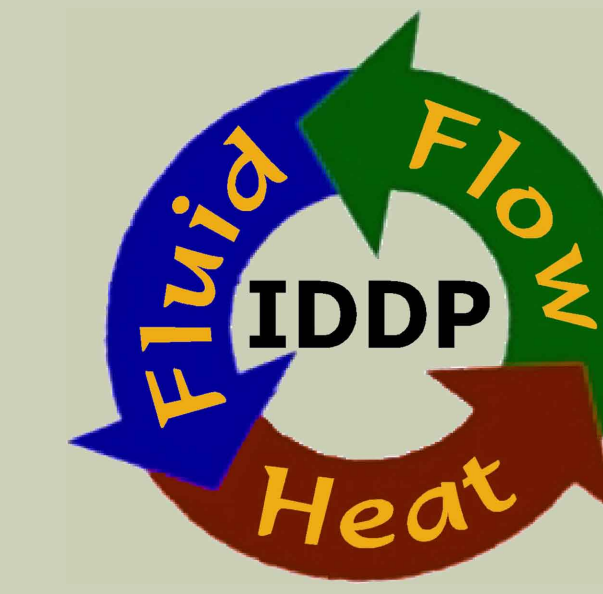


Iceland Deep Drilling Project (IDDP) II: Fluid Origin and Evolution in the Reykjanes Geothermal System - A Stable Isotope Study of Hydrothermal Epidote



