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Trace-element analysis of single fluid inclusions by 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 $<$30 um; a single mineral grain contains many inclusions, possibly generated by multiple distinct mechanisms and of different compositions. Therefore, microanalyses of individual fluid inclusions are required to decode the changes in fluid activity and geological conditions recorded in single minerals. Owing to its high spatial resolution, non-destructive character and high sensitivity for almost element ($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 8% relative for most elements and 14% 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, 50um x 30um x 30um; depth, 10 um; bubble size, 15 um; and NaCl solution, 10 wt. %) in quartz, at an integrated charge of 1.0 uC. The detection limits are improved by the analyses with long-time measurements.

Trace metal compositions of single fluid inclusions in quartz from two granite bodies were also analyzed by PIXE to elucidate chemistries and behaviors of hydrothermal fluids derived from calc-alkaline granite at island arc. Quartz samples were collected from miarolitic cavities, simple quartz veins, and hydrothermal ore veins in two Miocene granite bodies at Kofu, Yamanashi, and Uchiyama, Nagasaki, Japan. These veins and cavities are genetically related to the granite bodies and contained five types of fluid inclusions; two-phase, polyphase, vapor, liquid, and CO2 fluid inclusions. The predominant fluid inclusions were two-phase, polyphase, and vapor inclusions, so that trace elements in the three types of inclusions were analyzed. As the results, polyphase inclusions from the veins and cavities demonstrate lower contents of K and Rb and higher Ge contents than those from alkaline granites at the continental area. Trace-element contents in the polyphase, vapor, and two-phase inclusions were positively correlated with Cl contents (salinities), indicating behaviors as chloride complexes of these elements in the hydrothermal fluids. The Br/Cl ratios by weight of the two-phase and vapor-rich inclusions were nearly constant and were almost lower than the Br/Cl ratio of seawater. Those of the polyphase inclusions demonstrated higher ratios, and there were distinct trends of the variations for each of the three geological settings sampled. The characteristics of the polyphase inclusions can be explained mainly by P?T dependences of the partitioning of Cl and Br between fluid and magma during fluid segregation and between brine and vapor during boiling.

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