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Commentaries

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Commentary

Did Earth drive itself to a snowball?

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The icehouse model, in terms of low CO_2 effect, elegantly accounted for the global cooling events on Earth's surface,which has occurred at least several times in the history of Earth evolution. However, it does not appear to explain the great cooling events such as the Late Ordovician glaciation with an unusually high CO_2 level of 4000 ppmv[1], more than ten times higher than the CO_2 level of today. Previous published records shows a CO_2 increase during some glaciations[2], conflicting with the mainstream theory. Although Pagani et al.[3] later suggested that the evidences available support a drop in CO_2 as a critical condition for global cooling, whether CO_2 played a dominant role alone to cause the greenhouse-icehouse transition or whether a threshold level of CO_2 ultimately induced global cooling cannot be determined from their results.

Donnadieu et al.[4] believed that the extensive cooling event during the Sturtian episode may have been resulted in due to a high obliquity (750 Ma). However, it is impossible to produce large glaciations in the case of mid to high latitude paleogeographies such as the Varangian-Vendian episodes (620–580 Ma). In addition, if we accept the idea that high obliquity is a possible trigger for glacial events such as the Sturtian glaciation, we have to found a mechanism to recover from the high obliquity. Seeking primarily to explain the paleomagnetic data, Williams (1975) proposed that Earth's axial tilt (the obliquity of the ecliptic) exceeded 54° until the end of the Proterozoic[5, 6]. This implies that Earth's climatic zonation would accordingly have been reversed in the Proterozoic, meaning lower insolation at low latitudes than at the poles. However, the seasonal cycle would have been greatly amplified, resulting in hot biannual summers, which do not favor glaciation. The Williams's hypothesis of high-obliquity is not consistent with the observed glacial deposits with carbonates including inorganic sea-floor aragonite precipitates[5].

Despite the early skepticisms about the extent of CO_2 effect or the high-obliquity effect on global cooling, these hypothesis were subsequently used to account for almost all anomalous cooling events. However, the causal relationship between the decrease of CO_2 and global cooling from the original predictions of the hypothesis have not been confirmed.

Donnadieu et al.[7] try to explain the mechanism of Proterozoic snowball Earth by connecting it with the increase in runoff as a consequence of Rodinia breakup 800-700 Myr ago. They assume that the precipitation increase and runoff over the continents causes large quality of carbon dioxide to consume. However, Brune et al.[8] show that supercontinent breakup could also produce massive, long-term CO_2 emissions. A clear geological link between continental rifting or breakup and CO_2 degassing has been found on Earth, and more and more evidence of CO_2 flux measurements have been documented in many types of rift systems, such as the Basin and Range Rift, the Rio Grande Rift, the Eger Rift, the East African Rift System, and its western branch. All of these data indicate that the continental rifting system provides important pathway to connect the vast carbon reservoir in Earth's mantle to Earth's surface[8].

Hence, precise quantitative evaluation of the effect of atmospheric CO_2 fall in terms of runoff on the global cooling or the effect of atmospheric CO_2 rise in terms of rift emission on the global warming requires a sophisticated approach in considering their heat balance.

The history of Earth's evolution exhibits geologically active and quiescent periods, including magmatism, metamorphism, mineralization and tectonism. In the meantime, alternative cooling and warming have also occurred many times in the geological history of Earth. However, there is no consensus about the fundamental relationship between the thermal cycles and the episodic processes. Scientists generally ascribe the cause of cooling and warming either to bias in the effect of CO_2 cycles or astronomical effect. In a recent paper in Nature Geoscience[9], Spencer et al.'s discovery of a prominent magmatic gap seems challenge this geological belief. After a comprehensive evaluation of the geologic record from 2.4 to 2.0 Ga, they found a tectono-magmatic lull around 2.3 to 2.2 Ga. During this long geological quiescent period, global-scale continental magmatism and orogenic activity decreased greatly. The data also shows a lack of sedimentation activity on passive margin and rate of plate motions were relatively subdued. In fact, a period between 2.4 to 2.0 Ga called tectonic shutdown has previously been defined to interpret this tectono-magmatic lull[9].

The global cooling between 0.8 and 0.6 Ga, the second snowball Earth, also coincide with a prominent magmatic gap (the prominence of the zircon age lull)[1].

Spencer et al.[9] also posit that the geological quiescence ended about 2.2 billion years ago by a flare-up of juvenile magmatism, released significant thermal energy that had accumulated during the geological quiescence of the snowball Earth. This flux of mantle-derived energy could have provided a mechanism for Earth warming and cooling as a consequence of heat accumulation and loss underneath the crust. These events must be linked to the thermal cycle of the Earth's interior rather than the surface external causes. The correspondence of a prominent magmatic lull with the extensive 0.1 Ga duration of snowball Earth suggests that it is not convincing to correlate the snowball Earth climate with an enhanced consumption of atmosphere CO_2 through changes in runoff due to the dispersal of the supercontinent. This mechanism clearly ignores the fact that widespread continental rifting will result in huge heat loss, both through rifting induced de-compressive melting and lava eruption.

Although no unifying model explains all of the observed thermal fluctuations of Earth[1], we now know that