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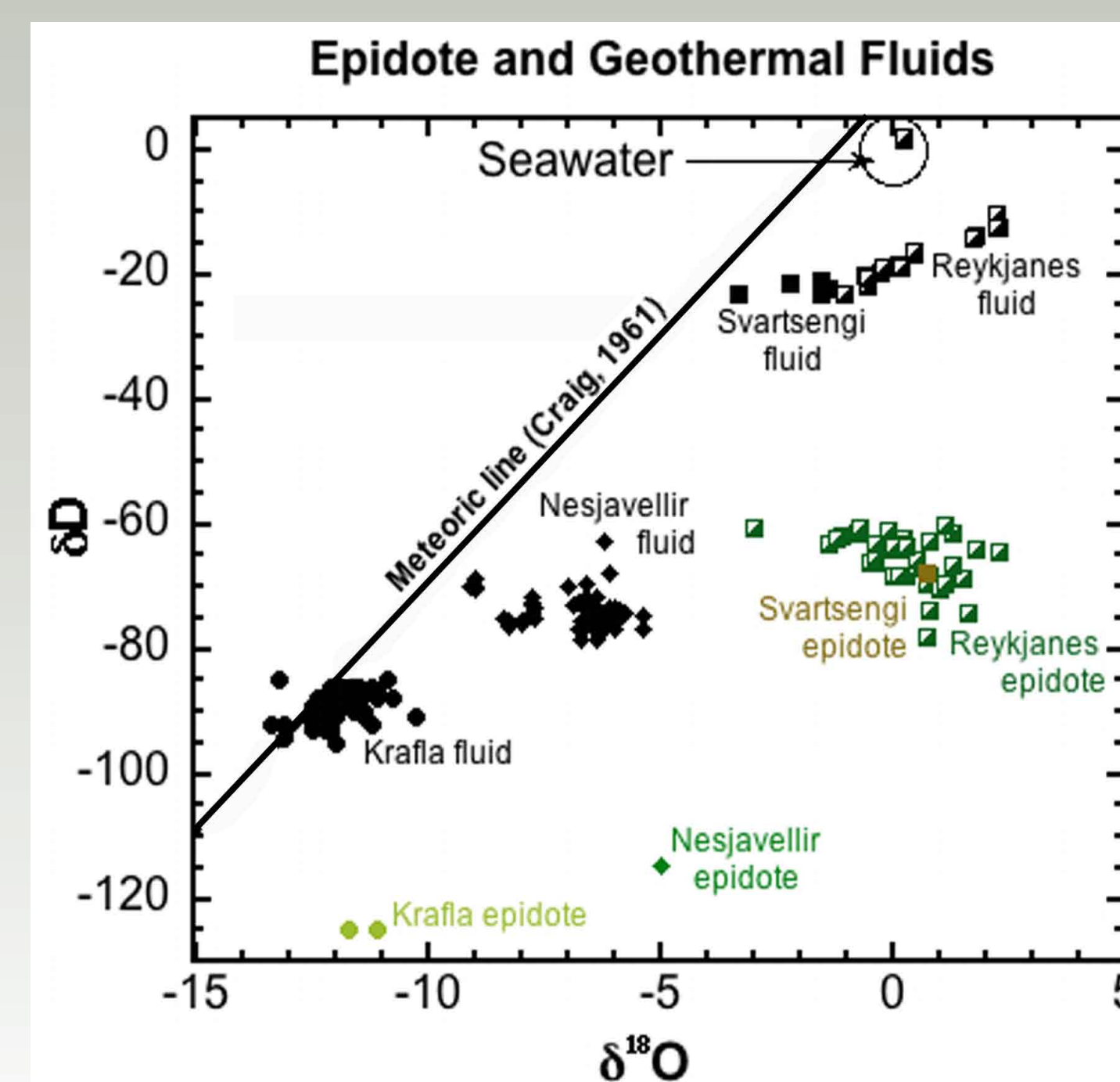
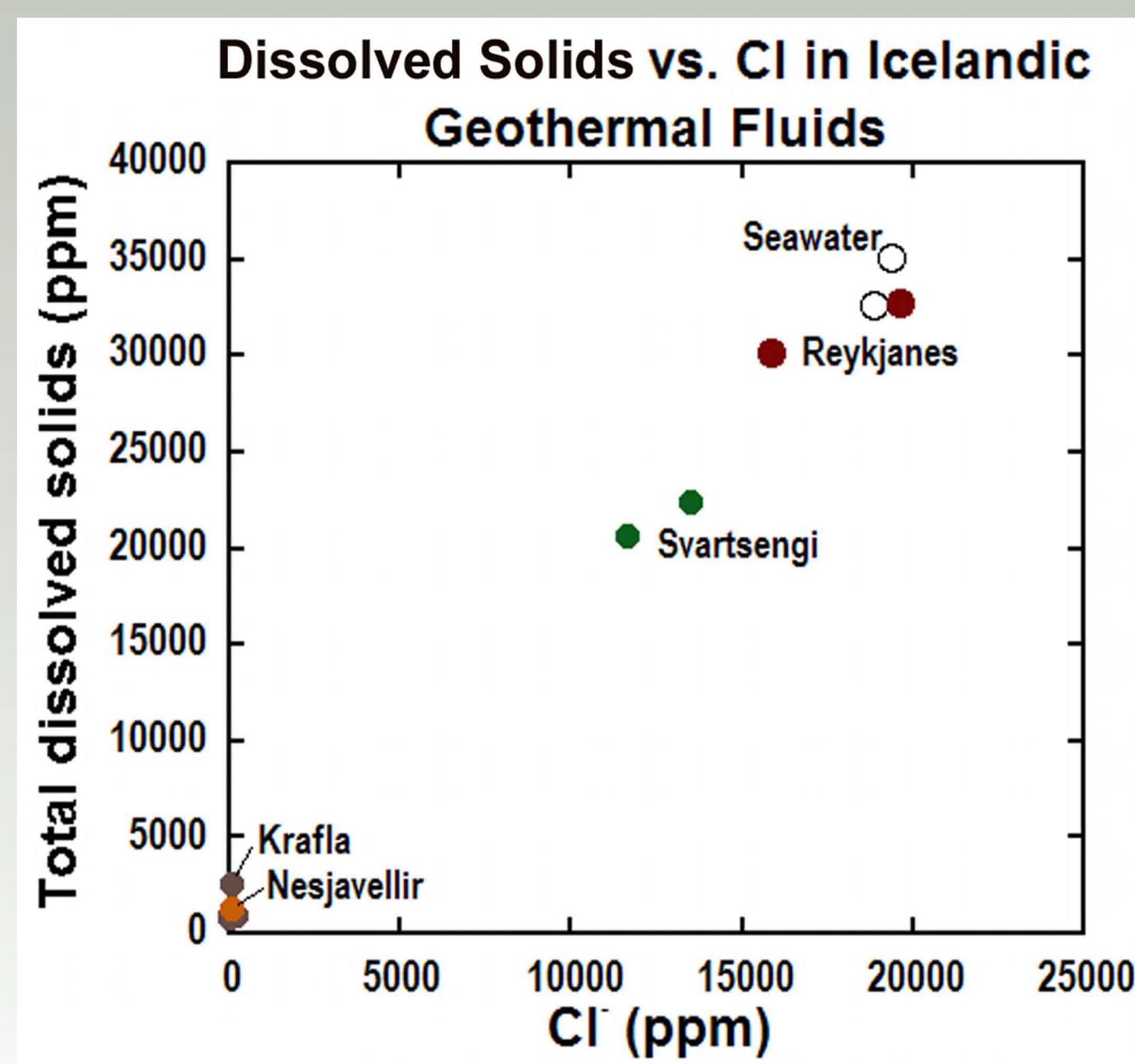


