Modeling the Carbon Cycle in the Aftermath of a Snowball Earth

J.A. HIGGINS AND D.P. SCHRAG

Dept of Earth and Planetary Sciences, Harvard University, 20 Oxford St., Cambridge, MA 02138, USA (jahiggin@fas.harvard.edu; schrag@eps.harvard.edu)

Using a simple 3-box model of the ocean-atmosphere system, we simulate the cycling of carbon in the aftermath of a global glaciation. Model simulations include the delivery of alkalinity to seawater from intense carbonate and silicate weathering under high pCO_2 conditions, as well as ocean mixing, air-sea gas exchange, and biological productivity. In general, our findings are consistent with the predictions of Hoffman et al. (1998). The initial $\delta^{13}C$ of the first carbonate precipitated after the glaciation depends on the pCO_2, temperature, the saturation state of the surface ocean, and kinetic effects associated with mineral precipitation. With no biological productivity, the model produces $\delta^{13}C$ values between +1 and –3 per mil, consistent with observations. This is in direct contradiction with arguments by Kennedy et al. (2001) who suggest that the $\delta^{13}C$ value of dissolved carbon in a snowball ocean (and directly afterwards) must be –5 per mil. However, Kennedy et al. assume the carbon isotope cycle is in steady state - clearly inappropriate for the snowball earth hypothesis - and also neglect any effect of high pCO_2 on the carbonate chemistry of seawater. A major difference between our findings and the qualitative predictions of Hoffman et al. (1998) is our interpretation of the cap dolostone as representing an interval dominated by carbonate weathering of exposed continental shelves. As a result, the ~2‰ drop in the $\delta^{13}C$ observed in the cap dolostone is unlikely to be a product of Rayleigh distillation of atmospheric CO_2 via silicate weathering. Instead, we interpret the ~2‰ drop in the $\delta^{13}C$ values as indicative of a change in the fractionation between HCO_3^- and $CaCO_3$ related to rapid precipitation of carbonate from highly supersaturated waters. Rayleigh distillation of atmospheric CO_2 via silicate weathering is a viable explanation for the continued drop in $\delta^{13}C$ values in the limestone sequence above the cap dolostone, with biological productivity driving a slow increase in $\delta^{13}C$ values once pCO_2 becomes closer to modern. Our study also simulates the cycling of strontium in seawater. In contrast to the findings of Jacobsen and Kaufman (1999) and Kennedy et al. (2001), model simulations show a drop in $^{87}Sr/^{86}Sr$ of less than 0.0005 during 5 million years of global glaciation, and an increase of less than 0.001 over the entire episode of intense silicate weathering. Our calculations emphasise the importance of considering the changes in seawater chemistry due to high pCO_2 in evaluating the Snowball Earth hypothesis.

Hoffman, P.F., et al. (1998) *Science* 281: 1342-1346.
Kennedy, M. J., et al. (2001) *Geology* 29: 1135-1138.
Jacobsen and Kaufman (1999) *Chem. Geol.* 161: 37-57.

Emplacement of komatiite flow fields: An inflationary model based on field evidence and modern mafic analogues

R.E.T. HILL, S.J. BARNES, S.E. DOWLING, C.S. PERRING AND T. THORDARSON

CSIRO Exploration and Mining, Kensington, Western Australia (Robin.Hill@csiro.au)

Recent pioneering work on active and modern mafic volcanism has provided a comprehensive understanding of the processes of emplacement of regionally extensive mafic pahoehoe flow fields on shallow slopes in Hawaii and in continental flood basalt terrain. Important components of the emplacement model are persistent long-lived lava flow and its predominance over lava supply rate as the controlling factor influencing aerial dimensions of flow fields; the inflation of sheet flow lobes under composite visco-elastic and brittle crusts; endogenous growth; and the development of preferred lava pathways or tubes which serve to focus lava flow and provide thermally-efficient delivery of lava to lobe-by-lobe advancing flow fronts, and act as loci for extensive thermo-mechanical erosion and lava breakouts. The resulting volcanic architecture is that of parent lava pathways flanked by a broad, complex, stratigraphic sequence of episodically-emplaced, variably-inflated lateral lobes and subsidiary flows fed by their own distributary pathways.

The thermal regimes required to develop recurring lithological field relationships, facies variations, and internal structures of flow units which we have identified in komatiite sequences are consistent with those required by the volcanic architecture of their basaltic analogues. Likewise, inflation, endogenous growth, and pathway delivery, are processes that can account for the aerial extent, thickness, and lithological profiles documented for komatiite flows and component flow lobes in the Archaean greenstone belts of Western Australia.

We have therefore applied the dynamic inflationary model to the evolution of komatiite flow fields and developed a broad volcanic facies classification that is commensurate with this model and results from detailed field-based studies. **Flood Flow Facies:** (1) Unconstrained sheet flow forming extensive regional sheet-like layered olivine adcumulate bodies and layered ultramafic-gabbro sequences, flanked by olivine orthocumulates and spinifex-textured, flow lobes; (2) Constrained lava flow in large erosional pathways forming large trough-shaped bodies of predominantly layered adcumulate up to 1km thick and 2km wide, commonly grading upwards into pyroxenite and gabbro, and flanking breakouts of lava producing extensive olivine orthocumulate and rarer inflated spinifex-textured, flow lobes. **Compound Flow Facies:** Long-lived lava flow (? distal) in laterally-confined smaller lava pathways (up to 10km long and 200m wide) filled with a variety of layered olivine ortho-mesocumulate, flanked by episodically-emplaced lava breakouts manifest as inflated spinifex-textured flow lobes.