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Ar-Ar dates for two different stages of the Variscan D3 recorded in metapelites of Serra da Freita (North-Central Portugal)

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Introduction

The Serra da Freita area lies in north-central Portugal, to the south of the town of Arouca. This region is part of the Central-Iberian Zone, one of the major geotectonic units of Iberian Variscan Chain. The main geological units cropping out in Serra da Freita are: (1) pre–Ordovician metasedimentary rocks of the "Slate-Metagreywacke Complex"; (2) syn- and late-D3 Variscan granitoids. Reavy (1987) attributed to the so-called Serra da Freita pluton (syn-D3 two-mica granite) an emplacement age of 324±4 Ma, based on whole-rock Rb-Sr analyses. However, in prolongations of the same granite body to south and southeast, different results have been obtained: a 315±3 Ma whole-rock Rb-Sr isochron (Priem *et al*., 1984) in a porphyritic facies to the southeast of Serra da Freita; and a 308 Ma U-Pb zircon and monazite age (Azevedo *et al*., 2003) on a sample collected to the south of the area of the present study.

In this work, new geochronological information, obtained by Ar-Ar dating of mica grains from metasediments, is presented and discussed.

Deformation and metamorphism in the Serra da Freita area

Three deformation phases (D1, D2 and D3) have been recognized in the Serra da Freita area. In low grade metapelites (slates and phyllites), the most penetrative tectonic structure is S1 slaty cleavage, which is usually disturbed by D3 asymmetric folds. In amphibolite facies micaschists, S2 and S3 planes are the most relevant tectonic anisotropies. Tardi-D3 transcurrent sinistral movements affected S1, S2 and S3 pla-

nar anisotropies, generating conspicuous S-C structures in both metasediments and granite.

Mapping of the metamorphic zonality, petrographic and microstructural observations, and mineral chemistry data show that the Variscan regional metamorphism: (a) is of low-pressure / high-temperature type, with mineral parageneses containing andalusite in medium and high grade metamorphic zones; (b) led to the formation of a prograde sequence (chlorite zone → biotite zone → staurolite-andalusite zone → sillimanite zone) marked by dehydration reactions; (c) is practically isobaric; (d) occurred mainly during two major blastesis events. The earlier metamorphic episode was contemporaneous of D2 and, in medium grade metapelites, it was characterized by the simultaneous growth of staurolite and andalusite. The second event is syn- to tardi-D3 and its most relevant consequences were the partial breakdown of staurolite (St+Ms+Qtz → And+Bt+H_2O), within the stability field of andalusite, and the formation of sillimanite at expenses of andalusite and staurolite, in areas that were submitted to higher temperatures.

However, locally, within staurolite-andalusite and sillimanite zones, the regional metamorphic sequence, marked by prograde dehydration reactions, is interrupted by parageneses including kyanite. These discontinuities correspond to areas where S3 and S-C structures are important and intense fluid circulation took place. The very significant role of an aqueous phase during blastesis in these domains is testified by the high density of syn-D3 metamorphic quartz veins, the presence of syn- and tardi-D3 quartz poeciloblasts and the modal importance of hydrous minerals (mainly muscovite).

Kyanite occurring in the strongly hydrated metapelites and in quartz veins is not a relic phase, since it replaces syn- to tardi-D3 andalusite and seems to be in textural equilibrium with both muscovite and a second generation of staurolite (resulting from partial breakdown of andalusite and biotite).

This anomalous metamorphic episode, of local extension, was probably a late Variscan event and seems to be related to an increase of ductility - and therefore an increase of mean stress - caused by the formation of hydrous minerals during fluid ascent along a shear zone. The fluids responsible by the development of the strongly hydrated parageneses probably resulted from devolatilization reactions in the sillimanite zone.

Ar-Ar muscovite and biotite ages

In order to attempt to further constrain the age of the Variscan tectonic and metamorphic episodes, biotite and muscovite from two well characterized rocks of the Serra da Freita area were selected for ^{40}Ar-^{39}Ar dating.

