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Excess ^{40}Ar as a tracer for metamorphic porosity

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Argon decoupled from its parent K ($^{40}\mathrm{Ar}_E$) is a ubiquitous feature of metamorphic rocks, specifically those which have formed under high pressure conditions. The factors controlling its presence are not clearly understood. Traditionally, $^{40}\mathrm{Ar}_E$ is interpreted as detrimental to geochronological studies, where the aim is to measure meaningful ^{40}Ar/^{39}Ar cooling ages. A global compilation of high-pressure (*HP*) muscovite and phengite ^{40}Ar/^{39}Ar data shows that ages typically lie between 1—200% in excess of the age of peak metamorphism as constrained by U—Pb, Lu—Hf or Sm—Nd geochronology. Intriguingly, mafic lithologies consistently yield older ages than cogenetic pelitic lithologies. Concentrations of $^{40}\mathrm{Ar}_E$ commonly vary on sub-millimetric lengthscales both between and within individual grains. These data confirm that the grain boundary network does not operate as an infinite reservoir to mica—fluid Ar exchange, as required for Dodson closure-temperature behaviour.

A physical model has been built for the accumulation of 40ArE under closed-system conditions. The model characterises the control of variable mica—fluid K_D (10^{-3}—10^{-5}), whole-rock mica abundance, porosity (10^{-6}—10^{-1} vol. fraction) and protolith history on muscovite $^{40}\mathrm{Ar}_E$ concentration. Furthermore, the model provides a means of estimating time-averaged metamorphic porosities from inversion of mica $^{40}\mathrm{Ar}_E$ concentrations. Porosity estimates based on recently published single-grain HP ^{40}Ar/^{39}Ar data from Oman and the Eastern Alps lie between 10^{-6} and 10^{-4} volume fraction, consistent with independent constraints on the mid—lower crustal background porosities. Calculated porosities for mafic rocks are 1—2 orders of magnitude smaller than pelitic lithologies, which is in agreement with the relative difference in devolatisation histories. Phase equilibria calculations show that a typical MORB loses ~25% of mineral-bound H_2O, between the greenschist and eclogite facies, compared to ~47% in the pelitic system. Model results require that the transition between open and closed system behaviour occurs at higher temperature and pressure conditions in pelites than mafic eclogites. This is supported by critical dihedral angle experiments.

The model results show that the accumulation of $^{40}\mathrm{Ar}_E$ may therefore be used a tracer for the time-averaged effects of transient crustal porosity. Furthermore, the results show that the build-up $^{40}\mathrm{Ar}_E$ is controlled by the presence or absence of a connected grain boundary network rather than merely the presence or absence of a fluid phase in the rock.