

Isotopic systematics and paleohydrology of the fracture fillings and deep saline groundwater at Laxemar, Sweden.

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Isotopic compositions of carbon ($\delta^{13}\text{C}$), oxygen ($\delta^{18}\text{O}$) and strontium ($\delta^{87}\text{Sr}$) in calcite fracture fillings and deep saline groundwaters are being used to reconstruct the source and evolution of the groundwater at Äspö and Laxemar, at the Äspö Hard Rock Laboratory (ÄHRL), south-eastern Sweden. The fracture fillings mark the pathways of past fluid movement so an understanding of their genesis is particularly important for understanding the paleohydrology in the area. The utility in applying the multiple-isotope approach to groundwater and fracture minerals derives from the fact that the different systems represent different processes.

The isotope data in the groundwater at Laxemar suggest two major groundwater types; a fresh groundwater with a uniform isotopic signature, typical of meteoric water, residing above 1000 m, whereas the deep saline groundwater below 1000 m show a significant deviation from the meteoric water line.

The calcites precipitated from groundwater in the fractured crystalline rocks at some time in the past, and $\delta^{13}\text{C}$, $\delta^{18}\text{O}$ and $\delta^{87}\text{Sr}$ values of the calcites reflect those of the source waters. At depth in excess of 900 meters, $\delta^{87}\text{Sr}$ (-5.6 to +8.4 o/oo) correlates positively with $\delta^{18}\text{O}$ (+8.8 to +20.5 o/oo) and negatively with $\delta^{13}\text{C}$ (-0.8 to -7.5 o/oo); $\delta^{87}\text{Sr}$ varies inversely with Sr concentrations (46.8 to 455.6 ppm). The $\delta^{18}\text{O}$ values (+8.8 to +20.5 o/oo) suggest that most of the calcites have not formed from the present-day groundwater although some of the larger $\delta^{18}\text{O}$ values could reflect equilibrium with groundwater under current *in-situ* temperature. Similarly, the low $\delta^{18}\text{O}$ values (+8.8 to 9.8 o/oo) could have formed from groundwaters but at temperatures 30°C to 40°C higher than ambient (approximately 18°C). If the spread in $\delta^{18}\text{O}$ values for the calcites were the result of increased temperature, the temperature distribution within the source water was probably strongly advective.

The stable ($\delta^{13}\text{C}$, $\delta^{18}\text{O}$) and radiogenic ($\delta^{87}\text{Sr}$) isotope systematics shown by calcite fracture fillings at Äspö record a paleohydrochemistry which is very much different than that of present day groundwater system. Conversely, it seems unlikely that the present-day groundwaters are dissolving calcite veins or the $\delta^{87}\text{Sr}$ values in the water would show much greater variability. The coupled variations in oxygen, carbon and strontium isotopes at depth in excess of 900 m indicate the presence of different groundwaters in the past, which in view of the glacial history of the region, is not surprising. Correlation of the $\delta^{87}\text{Sr}$ with Sr concentrations, could reflect water-rock interaction. The order-of-magnitude difference in Sr concentrations coupled with the isotopic differences suggests large compositional variations in the source waters; calcites containing smaller $\delta^{87}\text{Sr}$ values and larger Sr concentrations would have precipitated from waters with the largest dissolved load. Such waters could derive their dissolved ions in part from water-rock reactions. The small $\delta^{87}\text{Sr}$ values of some calcites could reflect preferential interaction with or dissolution of plagioclase feldspar, a process suggested to explain unradiogenic (small $\delta^{87}\text{Sr}$ values) Sr in deep saline waters of the Canadian Shield. Plagioclase from a sample of typical granodiorite at Äspö has a $\delta^{87}\text{Sr}$ of -6.4 o/oo which is consistent with the low $\delta^{87}\text{Sr}$ values of the high-Sr calcites. The relatively heavy $\delta^{13}\text{C}$ values (-0.8 to -7.5 o/oo) for all the calcite fracture fillings seem to indicate an equilibrium effect, reflecting a nonbiogenic origin, presumably a deep-seated carbon source.