Radiation damage and helium diffusion kinetics in apatite

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Experimentally determined diffusion coefficients for 39 different samples of apatite demonstrate that the closure temperature (T_c) for helium retention in apatite spans a wider range than previously recognized: from 44 ± 4 °C to 116 ± 18 °C (for 10 °C/Myr) and correlates with the radiogenic ^{4}He concentration ([^{4}He]) in a given sample. We find no correlation between helium diffusion kinetics and apatite chemistry, including the F/Cl ratio. We argue that [^{4}He] is a measurable proxy for the radiation damage which accumulated within each crystal over geologic time. As the volume density of lattice damage sites increases, apatite becomes more helium retentive. This implies that helium retentivity, and hence the effective helium diffusion kinetics, is an evolving function of time. Measured diffusivities thus reflect a snapshot in time and cannot alone be applied to the thermochronometric interpretation of a given sample.

Calibrated with diffusion kinetics of 39 different samples of apatite, we present a simple, quantitative *trapping model* which relates diffusivity to both temperature *and* [^{4}He]. This previously proposed model (Farley, 2000) consists of two Arrhenius relations: one for volume diffusion through undamaged mineral lattice and one for the release of helium from the damage traps back into the undamaged lattice. The model predicts much of the observed log-linear correlation between T_c and [^{4}He]. By inserting this function into a ^{4}He production-diffusion calculation, the *trapping model* predicts: (i) that the effective ^{4}He closure temperature of apatite will vary with cooling rate *and* effective U concentration (eU) and may differ from 70 °C by up to ±15 °C, (ii) the depth of the ^{4}He partial retention zone will depend on accumulation time and on eU, and (iii) samples subjected to reheating after the accumulation of substantial radiation damage will be more retentive than previously expected. These predictions are consistent with recent observations of unexpected apatite (U-Th)/He ages in some settings, most noteably (Flowers et al., 2006).

References

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Evolution of the Vestmannaeyjar volcanic system

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The Vestmannaeyjar archipelago forms the southernmost tip of the Eastern Volcanic Zone in Iceland. The volcanic islands (largest are Heimaey, 13.4 km^2 and Surtsey, 1.4 km^2), along with numerous submarine eruption sites, constitute the Vestmannaeyjar volcanic system. It has been suggested that the age of the Vestmannaeyjar system is about 0.1 Ma and that the Heimaey area is evolving into a central volcano (Jakobsson, 1979). A detailed mapping of Heimaey indicates that the island is built up of 12 eruptive units, ranging in composition from alkali olivine basalt to mugearite. We have sampled the island with emphasis on the complex Nordurklettar Formation of N-Heimaey and so far 31 rock samples have been analyzed for major and trace elements.

The Vestmannaeyjar rock suite divides into three groups based on mineralogy and rock chemistry. These are two groups of alkali basalts, VE I with MgO 8–12 wt% and VE II with MgO 5.5–7.7 wt%; and a group of hawaiites-mugearites, VE III with MgO 3.2–5.2 wt% (Jakobsson, 1979). The VE II basalts can be divided further into two groups based on trace elements where the older basalts are slightly more enriched in the more incompatible trace elements at the same MgO content.

There are strong indications that the volcanism on Heimaey has been cyclic, where each cycle starts with a VE I basalt, followed by the more evolved VE II basalt and ending with a hawaiite or mugearite VE III. During the Holocene one such cycle starts with the Storhöfdi eruption about 6500 BP, followed by the Saefjall and Helgafell eruptions approximately 6200 BP and ending with the Eldfell eruption in AD 1973. In the Nordurklettar Formation there appears to be at least one other comparative cycle present.

Four samples from the Nordurklettar Formation are currently being dated by the Ar–Ar method in order to get a better understanding of the inferred cyclic activity. Three drillcores from a 1600 m deep hole on Heimaey are also being dated; the samples are from depths of 905, 1010 and 1517 m (Palmason, 1965). In 2005 a new 2277 m deep hole was drilled on the eastern part of Heimaey (Franzson, 2006). Drill cuttings from this hole are being analyzed for major elements and will be analyzed for trace elements later in the year. In this and subsequent study we will try to determine more precisely the onset and evolution of the Vestmannaeyjar volcanic system.

References

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