

Stacking fault-enhanced argon diffusion in naturally deformed muscovite

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Recent advances in micro-scale ⁴⁰Ar/³⁹Ar geochronology have revealed non-Fickian argon concentration gradients interpreted to result from intragranular defect-enhanced diffusion. Defects observed by transmission electron microscopy (TEM) in naturally deformed muscovites with a significant intragranular argon diffusion component (Kramar et al 2001) are evaluated as a potential pathway for argon diffusion.

The heterogeneous presence of broad stacking faults is the most outstanding feature observed in the deformed muscovite. Some micro-cleavages were also observed in regions of medium-to-high linear stacking fault densities.

Two-dimensional defects, such stacking faults, occurring in ionic crystals is known to modify mechanical behavior or diffusion. Of particular interest for noble gas diffusion is the net dilatation that a stacking fault is able to generate in ionic crystals (Tasker and Bullough, 1981). In micas, partial dislocations defining the stacking faults and occurring in the interlayer, place the K ion into a hollow in the center of three oxygen ions of the adjacent tetrahedral layer (Caslawski and Vedam, 1971). Energy calculations based on electrostatic modeling conclude this configuration leads to an interlayer spacing on the order of 0.5 Å (Banos, 1985).

The interlayer spacing has direct implications for argon retention in micas. Numerical modeling of diffusion along the stacking faults was performed on the basis of the calculated interlayer spacing, the measured isotope data, and the observed linear stacking fault density. These calculations estimate the diffusivity ratios defined by volume diffusion and defect-enhanced diffusion which are comparable with diffusivity ratios in other materials (ceramics or metals).

In the absence of defects causing physical grain segmentation (e.g. kink bands or subgrain boundaries), stacking faults are potentially the main defect in the media controlling intragranular argon diffusion.

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Volatile element abundances point to a H₂O ocean on Earth at > 4.4 Ga

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Hydrogen, C, N, Cl, Br and I are highly concentrated in the Earth Surface Reservoirs (ESR: Atmo-hydrosphere, sediments and metasediments) and either reside in, or have been cycled through the atmo-hydrosphere. Their abundances in the ESR, normalised to Al in the whole Earth, show depletions of 10⁻⁸ - 10⁻² relative to Solar values, but solar-normalized patterns are broadly similar in shape to those of carbonaceous chondrites (CC). Notable features in the CC-normalised abundances of the ESR are an almost flat pattern for the halogens (~1.5×10⁻²) and a stronger depletion of H (~3×10⁻³), C (~3×10⁻⁴) and N (~8×10⁻⁴).

Possible sources for the volatiles, other than a CC-like component, are solar matter (either captured nebular gas or implanted solar wind, Podosek et al., 2000), and comets. A small solar matter contribution is required to explain Ne isotope ratios in the Earth's mantle (Kunz, 1999) but does not significantly affect the depletion pattern for the elements studied. An important comet H contribution is ruled out because: (1) (For Oort Cloud comets) D/H ratios are around 3×10⁻⁴, twice the terrestrial value (Meier et al., 1999); and (2) The H/C ratio of comets is chondritic or lower (Crovisier and Bockelée-Morvan, 1999). CC accretion or co-accretion is thus the essential source for terrestrial H, C, N, Cl, Br and I. Importantly, the irregularities in the CC-normalised ESR abundance pattern are a robust feature, reflecting differential loss from the atmosphere following release by degassing.

¹²⁹Xe(I) and ¹³⁶Xe(Pu) systematics show that such loss occurred < 250 Ma after Allende (Azbel and Tolstikhin, 1993) most likely by hydrodynamic escape (Pepin, 1998), where the rate of escape of a species is inversely proportional to its mass, and proportional to its abundance in the upper atmosphere. All aspects of the process predict greater loss of H than of C or N. This paradox and the problem of high halogen retention can both be resolved and numerically modeled if most H₂O, Cl, Br and I quasi-continuously resided in a liquid water ocean during this early atmosphere loss, resulting in their underproportional loss from the atmosphere. This finding corroborates δ¹⁸O data on >4 Ga detrital zircons (Peck et al., 2001).

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