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REPSOL

Petrophysical and geochemical characterization of the late-variscan Santa Eulália Plutonic Complex (Ossa-Morena Zone, Portugal)

Caracterización petrophysica y geoquímica del Complejo Plutónico de Santa Eulalia (Zona Ossa Morena, Portugal)

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Resumen: *El Complejo Plutónico de Santa Eulalia es un macizo granítico calco-alcalino, situado en la zona norte de la Zona de Ossa Morena, compuesto de un granito de color rosa de grano medio a grueso (grupo G0) que comparte con grandes y alargadas masas de rocas máficas (gabros) a rocas de composición intermedia (granodioriticas), grupo M, y una zona granítica central gris monzonitica (grupo G1) de grano medio. Mediante un enfoque multidisciplinar, análisis de la ASM y de curvas de Imanación Isoterma Remanente, y de y la geoquímica isotópica, (Nd y ^{18}O), se señalan que las diferencias encontradas en sus comportamientos magnéticos, fabricas magnéticas y geoquímica isotópica, pueden reflejar diferentes procesos petrogénicos asociados a diferentes condiciones redox y emplazamientos de los sistemas graníticos G0, G1 y M.*

Palabras clave: *Anisotropia de susceptibilidad magnética, geoquímica, granitos, imanación isoterma remanente.*

Abstract: *The Santa Eulália Plutonic Complex (SEPC) is a calc-alkaline granitic body located in the northern part of the Ossa Morena Zone, composed by a medium- to coarse-grained pink granite (G0 group) involving large elongated masses of mafic (gabbroic) to intermediate (granodioritic) rocks, M-group, and a central gray monzonitic granite (G1 group) which present dominant medium granular facies. A multidisciplinary study, including petrophysical, AMS and IRM measurements, and geochemical data, elemental and isotopic (Nd and ^{18}O), point out differences in magnetic behaviour, magnetic lineations patterns and geochemical features, reflecting distinct petrogenetic processes at the level of the magmatic sources and evolution, as well as the emplacement mechanisms of M, G0 and G1 facies associated in the SEPC.*

Key words: *Anisotropy of magnetic susceptibility, geochemistry, granites, isothermal remanent magnetization.*

INTRODUCTION

The Santa Eulália Plutonic Complex (SEPC) is a calc-alkaline granitic body that occupies an area of 400 km^2 and is located in the northern part of the Ossa Morena Zone of the Variscan Iberian sector, near the limit of the Central Iberian Zone. SEPC is considered as late-Variscan because it cross-cuts the regional variscan structures (Fig.1). The host rocks of the plutonic complex are composed by metamorphic formations from Upper Proterozoic to Lower Paleozoic. In the NE-sector of the shear zone a metasedimentary Ediacaran unit (Série Negra) outcrops, composed by metasedimentary siliciclastic rocks, including some black cherts. In the SW-sector of the shear zone, a low-grade metasedimentary and metavolcanic unit involving quartz-pelitic, carbonated and volcanic rocks correspond to the Early Cambrian sequence. In the western sector of SEPC, several metasedimentary enclaves are present mainly with pelitic and carbonated composition. The SEPC has two main granitic facies which present different compositions and textures. From the rim to the core, there is a medium- to coarse-grained pink granite (G0 group) involving large elongated masses of mafic (gabbroic) to intermediate (granodioritic) rocks, here designated by M-group, and a central gray monzonitic granite (G1 group) which present dominant medium granular facies being also visible textures with a slight porphyritic tendency close to the contact with G0 granite (Fig. 1). In this work a multidisciplinary approach including Anisotropy of Magnetic Susceptibility (AMS) and Isothermal Remanent

Magnetization (IRM) studies and isotopic geochemistry characterization is presented.

