PIXE and microthermometric analyses of fluid inclusions in hydrothermal quartz from the 2.2 Ga Ongeluk Formation, South Africa: implications for ancient seawater salinity

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Seawater salinity is a critically important component because of the control it exerts on the chemical species in the seawater in that the chlorine concentration limits the concentrations of other cations and chloro-complexes. The analyses of fluid inclusions in hydrothermal quartz precipitated during seafloor hydrothermal alteration are useful for estimating the salinity of ancient seawater. We performed microthermometry and PIXE analyses on fluid inclusions in quartz from the 2.2 Ga Ongeluk Formation, which consists mainly of submarine basaltic andesite volcanics (pillow lavas and sheet flows) erupted during a period of global glaciation, and these analyses were used to estimate the seawater salinity during the glaciation.
The hydrothermal quartz contains many primary and secondary liquid-vapor fluid inclusions as well as inclusions that are randomly distributed without a trace of secondary healed cracks. These fluid inclusions were individually analyzed with microthermometry to obtain the concentrations of Na, Ca and Cl and with PIXE methods to obtain the concentrations of Cl, K, Ca, Mn, Fe, Cu, Zn, Br, and other elements.
Our obtained results show a different model salinity between primary (high-salinity) and secondary (relatively low-salinity) fluid inclusions, wide Na/Ca variation in the primary fluid inclusions and wide variation in transition metal concentrations (excluding Fe) in the Na-rich primary inclusions. Based on a comparison with modern seafloor hydrothermal vent fluids, these patterns can be explained by the two distinct mixing process: one process involves 1) a Na-rich, Ca- and transition metal-poor endmember mixing with 2) a Ca-rich, Na- and transition metal-poor hydrothermal fluid affected albitization (Ca-Na exchange reaction), and the other mixing process involves 1) a Na-rich, Ca- and transition metal-poor endmember mixing with 3) a Na- and transition metal-rich, Ca-poor hydrothermal fluid affected high temperature water/rock reactions. The Na-rich, Ca- and transition metal-poor endmember (1) in the primary inclusions is considered to represent the 2.2 Ga Ongeluk seawater composition.
The estimated seawater salinity is approximately six times greater than the modern value and 3–4 times higher than the value estimated for the early seawater based on the total amount of the extant continental salt deposits and saline groundwater (1.5–2 times the present seawater salinity). The difference between these estimates may result from the presence of unknown salt deposits and saline ground water in the modern continental crust or the formation of ice from much as two thirds of the ocean water during the 2.2 Ga global glaciation.

Keywords: fluid inclusion, seafloor hydrothermal alteration, salinity, PIXE, Ongeluk Formation

