Estrutura interna do maciço granítico de Lusinde: aplicação da técnica de anisotropia de suscetibilidade magnética

Internal structure of the Lusinde granite massif: application of the technique of anisotropy of magnetic susceptibility

Portela, L.[1], **Ferreira, D.**[1], **Medina, J.**[1], **Valle Aguado, B.**[1], **Azevedo, M.dR.**[1]

[1] Universidade de Aveiro, Departamento de Geociências; GeoBioTec (UID/GEO/04035/2020), 3810-193 Aveiro, Portugal; luispedroportela@ua.pt

Resumo

O granito biotítico de Lusinde constitui um pequeno maciço Varisco tardi-pós-tectónico, instalado na extremidade ocidental da Zona de Cisalhamento de Juzbado-Penalva (ZCJP). Este trabalho teve como objetivo aplicar a técnica de anisotropia de suscetibilidade magnética para melhor compreender a estrutura interna do maciço e a sua instalação. O maciço apresenta valores relativamente baixos de suscetibilidade magnética (K_m = 102 × 10^{-6} a 536 × 10^{-6} SI), o que o permite incluir na série dos granitos com ilmenite, em que a biotite é a principal fase portadora do sinal magnético. As foliações magnéticas, com pendores elevados, tendem a dispor-se paralelamente às margens da intrusão. As lineações magnéticas, com direções variáveis e pendores elevados, sugerem que todo o maciço possa corresponder a um canal de alimentação. Com efeito, o plutão estudado parece fazer parte da faixa E-W de lineações subverticais que limita a norte a massa principal do granito de Cota-Viseu e os corpos de rochas básicas e intermédias a ele associados. Esta faixa foi interpretada como um alinhamento de zonas de alimentação relacionado com a terminação extensional da ZCJP, levando a concluir que a implantação do maciço de Lusinde foi tectonicamente controlada por este acidente.

Abstract

The Lusinde biotite granite constitutes a small late-post-tectonic Variscan massif, emplaced along the western termination of the Juzbado-Penalva Shear Zone (JPSZ). The main objective of this work was to apply the technique of anisotropy of magnetic susceptibility to better understand the internal structure and emplacement of the Lusinde massif. The Lusinde granite shows relatively low values of magnetic susceptibility (K_m = 102 × 10^{-6} to 536 × 10^{-6} SI), typical of granites of the ilmenite series in which biotite is the main carrier of magnetic signal. Magnetic foliations are steeply plunging and strike subparallel to the pluton irregular margins. Magnetic lineations show rather variable directions and steep plunges, suggesting that the whole massif may correspond to a feeder zone. The studied pluton seems to belong to an E-W band of steep lineations traced along the northern border of the main mass of the Cota-Viseu granite and associated mafic and intermediate rocks, which has been interpreted as an alignment of feeder zones related to the extensional termination of the JPSZ. As a result, it is concluded that the emplacement of the Lusinde granite was tectonically controlled by the Juzbado-Penalva Shear Zone.

Palavras-chave: *granitos Variscos tardi-pós-colisionais, anisotropia de suscetibilidade magnética, Zona Centro-Ibérica*

Key words: *Late-post collisional Variscan granites, anisotropy of magnetic susceptibility, Central Iberian Zone*

Introduction

In recent decades, the technique of anisotropy of magnetic susceptibility (AMS) has revealed to be a useful tool for characterising the internal structure of igneous massifs. This technique becomes particularly helpful in the study of plutonic rocks with no significant evidence of tectonic deformation, where application of traditional methods of structural analysis may be troublesome (Bouchez, 1997). In this work, we present the results of an AMS survey conducted on a small, irregular pluton of fine-grained late-post-kinematic granitoids, cropping out around the Lusinde locality, in the Viseu-Fornos de Algodres region (Central Iberian Zone; Fig. 1).

Geological setting

The Viseu-Fornos de Algodres region is located in the Central Iberian Zone (CIZ) of the Iberian Massif. It comprises voluminous intrusions of syn- to late-post-kinematic granitoids emplaced into metasediments of Ediacaran-Cambrian age

of the Schist and Greywacke Complex (SGC), during or immediately after the last Variscan ductile deformation event (D_3). In the study area, the late-post-D_3 granitoids are dominant and range from coarse porphyritic biotite granites and minor bodies of basic and intermediate igneous rocks to biotite- and biotite-muscovite granites of variable grain size and highly differentiated muscovite granites (Fig. 1; Azevedo & Nolan, 1998).

