STRONTIUM ISOTOPES IN NEOPROTEROZOIC CAP CARBONATES FROM NAMIBIA: EVIDENCE FOR INTENSE CHEMICAL WEATHERING IN THE AFTERMATH OF A SNOWBALL EARTH. D.P. Schrag[1], P.F. Hoffman[1], G.P. Halverson[1] S.A. Bowring[2] and K. Abbasi[2], [1] Dept. of Earth and Planetary Sciences, Harvard University, Cambridge, MA 02138, schrag@eps.harvard.edu, Dept. of Earth, Atmospheric and Planetary Sciences, Massachusetts Institute of Technology, Cambridge, MA 02139.

The Snowball Earth hypothesis proposes that Neoproterozoic glacial deposits and associated "cap" carbonates represent a series of global glaciations followed by extreme greenhouse conditions (Hoffman et al., 1998). To study the cap carbonates in the context of the Snowball Earth hypothesis, we measured the strontium isotopic composition ($^{87}Sr/^{86}Sr$) of carbonate rocks in Namibia from which we earlier obtained $\delta^{13}C$ data (Hoffman et al., 1998). The data come from four sections located several hundred kilometers apart, and from different parts of the carbonate platform including the intra-shelf basin, the shelf rim, and the fore-shelf slope. Regional variation in accumulation rate is inferred from the thickness of the basal dolomite member, and from the height of the carbon isotope excursion, and varies systematically with inferred water depth. The $^{87}Sr/^{86}Sr$ values in the carbonate rocks (500 m thick) underlying the glacial horizon climb range from 0.7072 to 0.7085. Above the glacial horizon, the data from all four sections show a similar pattern of variability. Initial post-glacial values are between 0.708 and 0.710 before climbing steeply to >0.714. Peak values show substantial variations between sections from 0.714 to 0.724. Higher in the section, values drop more gradually and then stabilize to ~0.708. The stratigraphic extent of the positive anomaly varies with the inferred sedimentation rate, greatest in the shelf rim (150 meters) and least in the fore-shelf slope (~20 m).

There are two possible frameworks for interpreting the strontium isotope data. First, it is possible that the entire pattern of isotopic variability was created by post-depositional diagenetic alteration, and that the extreme radiogenic values represent interaction with fluids from the granitic basement. However, there are several arguments against a diagenetic origin for these isotope profiles. In all cases, the radiogenic anomaly occurs in the same statigraphic position above the glacial deposit (which is itself predominantly carbonate and not a source of radiogenic strontium). Moreover, the distance from basement, and the local structure which could determine the direction of fluid flow varies between these four sections. In addition, the isotope excursion exists in sections where the dominant mineralogy is dolomite as well as calcite. Additional evidence against alteration includes the lack of strong correlation between $^{87}Sr/^{86}Sr$ and $\delta^{18}O$ values.

An alternative interpretation is that the strontium isotope data reflect primary values with some additional diagenetic overprint. If so, then the pattern requires an extraordinary explanation as it is impossible for the $^{87}Sr/^{86}Sr$ ratio of the whole ocean to change over the estimated duration for cap carbonate deposition (<10,000 years!). The snowball Earth hypothesis asserts that a global glaciation occurred once the equatorward extent of sea ice crossed a critical threshold. As the tropical oceans froze rapidly, mean surface temperatures dropped by ~40°C. In the absence of a strong hydrologic cycle, the rate of chemical weathering of silicate minerals would be severely reduced, allowing accumulation levels of CO_2 in the atmosphere from volcanic outgassing over ~10 million years to eventually overcome the high planetary albedo. Melting sea ice near the equator would drive a runaway ice-albedo feedback in reverse, shifting the planetary climate to extreme greenhouse conditions in less than 100 years with ~50°C surface temperatures at the equator. In the aftermath of the snowball Earth, the high surface temperatures and large surface area of fine grained silicate minerals, eroded by millions of years of glaciation and frost-shattering, would intensify silicate weathering, delivering alkalinity to seawater and driving rapid precipitation of cap carbonate in warm surface waters. In this context, it is possible that the $^{87}Sr/^{86}Sr$ excursion in the cap carbonate sequence reflects the response of the surface ocean to intense riverine input of radiogenic strontium derived from continental weathering. In the modern ocean, the delivery of strontium to the oceans by rivers is slow relative to the mixing rate between the surface and deep ocean, and hence the strontium isotopic composition of the surface ocean is identical to the deep ocean. However, in the extreme conditions immediately following a global glaciation, if the riverine flux of Sr were high relative to the rate of mixing across the thermocline, the isotopic composition of the surface ocean would drift towards the composition of the input and away from the deep ocean. This effect would be amplified by stratification of the ocean caused by intense radiative heating by the greenhouse atmosphere and lowered salinity of the surface ocean from melting sea ice (~400 m thick upon termination). The $^{87}Sr/^{86}Sr$ ratio of the surface ocean would return to the whole ocean value once riverine inputs decreased and/or stratification of the surface ocean was reduced, yielding the stable $^{87}Sr/^{86}Sr$ values at the top of the sequence. A simple box model suggests that this mechanism can produce values of ~0.714 if an intense pulse of chemical weathering occurred over hundreds to thousands of years. However, this cannot explain the higher $^{87}Sr/^{86}Sr$ values in excess of 0.714 which are anti-correlated with carbonate content and are likely due to addition of clays with radiogenic strontium from decay of rubidium.

References: Hoffman, P.F., A.J. Kaufman, G.P. Galverson and D.P. Schrag, A Neoproterozoic snowball earth, *Science*, 281, 1342-1346, 1998.