Solid inclusions in quartz veins from the Ryoke metamorphic belt in the Yanai district, SW Japan

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Solid inclusions in quartz veins from the Ryoke metamorphic belt in the Yanai district have been investigated to clarify characteristics of vein-forming fluids. The Ryoke metamorphic rocks in the district are divided into the following metamorphic zones: chlorite, chlorite-biotite, biotite, muscovite-cordierite, K-feldspar-cordierite, sillimanite-K-feldspar and garnet-cordierite zones (Ikeda, 2004). The quartz veins were collected from the biotite, K-feldspar-cordierite and garnet-cordierite zones. The veins in the biotite zone were formed during the retrograde metamorphism under flow deformation conditions probably above 300C at the Takabatake outcrop in Iwakuni City (Yamamoto et al., 2004) and after the regional ductile deformation at Kasado-Jima Island (Hoshino et al., 2006).

Solid inclusions in the veins confirmed by EPMA analyses are biotite, muscovite, K-feldspar and rutile/anatase. Raman microspectrometric analyses indicated that carbonaceous matters (CM, Hirotaka et al., 2006), native sulfur, wustite, plagioclase, andalusite, apatite and nahcolite also occur as the solid inclusions. Nahcolite in fluid inclusions in quartz veins was firstly reported in Japan from the quartz veins in the biotite zone at Kasado-Jima Island (Hoshino et al., 2006). Fluids in primary fluid inclusions coexisting with the solid inclusions in the veins are rich in CO_2 with minor amounts of CH_4, N_2 and H_2S as described by Hirotaka et al. (2006) and Hoshino et al. (2006). On the other hand, salinities of the fluids are very low (Hirotaka et al., 2006).

The quartz veins in the biotite zone include CM, biotite and native sulfur. Rutile and/or anatase are also found in biotite. Although a glauber's salt was found by Raman microspectromety, it disappeared at re-measurements. Hirotaka et al. (2006) pointed that the CM's show their organization temperatures of 530-610C averaging about 550C. They are higher than the temperatures of the biotite zone of about 450C estimated by Ikeda (2004). The occurrence of native sulfur as the solid inclusion may indicate a very low pH of the fluids.

CM, K-feldspar, muscovite, biotite, rutile/anatase, plagioclase, andalusite, apatite and nahcolite were observed as the solid inclusions in the quartz veins from the garnet-cordierite zone. The occurrences of idiomorphic rutile partly altered to anatase in the veins may indicate its precipitation temperature of 500-600C. CM's also show high organization temperatures of above 500C. However, nahcolite is conceived to have precipitated at a low temperature because of its low melting temperature (about 270C). Hoshino et al. (2006) estimated that nahcolite from Kasado-Jima Island was precipitated from the fluid containing high Na and low Cl.

It can be concluded from the above results that there might have been the fluids of various temperatures and pH during the retrograde stage(s). The variations of temperatures, pH and concentrations of Na and Cl are also typical characteristics of fluids in the present geothermal areas, where Na and CO_2 rich fluids are formed at the 'condensate zones' of vapor-dominant geothermal systems.