As shown at the inset of Figure 1, the Viseu-Fornos de Algodres area is transected by two major subvertical, D_3 shear zones: the ENE-WSW sinistral Juzbado-Penalva Shear Zone (JPSZ) and the NW-SE trending, sinistral, Douro-Beira Shear Zone (DBSZ) (*e.g.*, Iglesias & Ribeiro, 1981; Valle Aguado *et al.*, 2005).

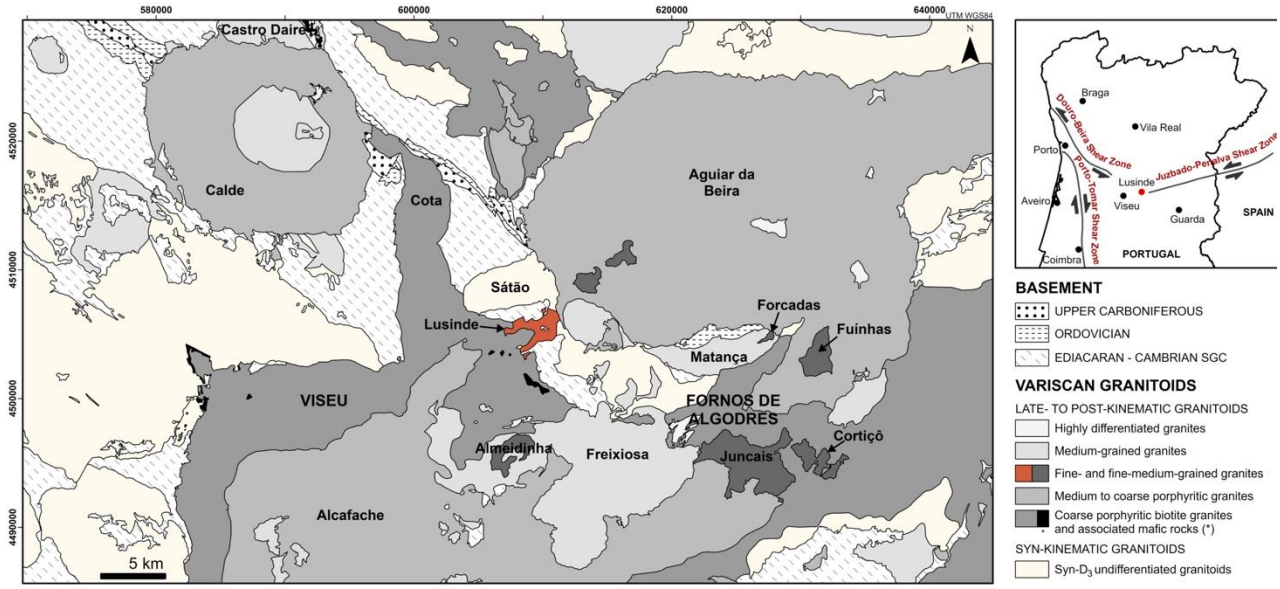

Figure 1: Geological sketch map of the Viseu-Fornos de Algodres area. The studied intrusion is represented in red. Inset on the right shows the major regional shear zones of Central-Northern Portugal and the location of the study area.

The Lusinde biotite granite

The Lusinde massif is a small (*ca*. 6 km^2), irregular, late-post-kinematic granite intrusion (Fig. 1). The granite contacts to the north and south with metasediments of the SGC. To the west, it is bounded by the Cota-Viseu coarse porphyritic biotite granite and to the east by the Aguiar da Beira medium porphyritic biotite-muscovite granite (Fig. 1). Contacts between the Lusinde granite and the adjoining intrusions vary from sharp to gradational. The presence of gradational contacts with the Cota-Viseu coarse porphyritic biotite granite, as well as the general increase in grain size and abundance of K-feldspar megacrysts along the western boundary of the Lusinde granite suggest a roughly coeval emplacement for the two intrusions (*ca*. 298 Ma; Valle Aguado *et al.*, 2017).

In the field, the Lusinde granite is characterised by a dark-blueish appearance, occurrence of clusters of lath-shaped biotite and presence of sparsely distributed K-feldspar megacrysts, mostly in the range of 1 to 3 cm (up to 6 cm). The granite does not show any evidence of tectonic deformation, although it may exhibit some planar alignment of K-feldspar megacrysts, particularly at the pluton margins. Rounded to ellipsoidal mafic microgranular igneous enclaves and angular dark xenoliths of metamorphic wall-rock of various sizes are unevenly distributed throughout the massif. One large, mappable microgranular igneous enclave (site 3; Fig. 2a) contains amphibole, pyroxene and titanite in addition to biotite as mafic phases.