Introduction

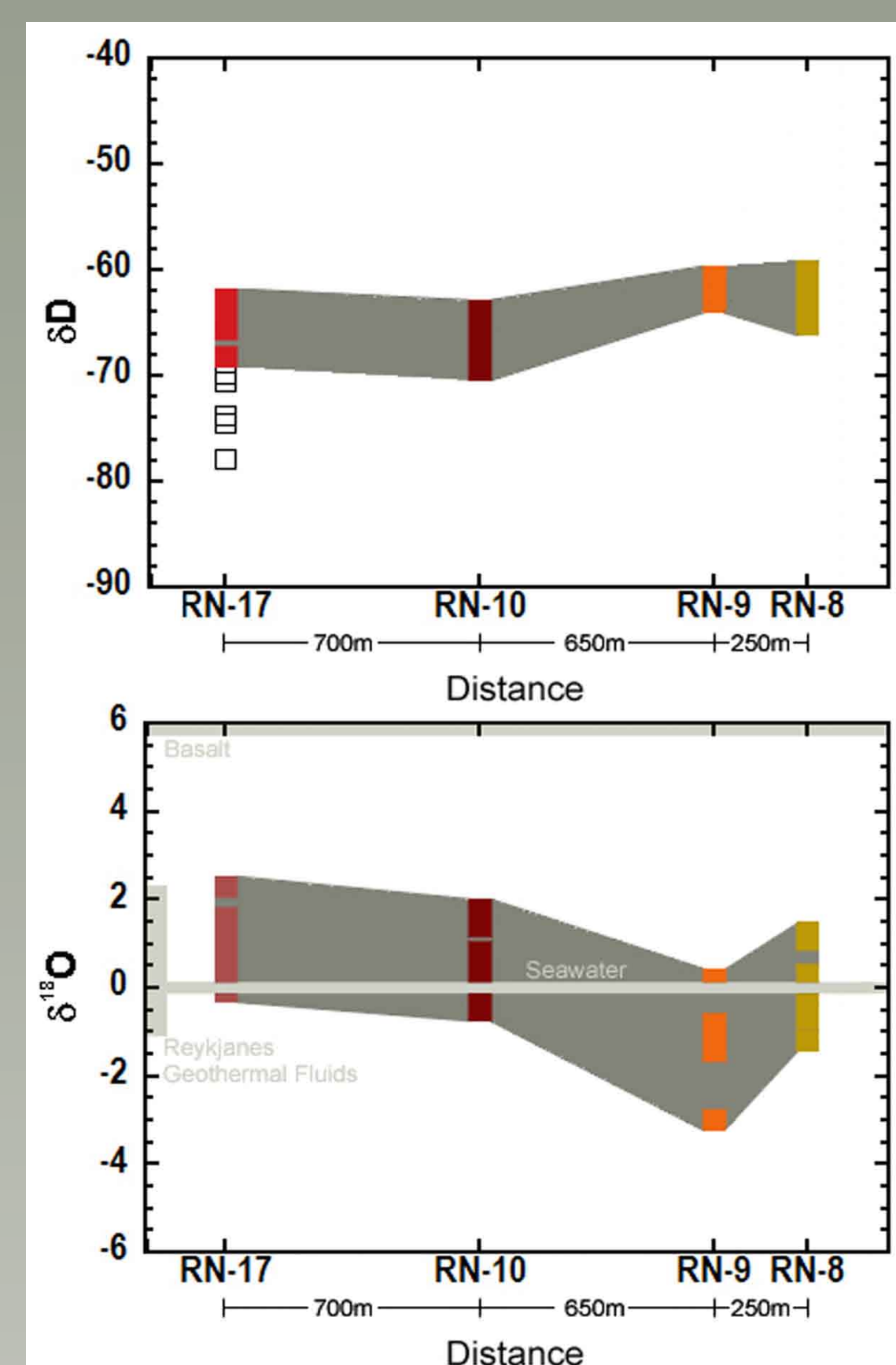
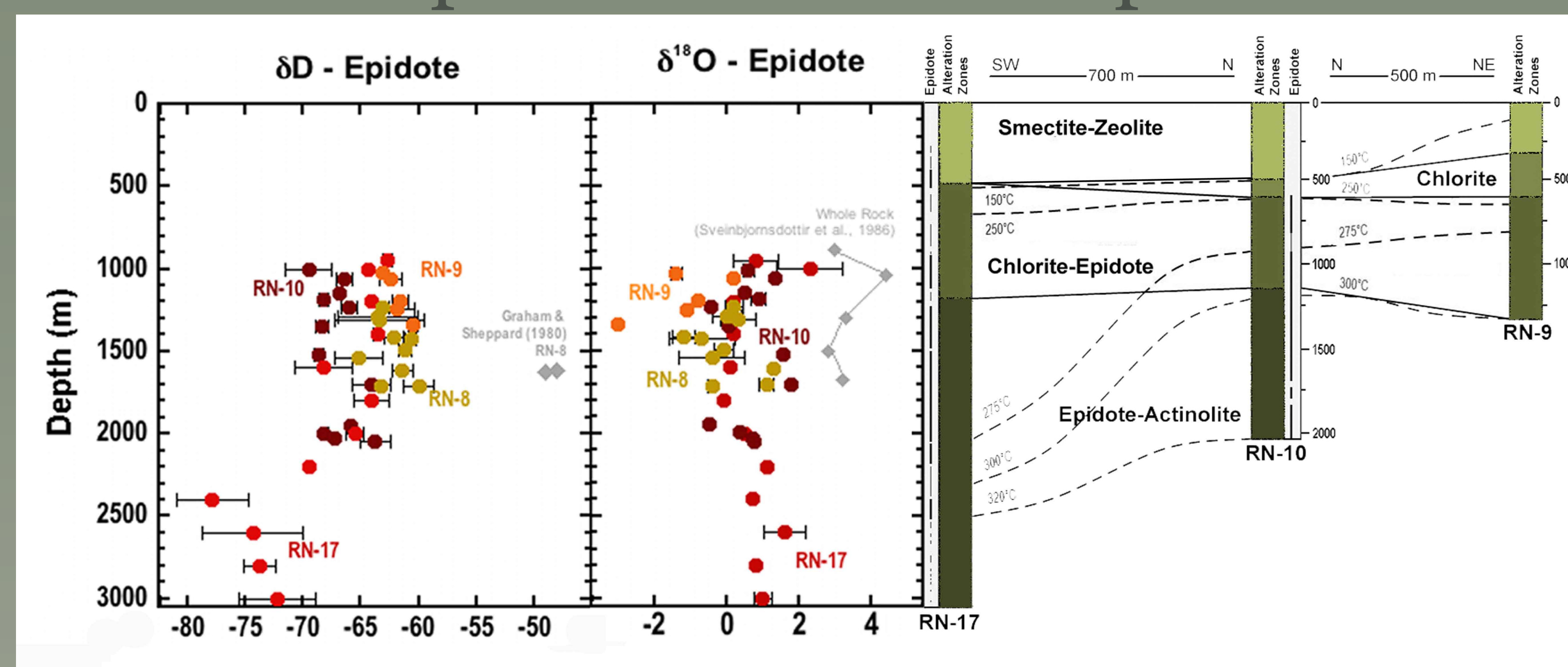
The Reykjanes Peninsula is located on the landward extension of the mid-Atlantic Ridge, and is host to one of the more than 20 high-temperature geothermal areas (filled circles) in Iceland. This geothermal system is unique in that it is thought to be dominated almost entirely by seawater, and consequently offers an excellent opportunity to study fluid-rock interactions in marine-dominated basalt hydrothermal systems similar to those of oceanic spreading ridges. However, the inconsistencies in the geochemistry of the fluids in the Reykjanes system indicate that the evolution of this system is more complex than simple basalt-seawater interaction models.