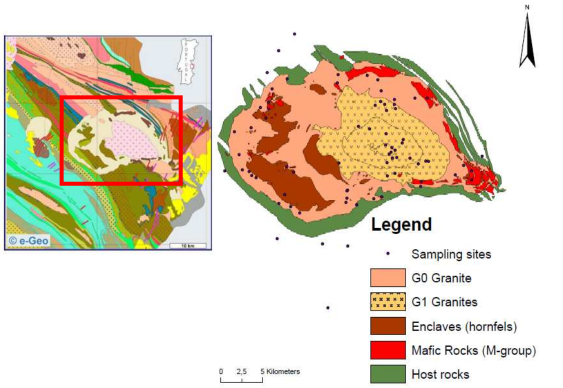


FIGURE 1. *Location of SEPC; sampling sites and mapping of M, G0 and G1 groups.*

MAGNETIC FABRIC

An AMS study was conducted to acquire a magnetic fabric of these granitoids. This study was based on 76 sampling sites where 8 specimens per station were available: 29 sites in G0 facies, 27 in G1 facies, 5 in M-group and 15 in enclaves and host rocks (Fig.1b). The measurements were made in the University of Porto using a KLY-4S Kappabridge susceptometer (AGICO). A sequence of 3 susceptibility measurements along different orientations of each specimen allowed us to compute the orientation and magnitude of the three main axes $k1 \geq k2 \geq k3$ of the AMS ellipsoid. For each site, the AGICO soft-ware enabled us to calculate the mean susceptibility Km and the intensities and orientations of the three axes $K1 \geq K2 \geq K3$, which are its tensorial means. K1, the long axis of the mean ellipsoid, is the magnetic lineation of the site and K3, the short axis, is the normal to the magnetic foliation. P%, the magnetic anisotropy, corresponds to (K1/K3-1)*100 and T, expressed by (2 ln (K2/K3)/ln(K1/K3)-1) is the shape parameter of the AMS ellipsoid.

The Km values range between 41.6 and 7343.7 x 10^{-6} SI in granitic rocks. Two major groups can be established: facies G0, with Km > 10^{-3} SI (mean: 1357.4 x 10^{-6} SI) which supports the presence of magnetite, and the central facies (G1) with Km< 10^{-4} SI (mean: 97.0 x 10^{-6} SI). In the central facies the paramagnetic behavior is due to ferromagnesian minerals, such as biotite, and ilmenite.

In basic rocks from M-group, Km values are homogeneous with a mean of 620.9 x 10^{-6} SI which is typical of gabbros and granodiorites and are due to the high contents of ferromagnesian minerals. In the enclaves and host rocks, Km values range between 55.9 and 717.8 x 10^{-6} SI, with a wide variation due to the different composition of these rocks (Fig.2).

The magnetic anisotropy and the magnetic fabric pattern were characterized only in granitic facies. P% ranges between 1.2 and 18.7% being in mean >5% in facies G0 and <3% in the central facies (G1). The high P% in G0 facies may be caused by the fact that the magnetite, which has a high susceptibility, is the bearer of the magnetic signal. Therefore a weak alignment of magnetite grains leads to a higher anisotropy of the rock. Nevertheless, microscope observations show signs of a post-magmatic deformation in G0. T ranges between -0.354 and 0.768 with the strongest oblate AMS ellipsoids in central facies and the slightly oblate in G0 (Fig.3).

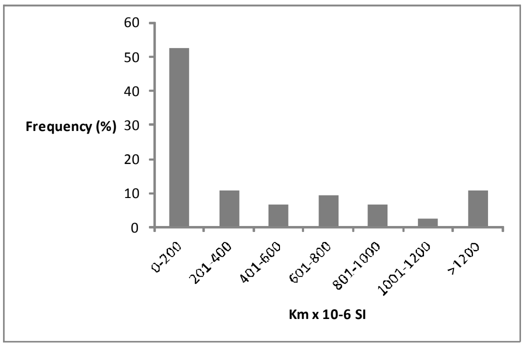


FIGURE 2. *Frequency histogram of bulk magnetic susceptibility.*

The magnetic foliations are subvertical ENE-WSW-striking in G0 and G1 granites. Magnetic lineations are subvertical in G0 and plunge moderated to the SE in facies G1 (Fig. 4).

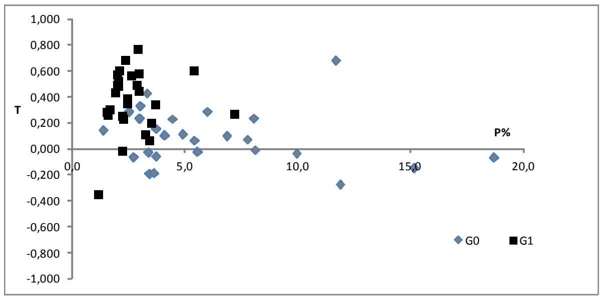


FIGURE 3. *Plot of the shape parameter (T) and anisotropy (P%) showing dominant oblate ellipsoids.*

ISOTHERMAL REMANENT MAGNETIZATION

The Isothermal Remanent Magnetization (IRM) values were measured using a Molspin spinner magnetometer and fields were imparted with a Molspin magnetometer from the University of Coimbra. Measurements were performed on samples in order to obtain the IRM values, the IRM and the -IRM acquisition curves (Fig. 5).

