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# Rb–Sr ages from phengite inclusions in garnets from high pressure rocks of the Swiss Western Alps

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## ABSTRACT

The Zermatt-Saas Fee Zone (ZSZ) was subducted to eclogite-facies conditions, reaching peak pressures and temperatures of 20–28 kbar and 500–630 °C. The rocks were partially overprinted under greenschist-facies conditions during exhumation. Previous Rb–Sr isochron ages obtained on matrix phengites in metasediments of the ZSZ have been interpreted to date early exhumation of the ZSZ. Here we present new Rb–Sr geochronology on phengite inclusions in garnets to date prograde growth of garnets. We show that garnet acted as a shield for the included phengites, limiting Rb and Sr isotope exchange with the bulk rock, upon complete enclosure of the mica, during garnet growth, even if peak metamorphism exceeded the Rb–Sr blocking temperature. Similarly, garnet isolated the micas from the matrix during subsequent recrystallization due to fluid infiltration or deformation during exhumation. Phengite inclusion ages for two metapelitic samples from the same locality (Triftji) are 44.86 ± 0.49 Ma and 43.6 ± 1.8 Ma, and are about 4 m.y. older than the corresponding matrix mica ages of 40.01 ± 0.51 Ma and 39.5 ± 1.1 Ma, respectively. The results confirm previous Sm–Nd and Lu–Hf geochronology on the ZSZ that indicated protracted garnet growth during prograde metamorphism, and confirm that at least parts of the ZSZ underwent peak metamorphic HP conditions less than 43 m.y. ago, followed by rapid exhumation to upper greenschist-facies conditions around 40 Ma ago.

## 1. Introduction

Understanding the time-temperature pathways of prograde metamorphism has been a long-standing goal of studies in orogenic belts. Garnet is common in the metamorphic assemblage in metamorphic mafic and metasedimentary rocks in Barrovian and subduction zone metamorphism, and hence has been targeted by quite a few geochronological studies (e.g. Baxter and Scherer, 2013). Garnet often grows along a prograde path (e.g. Spear, 1993), and major-element zoning patterns may retain information on the pressures and temperatures attained during the prograde history. The advances made in Lu–Hf and Sm–Nd geochronology of garnet (e.g. Lapen et al., 2003; Skora et al., 2006; Harvey and Baxter, 2009; Baxter and Scherer, 2013) have made direct dating of some garnets possible, thus permitting reconstruction of the timing of prograde metamorphic events relating specific geochronological data to periods of garnet growth. Garnet growth rates have been inferred from modelling of Lu–Hf and Sm–Nd and other REEs (Lapen et al., 2003; Skora et al., 2006, 2009) or by direct dating of rim and core (Pollington and Baxter, 2011; Dragovic et al., 2012). Although these isotopic systems have contributed greatly to our understanding of the timescales of garnet growth during prograde metamorphism, age errors are generally fairly high for these isotopic systems in contrast to other isotopic systems where the parent/daughter ratios may be quite high, such as the Rb–Sr isotopic system. In the case of garnet, however, Rb–Sr geochronology of garnets has rarely been utilized, because Sr concentrations in garnet are low and its Rb/Sr ratio is relatively small, making direct dating of garnet extremely difficult (e.g., Christensen et al., 1994, 1989; Vance and O'Nions, 1990; Kohn, 2009; Sousa et al., 2013).