Mica grains from two samples of micashists collected in the sillimanite zone (155-

217) and in the kyanite domain of the staurolite-andalusite zone (SF-1) were used for Ar-Ar dating.

Sample 155-217 – sillimanite zone

Sample 155-217 was collected near the sillimanite isograd and displays the mineral assemblage quartz + muscovite + biotite + andalusite + staurolite + sillimanite $\pm$ plagioclase + opaques + zircon.

The most penetrative anisotropy is S2, but it was crenulated during D3. The geometry of the microstructures corresponds to stages 3 and 4 of the scheme for crenulation foliation development proposed by Bell & Rubenach (1983). The S2 foliation is defined by the preferred orientation of biotite and muscovite. Mica grains are also found bent, strained and, sometimes, oriented parallel to the axial planes of D3 microfolds. There is also evidence for late partial replacement of biotite by muscovite.

Andalusite and staurolite occur commonly as poeciloblasts that grew mainly during the early stages of D3, since they have inclusions defining microfolded Si (S2) but the external foliation may be wrapping around the poeciloblasts and appear flattened close to their limits.

Sillimanite is usually associated to biotite, forming needles and small prisms that may be either slightly deformed - in the hinges of D3 microfolds - or undeformed and parallel to the axial planes of the microfolds.

The described features suggest that the peak metamorphic conditions were attained during the early stages of the third Variscan deformation phase.

$^{40}Ar/^{39}Ar$ measurements on biotite from this sample yielded a well defined plateau. The plateau age, the total fusion age and the inverse isochron age are all concordant. Therefore, the weighted mean plateau age of 333.5 ± 4.4 Ma may be assumed as a reliable geochronological datum.

In this sample the blastesis of biotite occurred essentially during D2. However, since the metamorphic peak took place during D3 folding, the 333.5 ± 4.4 Ma age is interpreted as dating the resetting of the K-Ar isotope system in the early stages of D3.

Sample SF-1 – kyanite domain of the staurolite-andalusite zone

This micashist sample was collected in a lenticular domain completely surrounded, in the outcrop plane, by a syn-D3 quartz vein. This quartz vein is parallel to S3 and is affected by late-D3 shear planes. Sample SF-1 is identical to the hydrated metapelites that are close to the outer limits of quartz veins in this metamorphic domain.

The studied sample is composed essentially by: euhedral muscovite crystals - with 1-3

cm length - either oriented following S3, or with no preferred arrangement and cutting D3 structures; euhedral kyanite, that has formed mainly statically (although some crystals shows weakly bent cleavage planes), with parallel intergrowth with euhedral staurolite; andalusite crystals, systematically showing replacement by kyanite. Biotite constitutes only rare relics within muscovite.

Textural relation analysis suggests that muscovite, kyanite, staurolite and andalusite are tardi-D3. The muscovite in this sample is interpreted to be of hydrothermal origin, resulting from reaction between ascending aqueous fluids (produced by dehydration reactions in the sillimanite zone) and the staurolite zone metapelites, in the late stages of the third Variscan deformation phase.

Muscovite grains from this sample were used for Ar-Ar dating. A weighted mean plateau age of 312.8±3.3 Ma - in concordance with total fusion and inverse isochron ages - was obtained. Considering the textural evidence, this geochronological result dates the late-D3 metamorphic event. The 312.8±3.3 Ma agrees, within the error, with recent datation of metamorphism in micashists with S3 foliation and late-D3 shear planes in the Oporto-Tomar shear zone (Acciaioli *et al.*, 2003). This result is also similar to two of the datations of the Serra da Freita granite.

Conclusions

In this work, biotite and muscovite from two samples were dated by the Ar-Ar method. Biotite from a sample where the last recorded metamorphic event was of an early D3 stage yielded an age of 333.5±4.4 Ma. In contrast, measurements on muscovite that resulted from fluid ascent during the late episodes of D3 gave a result of 312.8±3.3 Ma. Therefore, the third Variscan phase must have operated during a significant period: at 335-330 Ma folding of the previous structures was taking place, whilst at *ca*. 310 Ma major late-D3 shear zones were active.

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