The origin of the Arima-type brine: Implications for the possible link between slab-derived fluid and non-volcanogenic hot springs

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The main aim of this study is to contribute to better understanding of the fluid processes occurring in subduction zones with a comprehensive framework involving slab-derived fluids to near-surface fluids such as sea water, meteoric water and hot spring waters. In the non-volcanic or forearc regions, evidences which show an involvement of slab-derived fluids have been hardly found. One exception could be the so-called 'Arima-type brine,' welling up in the Kinki district, SW Japan. According to the previous geochemical and hydrological studies (Matsubaya et al., 1974; Masuda et al., 1985; Sano and Wakita, 1985; Matsumoto et al., 2003; Morikawa et al., 2005; 2008), their oxygen, hydrogen, and helium isotopic ratios are anomalously high and similar to those of magmatic fluids or the upper mantle, despite the absence of Quaternary volcanic activities or underlying magma. It is speculated that the Arima-type brine might be relevant to NaCl-CO_2-rich aqueous fluids originated from a deep part of the forearc region, which is possibly slab-derived fluids.

The purposes of this study are to examine the origin of the Arima-type brine and to test its possible relationship to slab-derived fluids. In order to resolve various processes and sources relevant to the origin of spring solutions, a multi-elemental and isotopic data set for each sample was obtained from the hot springs in the Arima area, and a robust multivariate database by accumulating such a dataset was constructed. In this study, the concentrations of major ions, total alkalinity, dD, $d^{18}O$, $d^{13}C$, the concentrations of noble gases, $^{3}He/^{4}He$, $^{87}Sr/^{86}Sr$, and Pb isotopes were measured.

The observed variations of the spring waters can be explained consistently in the multi-elemental/isotopic space by mixing of the two end-member waters, i.e., meteoric water and the possible 'original deep brine'. The binary mixing has already been proposed for the origin of the Arima-type brine in the oxygen-hydrogen stable isotopic space (e.g., Masuda et al., 1985), and for the first time this study identifies and characterizes the deep brine in the multi-elemental/isotopic space. In addition, the dissolved gases of each spring can be explained by mixing of components (mantle or subducted slabs) being contaminated by air at shallow depths. The mixing proportions of deep-originated or surface-originated components in the sampled waters and gases are different, which suggests that solvent and soluble gases are likely to behave differently. Therefore it must be pointed out that the origin of the water and the solutes should not be necessarily the same as that of the deep-sourced gases. In any case, a deep source(s) is confirmed to be involved in the Arima-type brine. Furthermore, the concentrations and radiogenic isotopic ratios of Sr support the binary mixing between (Sr, $^{87}Sr/^{86}Sr$) ˜(0.12 ppm, 0.70846) and ˜(86 ppm, 0.70873), which is consistent with the correlations with other ions and stable isotopes. The estimated $^{87}Sr/^{86}Sr$ ratio of the original deep brine is close to the predicted ratio of the Philippine Sea slab-derived fluid, i.e., 0.709492, and is distinct from the Pacific slab-derived fluid, i.e., 0.704762 (Nakamura et al., 2008).

Compared with other bicarbonate-rich brines occurring with the granitic basements in other countries, which are supposed to be formed by water-rock interactions (e.g., Edmunds et al., 1985; Goff et al., 1991), the Arima-type brine seems to be different in the extremely high concentrations and the unique ionic ratios of the solutes. Therefore it can be concluded that, although the interactions between the solutions and the basement rocks, i.e., the Arima and Rokko granites, might have occurred to some extent and may perturb the $^{87}Sr/^{86}Sr$ ratios of the brine, the 'original deep brine' seems to exist and the mixing with meteoric water is the most dominant formation process of the Arima-type brine.