Potassium-rich, high Rb/Sr phases such as mica, alkali-feldspar or even amphiboles have been successfully used to constrain the time of mineral growth. Isotopic resetting due to diffusive exchange or recrystallization during deformation and fluid flow can overprint the age of prograde crystallization of white micas. Therefore Rb–Sr mica ages often represent exhumation ages. Here we propose a new approach: the use of the Rb–Sr system to determine garnet growth timing by dating phengite inclusions in the garnet. Since diffusion in garnet is generally considered to be slow, this will likely prevent re-equilibration with matrix minerals, if micas

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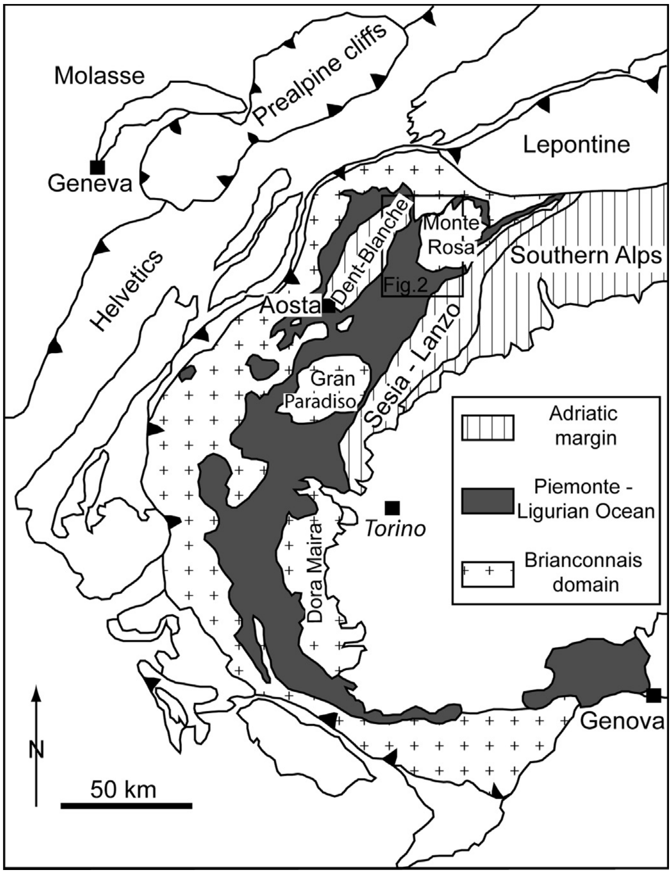

**Fig. 1.** Tectonic map of the Western Alps. The Zermatt-Saas Fee Zone (ZSZ) (see Fig. 2) is a lithologically defined unit within the northern end of the Piemonte-Ligurian oceanic basin. It underwent eclogite facies metamorphism. After Barnicoat and Fry (1986).

are entirely enclosed within garnet. This will result in an apparent increase in temperature for the Rb–Sr "closure", approaching the closure temperature of garnet for Rb–Sr dating. The concept of a texturally controlled shielding of minerals as a means for preventing isotopic resetting has been used amongst others by Montel et al. (2000), who showed that monazite does not exchange if it is shielded by garnet even well above its "Dodson closure temperature". Gouzu et al. (2006) applied Ar/Ar *in situ* geochronology on phengite included in garnet of the Lago di Cignana locality in the Zermatt-Saas Fee Zone (ZSZ; see Fig. 2). They found that the inclusions are about 6 m.y. older than the matrix phengites, in agreement with the shielding concept discussed above.

The study area is the Zermatt-Saas-Fee Zone (ZSZ) in the Western Alps (Figs. 1 and 2). The ZSZ is composed of deeply subducted rocks that were subjected to eclogite-facies metamorphism. Whereas the mafic eclogitic rocks have been the focus of much dating activity (e.g. Rubatto et al., 1998; Lapen et al., 2003; Gouzu et al., 2006; Skora et al. 2006, 2009), only a few attempts have been made to date the high-pressure peak metamorphic assemblages of the associated metasediments (e.g. Rubatto et al., 1998). Here, we analyzed metasediments containing garnets with phengite inclusions. The metasediments are part of the ZSZ, which are included in – and contain – eclogites. These rocks provide an ideal test case for the use of Rb–Sr geochronology on phengite inclusions for determining the timing of garnet growth.

