

Supporting Text

Observations of Dropstones in the Basal Hotazel Formation (Fm.). As reported previously (1), the contact between unweathered pillow basalts of the Ongeluk volcanics and the overlying ironstones of the Hotazel Fm. usually includes 10-20 cm of fine-grained, immature and unsorted volcanoclastic sandstone. The sandstone unit is overlain by \approx 50-100 cm of jaspilitic iron formation, which contains occasional small dropstones, observed in 7 of 19 industrial drill cores that penetrating the contact (1). The dropstones were interpreted as recording the rapid deglaciation at the end of the Makganyene snowball Earth. Because all of the observed clasts are composed of volcanic material, they might alternatively have been emplaced by volcanic activity; with data from isolated drill cores, it is not easily possible to distinguish between these two hypotheses.

In October 2004, two of us (J.L.K. and C.Z.N.) visited an access shaft of the Nchwaning Manganese mine in which the Ongeluk/Hotazel contact is exposed for a lateral distance of \approx 100m. *In situ* examination of this layer revealed that the dropstones occur in isolation in different layers, not clustered in specific layers as would be expected if they were deposited by explosive volcanism. Hence, we conclude that the dropstones were glacially deposited and that this unit records the termination of the Makganyene snowball.

An Ecological Stoichiometry Model of Planetary Oxygenation. To determine the minimum timescale on which oxygenic photosynthesis could destroy a methane greenhouse, we constructed two models, one in which productivity was P-limited and one N-limited, and took the minimum of the two productivities. Results are shown in Fig. 2.

P-limited ocean model. Following Bjerrum and Canfield (2), we assumed in the P-limited case that P was removed from the ocean either adsorbed onto Fe(III) particles or in organic matter and organic-derived carbonate fluoroapatite. We also assumed that P fluxes into and out of the photic zone were balanced and iterated toward a steady-state solution of the equations

$$F_{P,out} = F_{P,in} = \gamma \eta_{C:P} P_{CH_2O} + K_{ads} F_{FeIII,out} [P_d] \quad [1]$$

$$P_{CH_2O,anoxy} = \text{Min}[\eta_{C:P} u [P_d] f_{anoxy}, \frac{1}{4} F_{Fe,in}] \quad [2]$$

$$P_{CH_2O,oxy} = \eta_{C:P} u [P_d] - P_{CH_2O,anoxy} \quad [3]$$

$$F_{FeIII,out} = \alpha \text{Min}[F_{Fe,in}, 4\gamma P_{CH_2O,oxy} + P_{CH_2O,anoxy}] \quad [4]$$

$$P_{O_2} = \gamma (P_{CH_2O,oxy} + P_{CH_2O,anoxy}) - \frac{1}{4} F_{FeIII,out}, \quad [5]$$

where γ is the ratio of organic C production to organic C burial; $\eta_{C:P}$ is the ratio of carbon to phosphate in buried organic matter; K_{ads} is equilibrium constant for the adsorption of P onto Fe(III) particles; u is the velocity of upwelling bringing nutrient-rich waters into the surface oceans; f_{anoxy} is the maximum fraction of C production for which anoxygenic, Fe(II)-oxidizing photosynthesis can be accountable; and α is the maximum fraction of Fe buried as Fe(III). $F_{Fe,in}$ is the flux of Fe into the oceans, $F_{FeIII,out}$ is the flux of Fe(III) out of the oceans, $F_{P,in}$ is the flux of P into the oceans, $F_{P,out}$ is the flux of P out of the oceans, P_{CH_2O} is the rate of primary productivity, P_{CH_2O} is the net rate of surface ocean oxidation in O₂ equivalents, and $[P_d]$ is the concentration of dissolved P in the oceans.

N-limited ocean model. In a locally aerobic environment, denitrification may have compelled cyanobacteria to engage in the Fe-demanding process of N₂ fixation (3). We modeled this process using C/Fe ratios observed in field populations of *Trichodesmium* (4). We assumed the upwelling flux of Fe to be removed from the photic zone either as ferric particles or in organic matter, through the following modifications:

$$P_{CH_2O,oxy} = \eta_{C:Fe} \beta F_{Fe,in} - P_{CH_2O,anoxy} \quad [6]$$

$$F_{FeIII,out} = \text{Min}[(1 - \beta) F_{Fe,in}, 4\gamma P_{CH_2O,oxy} + P_{CH_2O,anoxy}], \quad [7]$$

where $\eta_{C:Fe}$ is the ratio of C to Fe and β is the efficiency of the cyanobacteria in capturing Fe.

1. Kirschvink, J. L., Gaidos, E. J., Bertani, L. E., Beukes, N. J., Gutzmer, J., Maepa, L. N. & Steinberger, R. E. (2000) *Proc. Natl. Acad. Sci. USA* **97**, 1400–1405.
2. Bjerrum, C. J. & Canfield, D. E. (2002) *Nature* **417**, 159–162.
3. Falkowski, P. G. (1997) *Nature* **387**, 272–275.
4. Kustka, A., Carpenter, E. J. & Sanudo-Wilhelmy, S. A. (2002) *Res. Microbiol.* **153**, 255–262.