Samples were magnetized firstly in the same direction from 12.5 mT up to 1T and secondly in the opposite direction also from 12.5 mT up to 1T. IRM_{1T} values range from 179.49 to 5875.46 mA/m (mean: 2042.12 mA/m, N=7) in G0; and between 8.09 and 35.59 mA/m (mean: 22.82 mA/m, N= 10) in G1 granites. In G0 granites, the IRM acquisitions curves

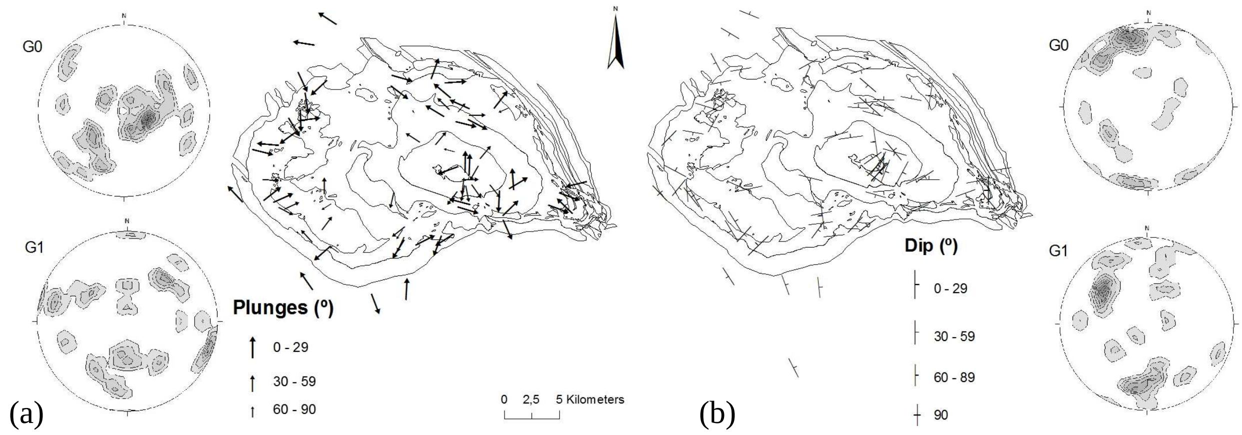
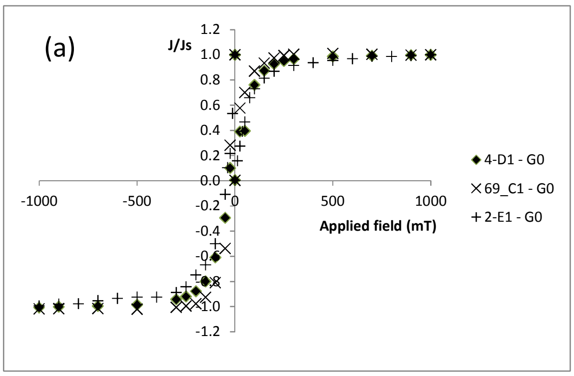


FIGURE 4. *Map of the magnetic lineations (a) and magnetic foliations (b) with orientations stereonets (Schmidt, lower hemisphere projection).*

show saturation in fields between 0.3 and 0.4 T followed by a small increase in intensity in increasing fields, suggesting that the main carrier of the remanence is low magnetite or Ti-magnetite. In G1 facies, the IRM values and acquisition curves point out a paramagnetic and antiferromagnetic fractions but a small fraction of magnetite can also be present (Fig. 5).



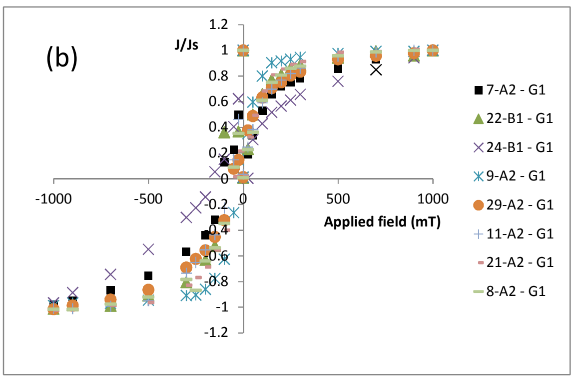


FIGURE 5. *IRM acquisition curves for representative samples. Js: saturation magnetization; J: magnetization. (a) G0 granites and (b) G1 granites.*

GEOCHEMISTRY

Major and trace element geochemical data highlight significant differences between M, G0 and G1 groups. Mafic to intermediate rocks (M group) are typically metaluminous, plot close to *M-type* granitoids (Fig. 6), and the less differentiated facies (gabbro) shows a positive Sr anomaly and a slight negative Ti anomaly. G0 (pink) granites correspond to the more evolved liquids present in SEPC (highest SiO_2 and lowest MgO wt% contents), have a metaluminous tendency, present compositional similarity with *A-type* granitoids (Whalen et al., 1987), and show REE patterns with negative Eu anomalies. Instead, G1 (gray) facies are typically monzonitic granites with a peraluminous (*S-type*) character. When compared with G0 group, G1 granites show high $(La/Lu)_N$ ratios and less pronounced negative Eu and Sr anomalies (Lopes *et al.*, 1998). Considering the mafic-intermediate (M group) and granitic rocks (G0 and G1 groups) of the SEPC as a whole, Nb anomaly (calculated between Th and La) is systematically negative (<1) and covers a wide range of values (0.09<Nb*<0.97) compatible with variable contributions of crustal fractions during magmatic differentiation processes (Fig. 7).

