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GR Focus Review

Initiation of leaking Earth: An ultimate trigger of the Cambrian explosion

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A B S T R A C T

For life to have dramatically evolved and diversified during the so-called Cambrian explosion, there must have been significant changes in the environmental conditions of Earth. A rapid increase in atmospheric oxygen, which has been discussed as the key factor in the evolution of life, cannot by itself explain such an explosion, since life requires more than oxygen to flourish let alone survive. The supply of nutrients must have played a more critical role in the explosion, including an increase in phosphorus (P) and potassium (K) which are key elements for metabolisms to function. So, what happened at the onset of the Cambrian to bring about changes in environmental conditions and nutrient supply and ultimately evolution of life?

An ultimate trigger for the Cambrian explosion is proposed here. The geotherm along subduction zones of a cooling Earth finally became cool enough around 600 Ma to allow slabs to be hydrated. The subduction of these hydrated slabs transferred voluminous water from the ocean to the mantle, resulting in a lowering of the sea level and an associated exceptional exposure of nutrient-enriched continental crust, along with an increase in atmospheric oxygen. This loss of water at the surface of the Earth and an associated increase in exposed landmass is referred to here as leaking Earth. Vast amounts of nutrients began to be carried through weathering, erosion, and transport of the landmass; rock fragments of the landmass would break down into ions during transport to the ocean through river, providing life forms (prokaryote) sufficient nutrients to live and evolve. Also, plume-driven dome-up beneath the continental crusts broadened the surface area providing a supply of nutrients an order magnitude greater than that produced through uplift of mountains by continental collision. Simultaneously, atmospheric oxygen began to increase rapidly due to the burial of dead organic matter by enhanced sedimentation from the emergence of a greater landmass, which ultimately inhibited oxidation of organic matter. Hence, oxygen began to accumulate in the atmosphere, which when coupled with a continuous supply of nutrients, resulted in an explosion of life, including an increase in the size. An enhanced oxygen supply in the atmosphere resulted in the formation of an ozone layer, providing life a shield from the UV radiation of the Sun; this enabled life to invade the land. In addition to a change in the supply of nutrients related to a leaking Earth, the evolution of life was accelerated through mass extinction events such as observed during Snowball Earth, possibly related to a starburst in our galaxy, as well as mutation in the genome due to radiogenic elements sourced from carbonatite magma (atomic bomb magma) in rift valley. There are two requirements to find a habitable planet: (1) the initial mass of an ocean and (2) the size of a planet. These two conditions determine the history of a planet, including planetary tectonics and the birth of life. This newfound perspective, which includes the importance of a leaking planet, provides a dawn of new planetary science and astrobiology.

Contents

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1. Introduction

The history of life on Earth, beginning some time in the Hadean, witnessed two distinct evolutionary phases: one at 2.1 Ga from prokaryotes to eukaryotes, and the other at 0.6 Ga from eukaryotes to metazoans (e.g., Maruyama et al., 2001, 2007; Payne et al., 2009). Though such an evolutional history of life appears relatively short-lived, the duration in each case is actually millions of years. Such change could be interpreted to be the result of a sudden increase in oxygen content in both the atmosphere and hydrosphere through increased activity of cyanobacteria, as observed at 2.1 Ga (from <1/1000 PAL to 1/100 PAL) and at 0.6 Ga (from 1/100 PAL to the present level 1 PAL) (Holland and Beukes, 1990; Holland, 1994, 2006).

The topic of Cambrian explosion has long been discussed, including attributes to both intrinsic causes such as hybridization, increased grade of complexity, and evolution of regulatory genes (e.g., summary by Shu, 2008), and external influences such as a supercontinent cycle and ocean chemistry, in addition to a rapid increase of pO_2. However, the ultimate trigger has not yet been confirmed.

One of the most critical influences on the evolution of life is nutrient supply, long assumed to be forever adequately present in the oceans of Earth by some unknown processes. This assumption, though, becomes invalid when considering the active geological processes of Earth which bring about constant environmental change, especially those driven by endogenic activity such as plate tectonics and superplume development, and ultimate variations in the amounts of continental and oceanic crustal materials and subaerial exposure of land masses, as well as the ever changing ocean volumes (Maruyama et al., 2013).

Though there was a significant enhancement in oxygen content since 0.6 Ga, with atmospheric and oceanic values both nearing 1 PAL, metazoans could not form during ancient times because of the lack of continuous supply of the major (e.g., K, P, Ca, Fe, and Mg) and minor (Mo, Zn, Mn, and others) nutrients (Maruyama et al., 2013). Considering much greater nutrient supplies (>1 million times as compared to previous supply), such as during times of enhanced exposure of continental crustal materials, and maintenance of a high-pO_2 since 600 Ma up to now, one of the essential geologically-derived changes in the Earth system, consisting of (1) solid Earth, (2) hydrosphere, (3) atmosphere and (4) magnetosphere, would have accordingly occurred around the onset of Phanerozoic.

The magnetosphere, which penetrates the other three systems, is caused by the convection of a liquid metallic iron core (Fig. 2). The biosphere is centered mainly in the hydrosphere, but also on-land and in the atmosphere with minor sub-ground microbial communities. But in the past, life was born in the hydrothermal system either in Hadean or earliest Archean, independently from Panspermia, and evolved in the hydrosphere throughout Precambrian time at least from 4.0 Ga until 0.6 Ga (Maruyama et al., 2001, 2007; Fig. 1). At the onset of Phanerozoic, metazoans were born, with life beginning to invade the land. Moreover during this time, life became extremely diversified. For example, all 35 phyla of metazoans alone appeared during the early Cambrian, referred to as the Cambrian explosion (Cloud, 1968; Gould, 1995; Shu, 2008). Significantly, the size of the biomass (total weight of whole life at a given geological time) would expand 1 million times during the Proterozoic–Phanerozoic transition, if considering the change in the Earth system, including the increase in land mass and the resulting supply of nutrients that are sufficient to explode the life system (Maruyama et al., 2013).

In this work, we propose that the change in the Earth system was triggered by initiation of return-flow of seawater into the mantle. Some of the fundamental arguments and observations were given in our earlier paper (Maruyama and Liou, 2005). Here we enlarge arguments specifically with emphasis on the role of nutrients, size increase of biomass, and significance of emergence of metazoans that