Petrographic observations show that the Lusinde granite tends to display a fine-grained non-porphyritic texture and a primary mineral assemblage consisting of quartz + plagioclase + K-feldspar + biotite + apatite + zircon + monazite + ilmenite + allanite + pyrite. Biotite is iron-rich (FeO_T = 24.2-30.5 wt. %; average 29.0 wt. %; $Fe_T/(Fe_T+Mg)$ = 0.70-0.86; average 0.84), explaining the strongly ferroan geochemical signature of the studied granite ($FeO_T/[FeO_T+MgO]$ = 0.90 to 0.92).

Methodology

Oriented rock samples from 13 locations were collected for AMS study (Fig. 2a). At each site, three to four oriented cores were drilled. Sample preparation and AMS measurements were carried out at the Faculty of Sciences of University of

Porto, using a Kappabridge KLY-4 susceptometer (AGICO, Brno). The obtained data were statistically assessed using the ANISOFT (version 5.1.08) software package (Chadima et al., 2020).

Results

Microstructural observations

The Lusinde biotite granite is characterised by a generalised absence of solid-state deformation fabrics either at a mesoscopic or microscopic scale. Prevalence of magmatic microstructures is attested by the occurrence of large, rounded quartz grains with some undulatory extinction. However, undulose extinction of quartz grains becomes more widespread to the southeast and, although rare, submagmatic microstructures such as subgranulation may be observed. No signs of biotite deformation or preferential alignment have been identified in the studied thin sections.

Magnetic susceptibility magnitudes

Mean bulk magnetic susceptibility (K_m) magnitudes are generally low, ranging from 102×10^{-6} to 271×10^{-6} SI, with one sample exhibiting a much higher value of 536×10^{-6} SI (mafic igneous enclave of site 3; Fig. 2a).

The range of K_m values observed in the majority of the analysed samples ($\leq 271 \times 10^{-6}$ SI) are typical of paramagnetic granites having biotite as the main magnetic carrier (Bouchez, 1997). The presence of a much higher K_m value in site 3 can be attributed to the occurrence of higher amounts of biotite and some amphibole and pyroxene. Nevertheless, all samples from the studied massif belong to the ilmenite-type granite series ($< 3.0 \times 10^{-3}$ SI) of Ishihara (1977).

It is worth noting that the measured K_m magnitudes for the Lusinde granite are within the interval of values reported for the adjacent Cota-Viseu granite ($K_m = 200 \times 10^{-6}$ to 450×10^{-6} SI; Valle Aguado *et al.*, 2017) and consistently higher than the published K_m values for the biotite-muscovite granites of Matança-Esmolfe (22×10^{-6} to 111×10^{-6} SI; Gonçalves *et al.*, 2020) and Aguiar da Beira (54×10^{-6} to 132×10^{-6} SI; Sant'Ovaia *et al.*, 2010).