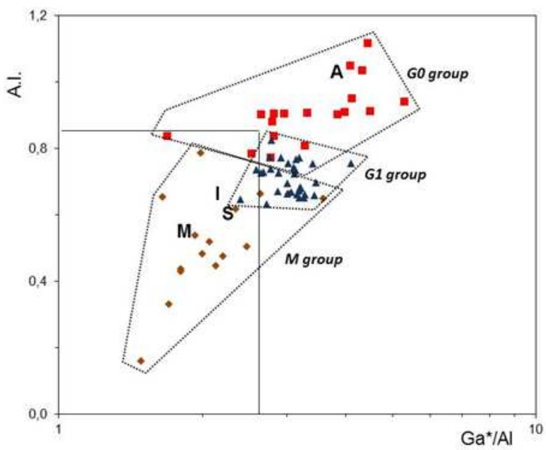


FIGURE 6. *(10^4·Ga/Al) vs. A.I. (agpaitic index) diagram for representative analysis of M, G0 and G1 groups of SEPC. The letters M, I, S and A correspond to average compositions of different types of granitoids according to the classification of Whalen et al. (1987).*

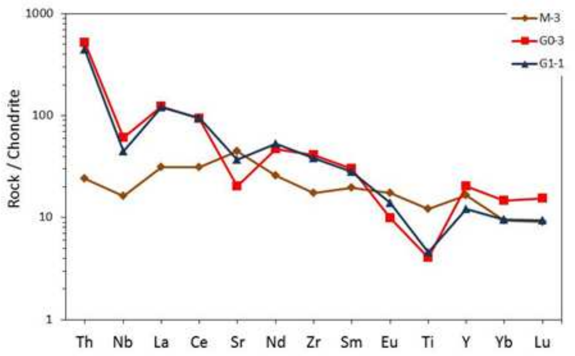


FIGURE 7. *[Th – Lu] spider diagram for representative samples of M, G0 and G1 groups of SEPC. Elemental concentrations normalized with values presented by Sun & McDonough (1989).*

Nd isotopic data are relevant in the petrogenetic approach of the SEPC. Considering an age around 290 My (Pinto, 1984), the less evolved gabbro of the M-group has a Nd isotopic signature (εNd290=+1.7) compatible with parental magmas extracted from the mantle. Isotopic data from representative samples of G0 granite (-2.67<εNd290<-1.86) are within the range of εNd290 values defined by mafic-intermediate rocks of M group (-4.0<εNd290<+1.7). In contrast, the grey granites (G1), placed in the central part of the SEPC, show lower εNd290 values (-5.9<εNd290<-5.7) suggesting petrogenetic processes with particular influence of crustal melts (Lopes *et al.*, 2012).

$\delta^{18}O$ values for SPEC were obtained by laser fluorination at the Stable Isotopic Laboratory of Salamanca. The G0 granite has low $\delta^{18}O$ values ranging from 9.5 to 10.3 $^0/_{00}$ and the G1 facies have higher values of $\delta^{18}O$ ranging of 10.0 and 11.9 $^0/_{00}$.

DISCUSSION

The AMS and IRM data support that the facies G0 and the facies G1 have a distinct magnetic behavior. G0 is controlled by a ferrimagnetic fraction (low magnetite or Ti-magnetite). The G1, Km< 10^{-4} SI, shows a paramagnetic behavior due to ferromagnesian minerals, such as biotite, and ilmenite. However IRM curves also reveal small contents of magnetite. In basic rocks from M-group, Km is typical of gabbros and granodiorites and is due to the high contents of ferromagnesian minerals. These different magnetic behavior suggest different redox conditions in magma genesis of the two main granitic facies. Magnetic anisotropy is higher in G0 granite which is due to the presence of magnetite but microscope observations also show signs of a post-magmatic deformation in G0. The magnetic foliations are subvertical ENE-WSW-striking in both granites. However, magnetic lineations have different patterns: are subvertical in G0 and plunge moderated to the SE in facies G1. Elemental geochemistry and Nd-isotopic results suggest the influence of an *ACF-type* differentiation process in the petrogenesis of SEPC granitoids, being the crustal assimilation more extensive in the case of the G1 facies. There is an inverse relationship between Km and $\delta^{18}O$ values of G0 and G1 granites which agrees with other granites of Iberian massif (Sant'Ovaia et al. 2012) showing that magnetite-type have low values $\delta^{18}O$ and that ilmenite-type are δ18O enriched. The different magnetic behaviour, the magnetic lineations patterns, and geochemical features, reflect distinct petrogenetic processes at the level of the magmatic sources and emplacement mechanisms of M, G0 and G1 facies associated in the SEPC.

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