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Analysis of fluid inclusion hosted by hydrothermally precipitated quartz in 2.2Ga Ongeluk Formation

Takuya Saitou[1*], Takazo Shibuya[2], Tsuyoshi Komiya[3], Kouki Kitajima[3], Shinji Yamamoto[1], Manabu Nishizawa[2], Yuichiro Ueno[1], Shigenori Maruyama[1], Masanori Kurosawa[4]

[1]Tokyo Institute of Technology, [2]JAMSTEC, [3]The University of Tokyo, [4]University of Tsukuba

One of the most fundamental enigmas of the Earth's palaeoclimate concerns the temporal and spatial distributions of Precambrian glaciations. Geological and palaeolatitudinal evidence suggests ice sheet sometimes, completely (or near completely) covered the oceans through the earth history (Evans et al., 1997; Kirschvink et al., 2000). But there is no quantitative estimate about degree of these glaciations. We present microthermometry and PIXE analysis of fluid inclusions in hydrothermally precipitated quartz within basaltic lavas in 2.2 Ga Ongeluk Formation, Kaapvaal Craton, South Africa. The studied lavas erupted probably during the Paleoproterozoic Snowball Earth event (Kirschvink et al., 2000), thus the purpose of this work is to obtain the information of seawater composition during the snowball period. The quartz crystals fill drainage cavities of pillowed basaltic lava and were probably precipitated soon after the eruption under the sea (Gutzmer et al., 2003). Relatively primary fluid inclusions in the quartz, which are selected based on the Petrographic observation, range from less than 5 to 40 micrometers across, and mainly form three-dimensional cluster. The primary fluid inclusions show final melting temperatures of ice from -31.4 to -3.6 degrees centigrade and show their bimodal distribution, final melting temperature from -47.0 to -21.7 degrees centigrade for hydrohalite, homogenization temperatures range from 64.4 to 160.0 degrees centigrade. Assumed the NaCl-CaCl2-H2O system, we calculated the salinity of fluid inclusions from their melting points. Estimated compositional variation shows three end-members: (1) a low NaCl and high CaCl2 end-member, (2) a high NaCl and low CaCl2 end-member, and (3) a low NaCl and low CaCl2 fluid end-member. They also show two mixing trends: between (1) and (2), and between (2) and (3), respectively. It is commonly thought that the mixing trend between (1) and (2) is derived from albitization of igneous plagioclase that generally observed in altered seafloor basalt (Ca/Na exchange reaction). Hence, the Na-rich end-member probably represents the seawater composition at 2.2 Ga Ongeluk sea. The estimated Cl content is about 3 mol/kg.
We also performed PIXE analysis of relatively large fluid inclusions (ca. 20 to 30 micrometers) at Tsukuba University. The result of PIXE analysis shows concentration of fluid inclusions from 56.4 to 136.0 ppm for Cl, 3.6 to 31.4 ppm for K, 1.6 to 44.4 ppm for Ca, 1.2 to 257 ppm for Fe, 76 to 70 4 ppm for Br, <40 to 714 ppm for Rb, and <40 to 455 ppm for Sr. Some fluid inclusions show low Cl/Br molar ratio (435 ~ 641), similar to that of modern-day seawater. The others show high Cl/Br molar ratio (more than 1300), implying that dissolution of evaporates is likely. The Cl concentrations estimated with PIXE analyses are consistent with the result of microthermometry. But, the high K concentration is not negligible for approximation of the ternary NaCl-CaCl2-H2O system. Especially, the Na content, besides K, Fe and others, is different between the estimates from thermometry and PIXE analyses. The data set suggests the Ongeluk seawater composition is very different from the modern seawater.
The result shows the Ongeluk seawater had higher salinity at least six times than the modern seawater. The salinity at 2.2 Ga is also higher than that of the ancient seawater estimated from total amount of continental salt deposits (Knauth, 1998, 2005). The high salinity could be

expected, if the Ongeluk sea was quantitatively frozen. Thus, our result supports the 'hard' Snowball scenario.

Keywords: hydrothermal fluid, seawater, proterozoic, fluid inclusion, Snowball Earth, PIXE