Field trip E3:

Granitic rocks of the European Variscan Belt: the case study of the Évora Massif (Alentejo, Portugal)

M. Francisco Pereira[1], António Castro[2],

Ícaro Fróis Dias da Silva[3], Carlos Fernández[4]

1 IDL, Departamento de Geociências, ECT, Universidade de Évora, Apartado 94, 7002-554 Évora, Portugal, mpereira@uevora.pt

2 Dpto. de Geologia, Facultad de Ciencias Experimentales, Universidad de Huelva, 21007 Huelva, Spain . dorado@uhu.es

3 IDL, Faculdade de Ciências da Universidade de Lisboa, Campo Grande, 1749-016 Lisboa, Portugal. ipicaparopo@gmail.com

4 Dpto. de Geodinámica y Paleontología, Facultad de Ciencias Experimentales, Universidad de Huelva, 21007 Huelva, Spain . fcarlos@uhu.es

CONTENTS

Introduction ……………………………………………... 2

Geological itinerary and stops ………………………… 5

Stop 1: Almansor stream ……………………………….. 6

Stop 2: Montemor-o-Novo ……….…………………….. 10

Stop 3: Arraiolos ……………………………………….. 12

Stop 4: Évora .………………………………………. 15

References ……………………………………………… 18

Introduction

Field trip E.3 is a complement to symposia “S1. Rocas graníticas del Cinturón Varisco Europeo” in honor of Guillermo Corretgé, organized by the “Grupo de Petrología, Geoquímica y Geocronología (PGG) de la Sociedad Geológica de España”. The study of granitic rocks of the Iberian Massif has been among the most important objectives and motivations of geological research in Iberia over the last 40 years. During this long period, there have been many studies, in particular those developed by Guillermo Corretgé, who decisively contributed to place the Geology of Iberia in the global context of the European Variscan Belt.

Field trip E3 aims to present the advances gathered in the last decade in the geological knowledge of the Évora Massif. This research activity will be supported by a multidisciplinary approach including description of field relationships, complemented by data of petrological, structural and geochronological data.

The Évora Massif is part of a kilometre-scale linear metamorphic belt, formed during the Variscan orogenesis, extending from Aracena Massif (Spain) to Évora (Portugal) in SW Iberia (Pereira et al. 2009) (Fig. 1). The stratigraphy of this domain of the Ossa-Morena Zone is dominated by Ediacaran to Ordovician sedimentary and igneous rocks (Pereira et al. 2007) (Fig. 1). The oldest rocks of the Serie Negra Group are Ediacaran pelites and greywackes deposited in a Cadomian magmatic arc setting in North Gondwana (Pereira et al. 2008). The Cambro-Ordovician sequence is related to the formation of ensialic rift basins with voluminous felsic and mafic magmatism (Chichorro et al. 2008). Cambro-Ordovician (?) rocks are unconformably overlain by Lower Carboniferous turbiditic strata and felsic volcanics (Cabrela basin) which are the youngest Paleozoic rocks of the Évora Massif (Pereira et al. 2012).