Studies done on Reykjanes geothermal fluids by Arnórsson (1978) indicate that fluid chemistry and salinity is comparable with seawater in contrast to other high-temperature fields in Iceland which have a meteoric source (Krafla and Nesjavellir), or a mixed meteoric-sea water input (Svartsengi). However, hydrogen isotopic values of Reykjanes fluids are anomalously low for a seawater composition; (δD as low as -23.5‰). This is comparable to the isotopic composition of Svartsengi fluids ($\sim -24\text{‰}$), which is considered to be a 70%/30% seawater-meteoric water mixture. To date, the source of this discrepancy is poorly understood.

In order to evaluate the source and evolution of fluids in the Reykjanes geothermal system, we use the hydrogen isotope composition of hydrothermal epidote from several active geothermal wells as a record of the average isotope composition of the fluids from which they precipitated. These values, in conjunction with the hydrogen and oxygen isotope composition and elemental chemistry of modern geothermal fluids, are used to model the relative impacts of fluid source, mixing, and rock-fluid interaction on the chemistry of present-day fluids. As a result, it is possible to constrain a variety of variables that impact the geochemical evolution of the Reykjanes geothermal system, making it an invaluable natural laboratory for studying metasomatic processes.



Epidote Stable Isotopes



δD values of geothermal epidote from wells RN-8, -9, -10 and -17 ranges from -60 to -63‰ , -61 to -63‰ , -64 to -70‰ and -63 to -78‰ , respectively. $\delta^{18}O_{\text{EPIDOTE}}$ in these wells are between -1.2 and 1.3‰ , -3.0 and 0.2‰ , -0.5 and 1.8‰ , and finally between -0.1 and 2.3‰ .

