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Fluctuation of oxygen content and its influence on biological evolution during the Precambrian-Cambrian boundary

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Estimate of environmental change in the Ediacaran to earliest Cambrian after the 630 Ma Marinoan Snowball Earth event is one of the key issues on the surface environmental change and its influence on biological evolution because two types of animals, Ediacaran fauna and Metazoan appeared after the Snowball Earth. Especially, the first appearance of metazoan in the Weng'an area, south China, suggests important constraints on environmental and biological evolution because of the presence of more active animals and initiation of biomineralization.

For the evolution of metazoans, the increase of oxygen content was crucial. Geological evidence indicates that oxygen content of seawater and atmosphere increased in the early Proterozoic and Neoproterozoic: the fossil record of appearance of eukaryotes and macrofossils, ubiquitous occurrence of stromatolite, the unstable minerals in fluvial sedimentary rocks, the behavior of Fe in subaerial environments, the evolution of sulphur-utilizing bacteria and geochemical cycle of sulphur, symbiosis of methanogenic and methanotrophic bacteria, geochemical cycle of carbon, decrease of iron isotope fractionation of iron sulfide and oxide and disappearance of mass-independent fractionation of sulphur isotopes (e.g. summary in Ohmoto, 2004). Recently, Komiya and others (2008) estimated the oxygen content in shallow and deep marine environment based on the patterns and contents of rare earth elements since the Middle Archean. The results show that the oxygen content of the deep sea was low and constant until at least 1.9 Ga, whereas that of shallow seawater increased after 2.7 Ga. It became quite high at 2.5 and 2.3 Ga, but eventually increased after the Phanerozoic. In addition, it decreased around 1.0 Ga, during and just after the Snowball Earth and early Cambrian.

The increase of oxygen content leads to aerobic rather than anaerobic respiration, and the former makes about 20 times more ATP. Higher oxygen content is also required in fully organelled eukaryotes with mitochondria for aerobic respiration and without their own oxygen-producing organelle so that the oxygen reaches their organelle for respiration (Runnegar, 1991). Therefore, the high oxygen content is necessary for active metabolism, and then became an essential trigger for biological evolution. However, the Proterozoic and earliest Cambrian Bio-Earth history suggests that it was not only the necessary and satisfactory condition to yield large living organisms and even vertebrates because they have never emerged until the aftermath of the Marinoan Snowball Earth through the Proterozoic with gradually increasing oxygen content.

There are many essential elements for living organisms among heavy metals, such as P, Ca, Fe, Cu, V, Mn, and Mo. Most of them like P, Fe, Mn, V and Cu are unstable in oxic seawater except for Mo for plants. Therefore, oxidation of seawater reduced the essential elements in seawater, apparently confident with biological evolution if sufficiency of essential elements promoted biological evolution. Therefore, development of mechanisms to store the deficient elements in their own bodies is also a key for the living organisms to survive during the change of surrounding environment, namely emergence of biomineralization. The fluctuation of oxygen content of seawater, especially the decrease, is also important for establishment of mechanism and efficiency of respiration as well as emergence of biomineralization. Especially, decrease of oxygen content of seawater led to oxygen-deficiency for organism with aerobic respiration, but increased nutrients including Fe and Cu or blood.

In summary, both increase and fluctuation of oxygen content of seawater are important for biological evolution. Geologic evidence indicates its frequent fluctuation in the Neoproterozoic to early Cambrian, suitable environment for sudden biological evolution and higher forms of life.