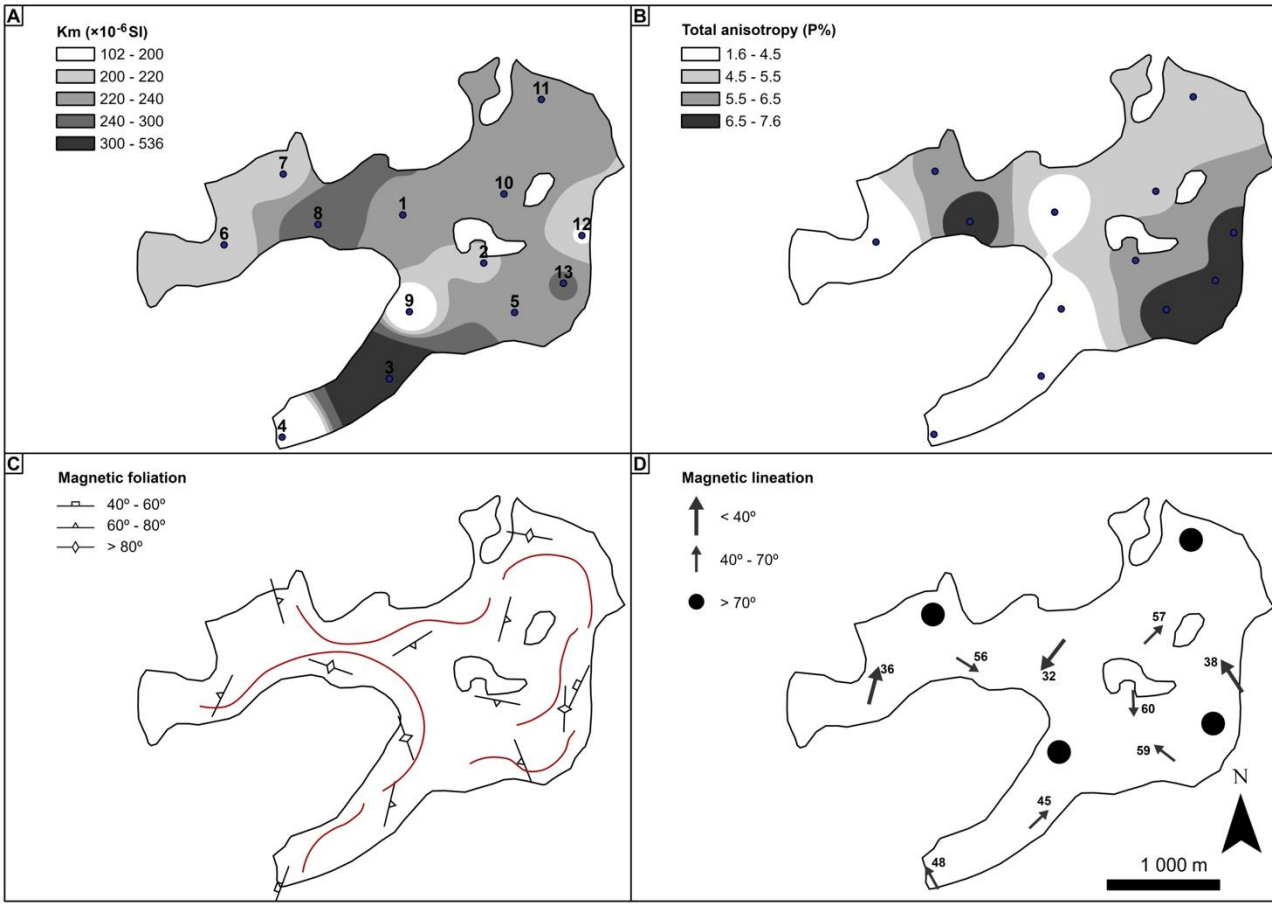

Figure 2: Interpolation (IDW) of AMS data for the Lusinde massif. (A) mean bulk magnetic susceptibility (K_m) and sampling sites; (B) total anisotropy (P%); (C) magnetic foliations (planes perpendicular to K_3 axes) and possible interpretation of foliation trajectories; and (D) magnetic lineations (K_1 axes). All maps are represented at the same scale.

Anisotropy degree and shape parameter

The samples from the Lusinde granite exhibit total anisotropy (P%) values of 1.6-7.6 % (Fig. 2b). P% values define a broad positive correlation with K_m magnitudes, probably reflecting variations in the modal amounts of biotite.

The T shape parameter values vary between +0.153 and +0.881 (oblate ellipsoids) and are not correlated with total anisotropy or bulk susceptibility magnitudes.

Magnetic foliation and lineation

In paramagnetic granites, magnetic foliation and lineation are generally parallel to the mineral fabric (Bouchez, 1997). Magnetic foliations in the Lusinde granite are roughly parallel to the intrusion boundaries. Dips are higher than 40° (Fig. 2c).

Magnetic lineations have variable strikes and are predominantly steeply plunging (> 55°; Fig. 2d) suggesting that the whole pluton may correspond to a feeder zone.

Discussion and conclusions

At map view, the Lusinde massif appears to be part of the E-W corridor of steep lineations traced along the northern border of the main mass of the Cota-Viseu granite and associated mafic and intermediate rocks. This corridor of subvertical lineations has been previously interpreted as an alignment of feeder zones related to the extensional termination of the JPSZ (Fig. 3; Valle Aguado *et al.*, 2017). As such, it is concluded that the emplacement of the Lusinde granite was tectonically controlled by the ENE-WSW trending, sinistral D_3 shear zone - the Juzbado-Penalva Shear Zone.

