth hypothesis (2-4).

Corsetti et al. (1) believe their's are the first reported microbiota from within Neoproterozoic glacial sequences, but syn-glacial microbiota have previously been described from the Tillite Group in East Greenland (5), the Mineral Forks diamictite in Utah (6), and from strata closely associated with glaciogenic sequences world-wide (6). However, most of the previously reported assemblages have notably low diversity, almost completely dominated by morphotypes of a single taxon, *Bavlinella faveolata*, interpreted to be an endosporulating cyanobacterium or microalga (7). The different morphotypes are interpreted as distinct stages of development (6). The abundance and low diversity of the *Bavlinella*-dominated assemblages are consistent with ecological stress (6). So the real question is, why does the lower Kingston Peak biota have such high diversity, virtually indistinguishable from pre-glacial biota of the same region (1), in contrast with other Neoproterozoic syn-glacial assemblages (5, 6)?

One possibility is stratigraphic duplication by a small thrust fault, such that the fossiliferous units in KP1 and KP3 are stratigraphically one and the same. This would be consistent with the observation that each unit is overlain by a lithologically identical diamictite (1). On the other hand, the occurrence of a distinctive oncolite layer only in KP3 (1) would argue against stratigraphic duplication if the oncolite was laterally continuous.

A more intriguing possibility stems from the snowball scenario (8) itself. Consider a severe climatic deterioration during which the polar ice packs advanced to the sub-tropics and the growth of continental ice sheets caused sea level to fall by >100 m. Large areas previously occupied by continental shelf waters and inland seas would be exposed. In the event of a runaway ice-albedo feedback, the tropical ocean would freeze over very rapidly according to most climate models (9-12), creating an intensely cold, dry climate in which low-lying continental areas of the sub-tropics and tropics would long remain ice free (3, 9-13). In a desert environment with mean annual temperatures well below freezing (4, 9-13), organic-walled microbiota from any exposed sediments would be widely transported by winds, thoroughly contaminating the ice, glacial tills, and glaciomarine sediments. This is a well-known phenomenon in the Cenozoic of Antarctica. Recycled marine microfossils (diatoms, sponge spicules, radiolaria, palynomorphs and foraminfera) ranging in age from Late Cretaceous to

Pliocene occur within Pliocene-age diamicts of the Sirius Group at elevations up to 2,500 m above sea level in the Trans-Antarctic Mountains (14). It was originally believed that their source lay in marine strata situated upstream beneath the inland ice, implying open marine conditions in the interior of East Antarctica in the Pliocene (14). However, oxygen isotope records from benthic foraminifera imply that the East Antarctic ice sheet was close to its present size in the Pliocene (15). Apparently, the marine microfossils were carried by winds from coastal or extra-Antarctic sites, consistent with the occurrence of marine diatoms throughout an ice core from the South Pole spanning the last 2,000 years (16).

Novel marine processes also extensively recycle sediments and biota in polar regions. During the formation of sea ice near shore, masses of so-called "anchor ice" form within and upon the sea bed in water depths <33 m (17). Anchor ice grows by progressive aggregation of sticky ice platelets (frazil ice), a process that increases the overall buoyancy of the anchor ice until it lifts off a clump of sediment and carries it to the surface, where it accretes to the base of the sea ice (17). Suspension freezing of anchor ice appears to be the dominant mechanism by which clumps of muddy sediment, including algae with holdfasts, well-preserved invertebrates (sea urchins, mollusks, ostracodes) and dropstones with glacial striations, are entrained in Arctic sea ice and dispersed throughout the Arctic basin (18). As multi-year sea ice on a snowball Earth would grow to be tens to hundreds of meters thick in dynamic steady-state (19, 20), large amounts of pre-glacial sediment and biota could be entrained. Some would remain fixed in landfast ice, but much would end up concentrated at the Equator as a result of the glacial flow of floating marine ice (20). As the "open tropics" solution (21) to the Neoproterozoic climate puzzle may be precluded by sea glacier dynamics (19, 20), reworking must be seriously considered for the lower Kingston Peak syn-glacial microbiota if they are truly as diverse as reported (1).

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