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# Dating incipient metamorphism using $^{40}Ar/^{39}Ar$ geochronology and XRD modeling: a case study from the Swiss Alps

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**Abstract** Six samples of a single carbonate-rich unit of the Swiss Préalpes, progressively metamorphosed from diagenesis to deep anchizone, yield $^{40}Ar/^{39}Ar$ spectra with variably developed staircase patterns, consistent with mixtures of detrital mica and neocrystallized mixed-layer illite/smectite. The lowest temperature heating steps for different size fractions (2–6 μm and 6–20 μm) converge to ~40 Ma providing an imprecise, maximum age of regional metamorphism. A method is described for distinguishing and quantifying the amount of pre-existing detrital mica versus neoformed illite layer in the illite/smectite formed during Tertiary Alpine metamorphism by comparison of X-ray diffraction patterns with Newmod© simulations. In the least metamorphosed samples the illite/smectite contains ~65% neoformed illite, and this illite accounts for approximately 17% of all dioctahedral phyllosilicate minerals in the rock (e.g., detrital mica and illite/smectite). In contrast, the illite/smectite from the more strongly metamorphosed samples contains >97% neoformed illite, which accounts for ~70% to >90% of all dioctahedral phyllosilicate minerals. Phyllosilicate morphologies viewed by scanning electron microscopy are consistent with these estimates. A process of dissolution/reprecipitation is inferred as a mechanism for the growth of the neoformed phyllosilicates. A plot of neoformed illite content versus $^{40}Ar/^{39}Ar$ total fusion age yields a near-linear curve with an extrapolated age of 27 Ma for 100% neoformed dioctahedral phyllosilicates. This age is interpreted as the time of incipient metamorphism and is consistent with independent biostratigraphic constraints. Model $^{40}Ar/^{39}Ar$ age spectra constructed with the XRD simulation results correspond well to the experimental data and illustrate the changes in degassing properties of progressively metamorphosed mixtures of detrital mica and neoformed illite.

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## Introduction

Isotopic dating of phyllosilicates in very low grade metamorphic rocks by K/Ar or $^{40}Ar/^{39}Ar$ methods is strongly dependent on the ratio of detrital mica versus authigenic (neoformed) mixed-layer illite/smectite present in the separated size fraction (see review in Clauer and Chaudhuri 1995). With increasing depth in sedimentary basins (burial metamorphism) K/Ar ages of phyllosilicate fractions decrease together with a corresponding increase in illite content within the mixed-layer illite/smectite (e.g., Perry 1974; Aronson and Hower 1976; Glasmann et al. 1989). Furlan et al. (1996) have also shown that the magnitude of the apparent age decrease is lithology dependent and is greater in sandstones than in shales. Very low grade regional metamorphic rocks represent a natural extension of metamorphism occurring in sedimentary basins, but the size of neoformed phyllosilicates is generally larger. With increasing illite crystallinity the apparent K/Ar and $^{40}Ar/^{39}Ar$ ages of phyllosilicate fractions generally become younger and the smallest size fraction is generally the youngest (e.g., Hunziker et al. 1986; Reuter 1987; Reuter and Dallmeyer 1989; Brockamp et al. 1994).

For the special case where no detrital mica or illite is present, such as in pure sandstones or bentonites, the effects of diagenesis producing illite/smectite can result in increasingly older apparent ages with depth (e.g., Hamilton et al. 1989; Matthews et al. 1994; Velde and Renac 1996). The geological significance of such ages is strongly dependent on the duration of the transformation(s) and the continuous production of illite with depth (Clauer et al. 1997). In a porous medium like sandstone or hydrothermal systems, illite crystallization is facilitated and can be extremely rapid (Barnes et al. 1992; Matthews et al. 1994; Bonhomme et al. 1995; Clauer et al. 1997).