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AGE VARIATIONS IN A DEFORMED TONALITE: A CASE STUDY FROM THE NORTH PATAGONIAN BATHOLITH

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INTRODUCTION

The timing of a deformation and/or heating event that has affected a particular rock is usually based on radiometric dating techniques. These do not usually take into account how deformation can modify closure temperatures and isotope diffusion and affect the way in which isotopes move through rocks and minerals. The traditional belief that isotope migration occurs mainly by volume diffusion strongly activated by temperature (1) commonly ignores that other controlling factors and mechanisms of transport may play a significant role during the deformation history of the rock (2). Grain size reduction promoted by deformation not only changes grain sizes and shapes but also creates new pathways to diffusion and new surfaces to chemical reactions. Dislocation glide drives isotopes through the subgrain network to the boundaries where a particular isotope may be released from its original grain. Those are just examples of a complex and still not well understood picture where grain size and grain shape control their closure temperatures and diffusion paths could be strongly controlled by microstructure.

The laserprobe argon dating technique has been employed to study argon distribution within several K-bearing metamorphic rocks from diverse geological settings in order to reassess metamorphic and deformation histories (2, 3, 4, 5, 6, 7) . The high spatial resolution achieved by this technique enables to run argon measurements within individual grains with control of their microfabric and location, overcoming problems related to rock heterogeneity (8). It can also assess the potential problem of excess argon incorporated into the rock during deformation. Combining this technique with orientation contrast images of the grain and subgrain network of the rock(9), a complete characterization of mineral fabric and age relationships are obtained. Those results have increased our understanding about argon migration and age interpretation, though they are still at the forefront of knowledge.

In this contribution, we use the argon technique to date deformed rocks from the southern Andean margin. We selected a meter-wide ductile shear zone of the North Patagonian Batholith, which shows a variable picture of apparent ages but with a well-constrained U-Pb crystallization age (10). One sample from this unit has been studied with SEM and $^{40}Ar/^{39}Ar$ laserprobe techniques, both tools combined in order to recognize the factors which control the variation and distribution of apparent ages, constrain the absolute age of deformation and thermal history of this unit.

GEOLOGICAL SETTING

The southern Andes accommodate transpressional dextral deformation along the Liquiñe Ofqui Fault Zone (LOFZ), an intra-arc Cenozoic duplex within the Meso-Cenozoic North Patagonian Batholith (NBP)(11, 12). Dextral transpression has been driven either by oblique subduction or ridge collision. Ductile dextral shear occurred during late Miocene-Pliocene time (13-3Ma) with brittle shear occurring after 3 Ma(13).

A tonalitic pluton of the BNP located at 42ºS, which is spatially related to one of the main traces of the LOFZ (13), has subparallel magmatic subsolidus fabric that indicates that dextral shear was probably continuous from emplacement through cooling under greenschist facies conditions. The emplacement age is 9,9 Ma and single crystal total fusion Ar-Ar ages of biotite range from 8.7 to 3.6 Ma (14) reflecting solid-state deformation and/or cooling following deformation (14). Previous high resolution laser dating of a deformed sample from this unit constrained the age of a regional deformation event that took place between 6 and 4,3+-0,3 Ma linked by Cembrano (14) to subduction of consecutive segments of the Chile Ridge.

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SAMPLE PREPARATION AND DESCRIPTION

The sample was prepared as a 6-cm square, 9-mm thick section to produce a 30-µm thin section and 2mm thick section. The thin section was studied under the light optical microscope and the SEM. The thick section was analyzed by using SEM to obtain a picture montage of the slab made up with backscatter atomic number contrast and forescatter orientation contrast images. For Ar methodology, the thick section was then prepared as 1-cm square, 250-µm thick polished section. Following irradiation, the sample was loaded into an ultra-high vacuum laser port with polished side up. The laser port was put under a heat lamp overnight to reduce atmospheric argon from sample surfaces.

The sample is a coarse-grained protomylonitic hb-bt tonalite. The schistosity is defined by aligned plagioclase crystals, flattened interstitial quartz and aligned aggregates of hornblende and biotite with grain sizes ranging from 0.1 to 5.5 mm. Centimeter-spaced shear bands transect the main foliation indicating dextral shear sense. Relatively less deformed specimens have a set of short shear bands nucleated within mafic (hb+bt) domains with a similar orientation. Shears bands show subhorizontal stretching lineations.