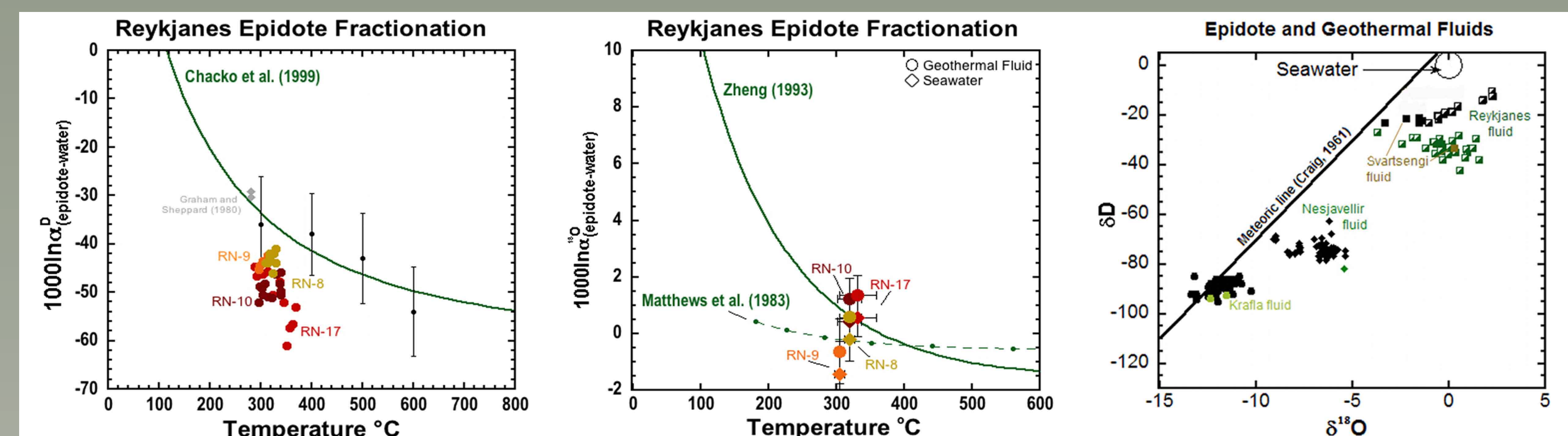
$\delta D_{\text{EPIDOTE}}$ shows a slight increase along a NW trend through the geothermal field, whereas $\delta^{18}O_{\text{EPIDOTE}}$ values generally decrease. This suggests a SE to NW migration of the geothermal upflow zone with time, which is consistent with measured down-hole temperatures and observed hydrothermal mineral zones.

Finally, each well has $\delta^{18}O_{\text{EPIDOTE}}$ values less than 0‰ . These epidotes could not have formed only from seawater-derived fluids. Instead, the values suggest a fluid source with a meteoric component that has undergone variable amounts of isotope exchange with the surrounding host basalt.

Epidote-Fluid Isotope Fractionation

$1000\ln\alpha_{\text{EPIDOTE-H}_2\text{O}}$ is determined for D and ^{18}O using measured epidote isotope values (this study) and published fluid isotope values of deep wells ($\delta D = -20.8\text{‰}$, $\delta^{18}O = -0.6\text{‰}$). Results are plotted against temperatures approximated from the boiling point curve, and compared to the temperature-fractionation curves by Chacko et al. (1999) for D, and Zheng (1993) and Matthews et al. (1983) for ^{18}O . Hydrogen isotope fractionation between Reykjanes epidotes and geothermal fluid is lower than estimated equilibrium values. In contrast, oxygen fractionation correlates closely with published equilibrium curves.

These results are shown relative to other Icelandic geothermal systems by comparing fluids calculated to be in equilibrium with measured epidote to modern geothermal fluids. Epidotes from the Krafla and Nesjavellir systems predict fluids in close agreement with modern values. In contrast, the δD of fluids in equilibrium with Reykjanes and Svartsengi suggest a significant component of meteoric- or glacially-derived fluids not observed in the modern system.