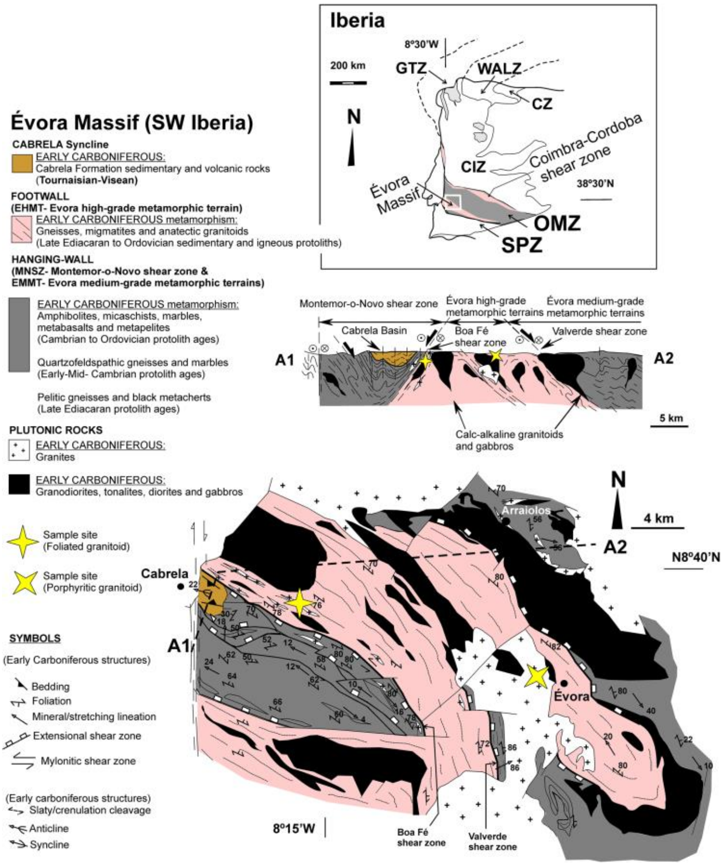

Figure 1.- Schematic representation of the geology in the Évora Massif (from Pereira et al., 2015).

The overall structure of the Évora Massif has been interpreted as being the result of Variscan D_2 sinistral transtension later folded during the D3 contractional phase (Pereira et al. 2003; 2007; 2009; 2012) (Fig. 1). D_1 deformation has been tentatively ascribed to an earlier phase of contraction but this is still controversial. D_1 structures are difficult to recognize due to D_2 deformation overprint.

The Évora Massif represents a dome-like structure that includes a metamorphic core with a footwall comprising high-grade gneisses, migmatites, granitoids, gabbros and diorites (Évora high-grade metamorphic terrains; Pereira et al. 2007, 2012) (Fig. 1). The footwall is separated by mylonitic shear zones from the southern (Montemor-o-Novo shear zone) and northern (Évora medium-grade metamorphic terrains) hanging-wall blocks of relatively low metamorphic grade, mainly composed of medium-grade gneisses, schists and amphibolites (Fig. 1).

Variscan D_2 extensional deformation is associated with the growth of high-medium temperature and medium-low pressure mineral assemblages related to isobarically-cooled P-T paths along major shear zones (Chichorro, 2006; Pereira et al., 2009). The available geochronological data shows that mylonitization in the Variscan shear zones took place in the period ca. 356–322 Ma (Pereira et al. 2012b) coevally with voluminous magmatism. Mylonitic S_2 foliation and associated tight folds are folded by later D_3 contractional deformation with the development of chevron, open and upright folds, and S_3 slaty, fracture or crenulation cleavages (Pereira et al., 2013). The later D_3 deformation affects the Tournaisian-Visean turbidites of the Cabrela basin (Chichorro, 2006; Pereira et al., 2007).

Early Carboniferous magmatism is dominated by granitoids (ca. 340-317 Ma; Pereira et al., 2009, 2015; Lima et al., 2011; Moita et al., 2015), but it is also represented by gabbros and diorites that occur extensively at the SW border of the Ossa-Morena Zone in the Beja massif (ca. 353–318 Ma; Pin et al. 2008). The field relations and geochemistry of different types of granitoids of the Évora Massif suggest the complex mechanical and chemical interaction of distinct melts with crustal, mantle and hybridized sources (Moita et al., 2005a,b; 2009; Moita, 2007).

The topic that arises for discussion is whether this early Carboniferous plutonism represents or not a Variscan magmatic arc?

GEOLOGICAL ITINERARY AND STOPS

During these two days of field trip in the Alentejo region (Portugal) we will visit four selected sites of the Évora Massif.

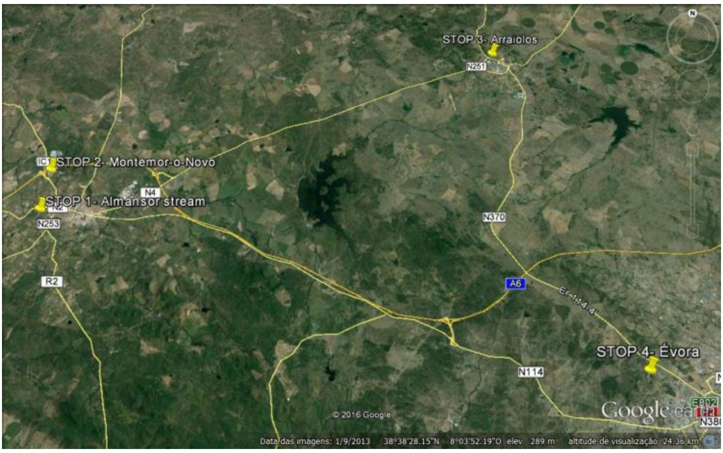

Figure 2.- Google map with location of stops 1-4.