SEM work has revealed a complex intragrain structure of the igneous minerals. Hornblende shows corroded boundaries, fractures, fluid inclusion trails and a complicated intragrain structure. Structure of hornblende consists of different and separate domains with sharp and/or diffuse boundaries and with/without intradomain variations apparently randomly distributed. They also have inclusions of biotite and feldspar. Plagioclase behavior is brittle with frequent fluid inclusion trails and no intragrain variations, whereas K-feldspar shows a complex structure similar to that developed in amphibole. Biotite is intergrowth with amphibole and shows frequent subgrains. Large grains pass laterally to smaller grains towards the shear zones suggesting grain size reduction. Larger biotite shows small amount of slip along their basal cleavage, which is parallel to the main foliation. Quartz shows heterogeneous fabric with a wide range of crystal sizes ranging from < 0.1-2.5 mm. Grain size decreases towards the shear bands. Larger grains show irregular grain boundaries with undulose extinction and show elongate subgrains, which pass laterally into domains of smaller dynamically recrystallized grains. The microstructure present in this sample shows a heterogeneous picture of conditions of deformation (greenschist facies) and cannot constrain better deformation temperatures.

RESULTS

Fifteen analyses of biotite and amphibole were extracted using a focussed infrared laser producing melt pits around 100-150 microns in diameter. The analyses of amphiboles yielded ages in the range 49.9±0.3 Ma to 280±1.6 Ma, older than the known intrusion age of the original igneous protholiths. Laser pits in biotites yielded ages in the range 3.7±0.1 Ma to 10.3±0.5 Ma. All Ar-Ar analyses yield information not only on the age but also the chemistry of the analyzed sample, in particular the Ca/K ratio of the analyzed volume can be determined rapidly from the $^{37}Ar/^{39}Ar$ ratio. Biotites generally have little or no calcium and thus yield very low $^{37}Ar(Ca)/^{39}Ar(K)$. Amphiboles have much higher $^{37}Ar/^{39}Ar$ ratios and tend to be more variable reflecting Ca and K zonation what explains amphibole analyses yielding ratios of 2.9 to 12.7. The analyses of biotite however show a range of $^{37}Ar/^{39}Ar$ values indicating that in fact despite the intention to analyze pure biotite, amphibole was also involved in many of the analyses. Clearly although the surface of the rock slice was biotite, at depth the laser was also melting amphibole. As a rough guide, the laser pits are as deep as they are wide. A mean of the younger ages yields 4.5±0.5 Ma. The age variation can not simply be described in terms of a mixture of amphiboles containing excess argon and biotites with no excess argon. Although there is a good correlation between $^{37}Ar/^{39}Ar$ and age, there are high 37Ar/39Ar analyses, which yield low ages and samples with low $^{37}Ar/^{39}Ar$ yielding ages significantly older than 4.5 Ma. This seems to indicate that some of the amphibole contains little or no excess argon, probably small grains of the edges of large grains and that some of the biotites have incorporated excess argon. There is no obvious correlation between position relative to the shear bands and the age produced from biotite. The SEM montage seems to show that some are in the shear band and yield ages ranging from 4.3±0.3 Ma to 8.5±0.4 Ma. Whereas those analyses out of the shear yield ages in the range 3.7±0.1 Ma to 10.3±0.5 Ma.

CONCLUSIONS

Isotope analyses in a deformed tonalite shows inter and intragrain age variations which cannot being explained by volume diffusion through the different mineral grains. There is no clear relation between age and grain size in both amphibole and biotite grains. It seems that subgrain network controlled argon removal or supply along the subgrain boundaries. Old ages yielded in amphibole are older than original igneous precursor. This can be explained by diffusion of excess argon into the grains. Biotites yielded ages in the range 3.7±0.1 Ma to 10.3±0.5 Ma, variation probably due to excess argon leaking from the amphiboles during deformation. Temperature subsequently dropped rapidly through closure temperatures in order to keep the age difference. Deformation and subgrain formation probably occurred above the closure temperatures, therefore apparent ages represent cooling rather than deformation ages.

Our results confirm that deformed rocks show very complex isotopic patterns at the grain scale. This fact has to be taken into account when trying to date deformation in mylonitic rocks, otherwise apparently consistent results can be misleading and with no geological meaning. By combining SEM microstructural studies and Ar laserprobe analysis it is possible to better understand the geologic significance of isotopic age variations at the sample and intra-grain scales.

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