



Origin of secondary quartz in the Icelandic crust – A coupled $\delta^{18}\text{O}$ and $\delta^{30}\text{Si}$ study

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Quartz and SiO_2 polymorphs are among the most abundant minerals in the continental crust and major constituents in a variety of plutonic, sedimentary and metamorphic rocks as well as an important secondary product in many hydrothermal systems. As quartz is often associated with hydrothermal and ore deposits, its origin and paragenesis remains subject of considerable discussion. This study focuses on quartz formation processes within the Icelandic crust.

The studied sample set contains (1) igneous quartz from crustal xenoliths and micro-granites ($>550^\circ\text{C}$), (2) high-temperature hydrothermal quartz ($\sim 200\text{--}400^\circ\text{C}$) and (3) low-temperature hydrothermal quartz and amorphous silica ($<150^\circ\text{C}$). Oxygen ($\delta^{18}\text{O}$) and silicon ($\delta^{30}\text{Si}$) isotopes in quartz and SiO_2 polymorphs were analysed in-situ using SIMS to investigate the sources of O and Si to the crust but also to unravel crustal processes (e.g., fluid-rock interaction, boiling and cooling) that affect major reactions and isotope fractionation during secondary mineral formation in hydrothermal settings.

The measured isotopic values are strongly correlated with quartz formation conditions and the source of O and Si to the system. $\delta^{18}\text{O}$ and $\delta^{30}\text{Si}$ range from (1) -5.6‰ to $+6.6\text{‰}$ (O) and -0.2‰ to -0.7‰ (Si) when formed under magmatic conditions, (2) -9.3‰ to -12.1‰ (O) and -0.9‰ to $+0.7\text{‰}$ (Si) when formed under high-temperature hydrothermal conditions and (3) -0.9‰ to $+30.1\text{‰}$ (O) and -4.6‰ to $+0.5\text{‰}$ (Si) when formed under low-temperature hydrothermal conditions.

By using quantitative isotope modelling, crustal processes including fluid-rock interaction, boiling and cooling were simulated to investigate their effects on the formation of secondary quartz and its isotopic composition. Modelling results were subsequently compared with our new dataset. At high hydrothermal temperature ($\sim 200\text{--}400^\circ\text{C}$), variations in $\delta^{18}\text{O}$ and $\delta^{30}\text{Si}$ of quartz can be explained by equilibrium isotope fractionation accompanying progressive fluid-rock interaction. At low hydrothermal temperature ($<150^\circ\text{C}$), boiling followed by cooling may result in ^{30}Si -depleted quartz and amorphous silica. Kinetic isotope fractionation may also play a role at such low temperatures. $\delta^{18}\text{O}$ values of the same grains were found to be dependent on the source of the water (e.g. seawater or meteoric water) and fractionation between liquid, vapor and secondary minerals. These results demonstrate that $\delta^{30}\text{Si}$ and $\delta^{18}\text{O}$ values of quartz can be utilized to constrain and quantify various hydrothermal processes occurring in the Earth's crust.