

Quantitative analysis of trace elements in single fluid inclusions by micro-PIXE

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A fluid inclusion is a minute "fossil" of Earth's fluid trapped in a crystal during crystallization or recrystallization. Elemental composition of the fluid inclusions is so important because it can provide direct information about the generation and behavior of fluids and element transport by fluids. Fluid inclusions are commonly small, typically <30 μm; a single mineral grain contains many inclusions, possibly generated by multiple distinct mechanisms and of different compositions. Therefore, microanalyses of individual fluid inclusions are required to decode the changes in fluid activity and geological conditions recorded in single minerals. Owing to its high spatial resolution, non-destructive character and high sensitivity for almost element ($Z > 17$), proton-induced X-ray emission (PIXE) is a reliable technique for quantitative element analysis of single fluid inclusions. In this paper, we report the quantification methods for trace elements in fluid inclusion by PIXE and chemistries of fluid inclusions in quartz from island arc granite.

PIXE is effective for nondestructive trace-element analyses of minerals and the technique is also useful for trace-element analyses of single fluid inclusions buried in a mineral matrix because of the large penetration of the high-energy ion beam. In quantification of natural fluid-inclusion analyses, analytical errors of 10% relative for most elements and 40% relative for Cl. The major source of error in the quantification was the uncertainty in the determination of the inclusion depth. Detection limits of 15 to 40 ppm for elements with mass numbers 25-38 were achieved in analyses of ellipsoidal fluid inclusions (size, 50 μm x 30 μm x 30 μm; depth, 10 μm; bubble size, 15 μm; and NaCl solution, 10 wt. %) in quartz, at an integrated charge of 1.0 μC. The detection limits are improved by the analyses with long-time measurements.

Trace metal compositions of single fluid inclusions in quartz from a granite body were also analyzed by PIXE to elucidate the compositional change of granite-derived fluids during a migration in granite body. Quartz samples were collected from a pegmatite and miarolitic cavities, and hydrothermal quartz veins in the Miocene Kofu granite body, Yamanashi Prefecture, central Japan. These veins and cavities are genetically related to the biotite granite body. Quartz samples from the pegmatite and miarolitic cavities, and the most hydrothermal quartz veins include two-phase fluid inclusions, while the hydrothermal quartz veins near elevations of 1200 m include two-phase inclusions and polyphase inclusions including a halite crystal. Salinities (NaCl eq %) of the polyphase inclusions are 30-38%. Two-phase inclusions from the miarolitic cavities and the pegmatite contained up to 8 wt.% for Cl, 2-6 wt.% for K and Ca, 1000-3000 ppm for Fe and Ba, 200-500 ppm for Mn, Zn, Pb, Cu, Br, and Ge, several tens ppm for Rb and Sr. This result indicates that fluids released during the granite solidification had low contents of transition metal elements. The polyphase inclusions contained up to 17 wt.% for Cl, 2-3 wt.% for K and Ca, 2000-10000 ppm for Fe, Mn, and Zn, 200-700 ppm for Pb, Cu, Br, Sr, Ba, and Rb, 20-30 ppm for Ge. The polyphase inclusions could be formed by a phase separation into vapor and high-salinity water due to boiling of the original low-salinity fluids, because the veins including polyphase inclusions also contained vapor-rich fluid inclusions derived from the vapor. The result demonstrates that a part of the miarolitic cavity-forming fluid had probably had experienced boiling and metal concentration during the boiling in the biotite granite body.

Keywords: Fluid inclusion, trace element, X-ray analysis, granite, PIXE, ion beam