Snowball Earth: stability and instability of the Earth system

Eiichi Tajika[1]

[1] Dept. Earth Planet. Sci., Univ. of Tokyo

http://www-sys.eps.s.u-tokyo.ac.jp/~tajika/

Climate of the Earth has been regarded as stable owing to a negative feedback mechanism derived from dependency of silicate weathering process on the surface temperature. However, evidence for low-latitude ice sheets during the Proterozoic glaciations strongly suggests that the Earth was globally ice-covered in the Proterozoic ice ages. The snowball Earth hypothesis implies that the climate of the Earth could be rather unstable.

The cause of the snowball Earth events remains unknown. It is possible to for global glaciation to occur either by (1) decrease of CO2 supply rate to the atmosphere-ocean system from the solid Earth owing to reduction of volcanic activity, or by (2) collapse of the methane-rich atmosphere which might have existed during the Proterozoic. In any case, the Earth could be globally glaciated because the globally ice-covered is one of the stable climate states of the Earth. The snowball Earth event should be understood as a "phase change" of the climate of the Earth from one to the other state.

Although there is evidence for low-latitude ice sheets in the three major glaciations (the Marinoan, the Sturtian, and the Huronian) during the Proterozoic, there is no such an evidence in the glaciations during the Phanerozoic. What is the reason for the difference? Dimmer sun during the Proterozoic as a result of the evolution of the sun cannot explain for this, because its effect would be largely canceled out by lower effeciency of the silicate weathering rate due to lower soil biological activity at that time. Rather, drastic increase of the soil biological activity due to the emergence of the terrestrial higher plants during the Phanerozoic should decrease the equilibrium level of the surface temperature of the Earth, resulting in more susceptible of the Phanerozoic Earth to snowball conditions. In fact, the Gondwana glaciation during Carboniferous to Permian is shown to have been very close to the snowball condition according to the analysis of the carbon cycle model. Position of the supercontinent could have played a key role in the snowball Earth events during the Proterozoic.

It is probable that plate tectonics will cease in the future because of cooling of the Earth"s interior. If it were the case, the CO2 supply rate to the atmosphere-ocean system will also cease, resulting in ever-lasting snowball Earth. On the other hand, the increase of solar luminosity due to the evolution of the sun results in runaway warming due to runaway evporation of seawater (i.e., runaway greenhouse effect). Therefore the future of the terrestrial environment should link very close to the evolution of the mantle and the sun.