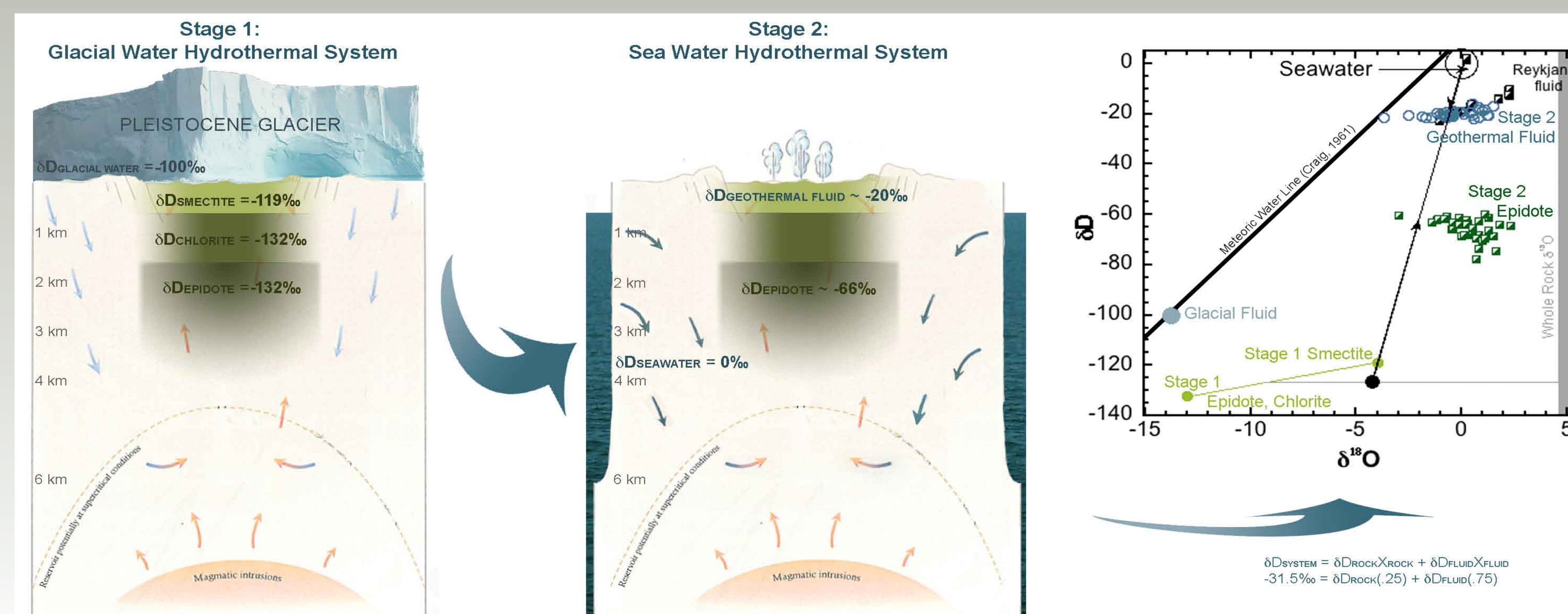


Evolution of Reykjanes Geothermal Fluids

Evidence from stratigraphic and fluid inclusion analyses of Reykjanes wells suggests that the geothermal system originated with glacial meltwater as the primary source for hydrothermal solutions. If this is the case, hydrous minerals that formed in equilibrium with these fluids would have isotopic values much lower than those formed in the present-day system. As the geothermal system has evolved to a seawater-dominated regime, hydrogen contained in these relict minerals should diffusively exchange with modern fluids, approaching a new isotopic equilibrium by increasing $\delta D_{\text{MINERAL}}$ and decreasing δD_{FLUID} . To determine whether there is enough low-D water structurally bound in Reykjanes alteration minerals to affect the hydrogen isotope composition of modern geothermal fluids, we consider a simple closed-system, mass-balance model. In a closed system, the total δD of the system remains constant, and is determined by:

$$\delta D_{\text{SYSTEM}} = \delta D_{\text{ROCK}} \times X_{\text{ROCK}} + \delta D_{\text{FLUID}} \times X_{\text{FLUID}}$$

δD_{SYSTEM} is calculated given the starting conditions of $\delta D_{\text{ROCK}} = -125\text{‰}$ (average composition of hydrous minerals precipitating from $\delta D_{\text{GLACIAL FLUID}} = -100\text{‰}$, $\delta D_{\text{FLUID}} = 0\text{‰}$ (seawater), and X_{ROCK} and X_{FLUID} determined from the W/R ratio (calculated by average $\delta^{18}O_{\text{EPIDOTE}}$ after Criss and Taylor, 1986; W/R = 0.2). As the geothermal minerals and fluid undergo diffusional isotope exchange, we can use the constant δD_{SYSTEM} to estimate the composition of fluids if δD_{ROCK} is equal to measured epidote values. The resulting δD_{FLUID} estimate is $-20.0 \pm 0.06\text{‰}$. Thus it is likely that modern $\delta D_{\text{EPIDOTE}}$ and δD_{FLUID} values in the Reykjanes geothermal system are the result of diffusional exchange between modern seawater-derived fluids and hydrous alteration minerals that precipitated from early glacially-derived geothermal fluids.



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