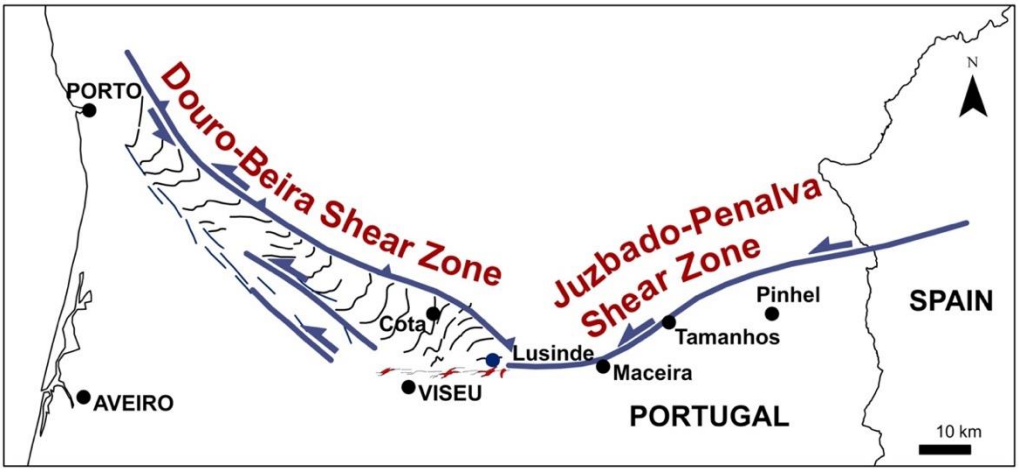

Figure 3: Sketch map of the kinematic context prevailing during the emplacement of the Viseu-Fornos batholith (modified from Valle Aguado *et al.*, 2017). E-W band of steep lineations is represented in red to the north of Viseu city. Dark blue circle symbolises the location of the studied massif.

Acknowledgments

This work received financial support from the Research Centre GeoBioTec (UID/GEO/04035/2020) and a PhD grant (2021.08848.BD), both sponsored by the Portuguese Foundation of Science and Technology (FCT). The authors kindly acknowledge Professor Helena Sant'Ovaia and Doctor Cláudia Cruz for their assistance in the AMS measurements.

References

Azevedo, M.R., Nolan, J. (1998). Hercynian late-post-tectonic granitic rocks from the Fornos de Algodres area (Northern Central, Portugal). Lithos 44, 1-20.

Bouchez, J.L. (1997). Granite is never isotropic: an introduction to AMS studies of granitic rocks. In: Bouchez, J.L., Hutton, D.H.W., Stephens, W.E. (Eds.), Granite: from Segregation of Melt to Emplacement Fabrics. Kluwer, Dordrecht, pp. 95-112.

Chadima, M., Hrouda, F., Jelínek, V. (2020). Anisoft5. AGICO: Brno, Czech Republic.

Ishihara, S. (1977). The magnetite-series and ilmenite series granitic rocks. Mining Geology 27, 293-305.

Gonçalves, A., Sant'Ovaia, H., Ribeiro, M.A., Noronha, F. (2020). The Esmolfe-Matança granite (Penalva do Castelo, central Portugal): A keystone to understand the ascent and emplacement of magmas under low tectonic stress. Journal of Structural Geology 139, 104143.

Iglesias, M., Ribeiro, A. (1981). La zone de cisaillement ductile de Juzbado (Salamanca)- Penalva do Castelo (Viseu): Un linéament ancien reactivé pendant l'orogenese Hercynienne? Comunicações dos Serviços Geológicos de Portugal 67(1), 89-93.

Sant'Ovaia, H., Olivier, P., Ferreira, N., Noronha, F., Leblanc, D. (2010). Magmatic structures and kinematics emplacement of the Variscan granites from Central Portugal (Serra da Estrela and Castro Daire areas). Journal of Structural Geology 32,1450-1465.

Valle Aguado, B., Azevedo, M.R., Schaltegger, U., Martínez Catalán, J.R., Nolan, J. (2005). U-Pb zircon and monazite of Variscan magmatism related to syn-convergence extension in central northern Portugal. Lithos 82, 169-184.

Valle Aguado, B., Azevedo, M.R., Nolan, J., Medina, J., Costa, M.M., Corfu, F., Martínez Catalán, J.R. (2017). Granite emplacement at the termination of a major Variscan transcurrent shear zone: The late collisional Viseu batholith. Journal of Structural Geology 98, 15-3.