The influence of neutron irradiation and thermal annealing on helium diffusivity in apatite

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Accurate extrapolation of helium diffusivity over temperature and time is essential for quantifying long term erosion rates and the topographic evolution of Cenozoic orogens using (U-Th)/He thermochronometry. Naturally occurring radiation damage was recently shown to influence helium diffusion in apatite, such that the kinetics is controlled by the parent nuclide conentrations as an evolving function of time [1]. This implies that apatite helium ages are sensitive to lower temperatures and shallower depths than indicated by the diffusion kinetics presently observed in a given mineral. Here, we present results of controlled experiments to quantify the effects of (a) synthetic irradiation and (b) thermal annealing on helium diffusion kinetics in both synthetic and natural apatites. Exposure to a 1 MeV equivalent neutron fluence ($\Phi_{eq,\ 1MeV,\ Si}$) of 2×10^{18} n/cm$_2$ (90 hours in the cadmium lined in-core irradiation tube, CLICIT, facility of the Oregon State University TRIGA reactor) caused the helium closure temperatures (T_c; 10 ºC/My) to increase by up to +27 ºC. The ΔT_c negatively correlates with the initial T_c, where apatites with higher initial T_c were less perturbed by the neutron irradiation than samples with lower initial T_c. Conversely, simply heating natural apatites to 550ºC for 1 hour caused T_c in all cases to decrease to 47±7 ºC regardless of the initial T_c (the maximum observed ΔT_c= -44 ºC). The resulting T_c agrees well with diffusion parameters constrained [1] for radiation damage-free apatite, T_c = 52 ºC.

These results clearly demonstrate that exposure to radiation causes the retentivity of helium in apatite to increase, whereas exposure to temperatures at which thermal annealing occurs causes the retentivity to decrease. The experiments suggest that after 1 hr at 550ºC, effectively all natural radiation damage was annealed in each sample to yield a common T_c. This closure temperature (~47ºC) would correspond to the diffusion kinetics in the damage-free apatite structure. From radiation damage theory we estimate the damage caused by the 90 hr neutron irradiation to be roughly equal to the alpha recoil damage corresponding to [^{4}He] ~10^{-8} mol/g, or roughly the present ^{4}He concentration of Durango apatite. This implies that Durango apatite should presently have T_c ~27ºC above the completely annealed state, or ~74ºC, which is in excellent agreement with observations. This study highlights a need to quantify the kinetic effects of damage accumulation *and* annealing on helium diffusion in minerals used for (U-Th)/He thermochronometry.

Reference

[1] Shuster, D.L., R.M. Flowers, and K.A. Farley, (2006). *Earth and Planetary Science Letters*,. **249**,. 148-161.

Geochemistry of Late Cretaceous tholeiitic volcanism and oceanic island arc affinities of the Chagai arc

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The major part of the Chagai arc occur in the western-north part of Pakistan and a small part of it also extends towards north in Afghanistan and west in Iran. The Late Cretaceous volcanic rocks which are designated as Sinjrani Volcanic Group, is the most wide spread and the oldest unite of the Chagai arc. This volcanic Group is mainly composed of basaltic to andesitic lava flow and volcaniclastics including agglomerate.

The petrological studies of various lava flow revealed that these are mainly basaltic-andesites (53.27-55.93 wt.% SiO_2) with minor basalts (49.57-52.14 wt.% SiO_2) and andesites (59.12-.59.88 wt.% SiO_2). Petrochemical studies based on major and trace elements suggest that these are medium to low K tholeiites. The trace element show variable enrichment in LILE and depletion in HFSE relative to N-MORB. Their primordial mantle-normalized trace element patterns show marked negative Nb anomalies with positive spikes generally on K, Ba and Sr which strongly confirm their island arc signatures. The chondrite normalized REE patterns shows minor but variable enrichment of LREE and positive Eu anomalies. The Zr/Y versus Zr, and Cr versus Y studies, lowers Mg # and lower abundances of Ni and Co suggest that the parent magma of these rock suites was generated by about 15-30 % melting of depleted sub-arc mantle source, and fractionated in an upper level magma chamber en-route to eruption. These volcanics exhibit lower $^{87}Sr/^{86}Sr$ ratios (0.7038-0.7049), which are consistent with a depleted mantle source and closely correlate with oceanic island arcs rather than continental margin type arcs. On the basis of these studies it is concluded that the Chagai arc was initially developed as an oceanic island arc which was formed due to the intra-oceanic convergence in the Ceno-Tethys during the Late Cretaceous rather than constructed on the southern continental margin of Afghan block, as previously claimed by several workers.