## 2. Sample selection and analytical techniques

Garnet-bearing metasediments of the ZSZ were collected and characterized by micro-computed X-ray tomography ($\mu$-X-CT) and electron microprobe analysis (EMPA). Samples were selected on the basis of the following criteria: 1) most garnets contain several white mica inclusions per grain 2) mica inclusions are phengites, rather than paragonites; and 3) garnet porphyroblasts are not fractured or strongly poikilitic. For each sample the crystal size distribution and the general shape and amount of garnet fracturing was determined on a representative volume of the sample from 3D-images reconstruction from $\mu$-X-CT. Qualitative and quantitative chemical analyses of mica inclusions were obtained by EMPA on thin sections to evaluate the textural context and chemistry of the white mica. Only samples containing phengite inclusions isolated from the matrix were selected on the basis of both 3D tomography images and 2D thin sections.

*Mica inclusions.* Entire garnet crystals were separated from samples using a Selfrag$^{\mathrm{Tm}}$ electro disintegrator at the University of Bern. Selfrag$^{\mathrm{Tm}}$ fractures the rock samples mostly along grain boundaries using high-energy electrical discharges. Garnet grains, along with the other minerals grains, are mainly obtained as whole crystals. About $\sim$2 kg of each sample were disintegrated. The fragmented material was wet sieved into several fractions ($>$4 mm, 2–4 mm, 1–2 mm and 0.5–1 mm) and dried in an oven at 60 °C. Garnets were handpicked from each of those fractions. The garnet fractions were separated into poikilitic and non-poikilitic fractions when both textures occurred in the sample. For sample 09CDM105 all of the garnets, and for sample 09CDM110 only the non-poikilitic garnets were selected for further processing. Garnets bigger than 2 mm were mechanically abraded by packing them into small plastic tubes filled with water and the tubes placed into a shaker apparatus (see Supplementary Materials for images of garnets before and after abrasion). This procedure removes the outermost rim of the garnet, together with any attached micas. The garnets were checked under a binocular after 15–30 min for attached mica grains and the process was repeated until all external mica was removed. Up to two hours of shaking was required. Only those garnets without any visible micas or other minerals at their surface or in cracks were selected for further processing.

Phengite inclusions were extracted by crushing the cleaned garnets in a steel hand crusher followed by handpicking under a binocular microscope. A total of 0.2 to 2.1 mg of white mica was obtained for each sample. The size of the included micas varies from less than 100 μm (sample 09CDM105) to a maximum size of $\sim$300 μm (sample 09CDM110). The chemical sample selection procedure (e.g. EMPA) ascertained that these micas were mainly phengite, with less than 10% paragonite.

*Matrix minerals.* The fragmented, wet sieved fraction smaller than 600 μm was further dry-sieved and separated into four size fractions of 600–500 μm, 500–400 μm, 400–300 μm, and 300–180 μm. Matrix minerals (zoisite and tourmaline) were hand-picked from the whole rock fractions under a binocular microscope. White mica was magnetically separated from the whole rock fractions using a Frantz separator. A second pass in the Frantz magnetic separator and hand picking under a binocular microscope was necessary to increase purity of the phengite separates.

*Rb and Sr analysis.* All Rb–Sr isotope analyses were performed at the University of Wisconsin-Madison using a Micromass *Sector 54* thermal ionization mass spectrometer (TIMS). Samples were spiked using a mixed $^{87}$Rb–$^{84}$Sr spike that was calibrated against multiple normal solutions to determine Rb and Sr concentrations by isotope dilution mass spectrometry (IDMS) and dissolved in a 10:1 HF:HNO$_3$ solution. Rubidium and strontium were subsequently purified using EiChrome Sr-specific resin and HNO$_3$ to obtain a pure Sr cut, followed by purification of Rb using BioRad AG MP-50 macroporus cation exchange resin with 2 M HCl (e.g. Beard et al., 2013). Strontium was loaded onto Re filaments with a TaF activator