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Geochemical analyses of the 2.2 Ga fluid inclusions: Impact of Snowball Earth on eukaryote diversification.

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Study of biomarker suggests eukaryote was present 2.7Ga, but a body fossil is not found until 1.9Ga. The time gap may reflect the eukaryote survived at restricted environments in the Late Archean, and became widely diversified after the Paleoproterozoic. Possibly, seawater composition played an important role on the diversification. At 2.2Ga, surface of Earth was completely (or near completely) covered with icesheet (Snowball Earth event), possibly influencing on both bioactivity and surface environments. Kirschvink et al. (2000) predicted Fe and Mn contents of seawater were very high during the event. On the other hand, previous works suggested that the event also reduced the bioactivity due to the extreme low temperature and restriction of liquid water. However, the influence of changes in seawater composition on the bioactivity is still ambiguous.

We present microthermometry and PIXE analysis of fluid inclusions in hydrothermally precipitated quartz within basaltic lavas, which probably erupted in the Snowball Earth (Kirschvink et al., 2000), in 2.2 Ga Ongeluk Formation, Kaapvaal Craton, South Africa to obtain the information of seawater composition during the period.

We selected primary fluid inclusions from 5 to 40 micrometers across, characterized by the occurrence as three dimensional clusters or parallel to growing planes of a host mineral based on detailed petrography of over 100 fluid inclusions. These inclusions show final melting temperatures of ice from -31.4 to -3.6 C with the bimodal distribution from -7.0 to -3.6 C and from -11.0 to -31.4 C, respectively, final melting temperature of hydrohalite from -47.0 to -21.7 C, and homogenization temperatures from 64.4 to 160.0 C. All primary inclusions, which form as a plane parallel to growth zoning of host minerals constitute the high-saline group. The result suggests that low-saline fluid inclusions are secondary; nevertheless little petrographic difference. We discuss about the primary fluid inclusions with high salinity. Assumed the NaCl-CaCl2-H2O system, we calculated the salinity of fluid inclusions from their melting points. Estimated compositional variation shows two end-members: (1) a low NaCl and high CaCl2 and (2) a high NaCl and low CaCl2 end-members.

We also performed PIXE analyses of relatively large fluid inclusions (ca. 20 to 30 micrometers) at Tsukuba University. The result of PIXE analysis shows concentration of each element (mmol/kg): (Cl) 674.0 to 3835.5, (K) 17.6 to 803.4, (Ca) 9.8 to 1113.8, (Mn) 0 to 10.2, (Fe) 1.8 to 283.9, (Cu) 0 to 20.9, (Zn) 0 to 7.9, (Br) 1.0 to 8.8, (Rb) 0 to 8.4, (Sr) 0 to 5.2, and (Pb) 0 to 10.6, respectively. We calculated sodium concentration (Na_{cal}) from charge balance of the PIXE data. The result shows negative correlation between Ca and other cations (Na_{cal}, K, Fe, Cu, Zn, Mn and Pb), especially between Ca/Cl and Na_{cal}/Cl with a slope of 1/2, and consistent with result of microthermometry.

The negative correlation between Ca/Cl and Na_{cal}/Cl and the slope of 1/2 strongly suggest that these fluid inclusion compositions are derived from albitization between basaltic andesite and water, and that the Ca-rich fluid is hydrothermal end-member whereas another end-member is seawater. The 2.2Ga seawater composition is estimated below: (Cl) ca. 3000, (Na_{cal}) 2236.3, (K) 731.5, (Ca) 134.5, (Fe) 2.7, (Cu) 20.9, (Zn) 7.9, (Mn) 10.1 and (Pb) 10.6 mmol/kg, respectively.

Ongeluk seawater during Snowball Earth event is characterized by extremely high chlorinity and high Fe and Mn contents (at least 1000 times higher than the modern). The first quantitative estimate of the high Fe and Mn contents indicates reduced condition of seawater at the Snowball Earth, supporting Fe and Mn accumulation during the period (Kirschvink et al., 2000). The quite high salinity significantly affected bioactivity of eukaryotes, and the dilution of Cl after the Snowball Earth, liberated the environmental pressure and expanded the niche for eukaryote.

Keywords: seawater, fluid inclusion, eukaryote, proterozoic, salinity, Ongeluk