The first day is devoted to the study of different metamorphic and plutonic rocks included in the Évora high- (footwall) and medium- (northern hanging wall) grade metamorphic terrains. Stops 1 and 2 are located close to Montemor-o-Novo (30 km from Évora). Stop 3 is located in Arraiolos (23 km from Montemor-o-Novo and 22 km from Évora). The morning of the second day will be spent in Évora to study different plutonic rocks intruded in the Évora high-grade metamorphic terrains.

Stop 1

Almansor stream

Location: Almansor stream (SW of Montemor-o-Novo)

Description: This stop is a particularly well-exposed, subhorizontal 105 metre-long outcrop of diatexites and granitoids of the Évora high-grade metamorphic terrains (Pereira et al., 2013). The rocks forming this outcrop display a wide variety of structures with complex temporal and spatial relationships and show evidence of a complex mingling of magmas resulting from injection of mantle-derived melts into host diatexites (Moita et al., 2009). The outcrop is dominated by the presence of a compositional layering parallel to the main S_2 foliation, with azimuth N120-130º and steep (76º-80º) SW-dips. The compositional layering of the diatexites is mostly affected by sinistral N90º-105º-trending shear zones but locally show antithetic dextral shear zones N160º-170º-trending. The compositional layering is composed of centimetre- to metre-thick layers of foliated brownish host monzogranitic diatexite (Host) and two types of leucocratic intrusions (around 35-40% of the area): centimetre- to metre-thick leucocratic dykes ranging from grayish granodiorite to quartz-monzogranite (Leuco1) and leucogranite (Leuco2) are mostly concordant with the layering (S_2) in the host monzogranitic brownish diatexite.

Goal: We intend to discuss relationships between the Host, Leuco1 and Leuco2. Leuco2 veins with sharp contacts generally cut Leuco1 but may also show gradual parallel contacts. Leuco1 and Leuco2 also occur as centimetre- to metre-thick discordant (cross-cutting) dykes and also filling shear zones (N90º-105º-trending) and boudin necks. The compositional layering of diatexites and concordant, sub-concordant and discordant leucocratic dykes are folded at various wavelengths and amplitudes, but show uniform orientation of axial planes (N130º-140º-trending). Metatexites, amphibolites, mica schists and black metacherts occur as schollen, schlieren and fragments of relict layers in the host diatexite. Isolated fragments of metasedimentary rocks are the result of strong boudinage of competent layers and/or metamorphic layering. The geometry of asymmetric boudin tails, which acted as mesoscopic porphyroclasts, allows for the identification of sigma- and delta-structures compatible with sinistral movement. Metre-thick mesocratic dykes (andesites) injected in the host diatexite were stretched, fractured and separated, into pinch-and-swell-like structures.

Figure 3.- Relationship between diatexites, leucogranitoids and isolated rock fragments.

Interpretation: Petrography reveals the compositional differences that exist between monzogranitic diatexites and leucogranitoids. The host diatexite is characterized by the highest mica content (biotite and muscovite) associated with K-feldspar, plagioclase, quartz, zircon, sillimanite and cordierite. Diatexites have metamorphic and igneous-like microstructures. Metamorphic-like textures are well preserved within isolated rock fragments (schollen) or within biotite and feldspar-rich centimetre- to millimetre-layers (schlieren) that define the foliation of diatexites. The microstructure of the diatexites indicates intense strain and limited late recrystallization. In contrast, Leuco1 and Leuco2 have igneous-like textures with biotite crystals uniformly distributed and moderately-to-weakly oriented along grain boundaries of quartz and feldspar. Leuco1 includes: i) a fine-medium grain size quartz-monzogranite that presents a well- to weakly-defined foliation, with a mineral composition similar to the host diatexite but with a lower content of biotite and ii) a coarse-grained granodiorite composed of plagioclase, quartz and K-feldspar, which shows a weak magmatic foliation marked by the alignment of biotite. Leuco2 is an extremely siliceous leucogranitoid mainly made up of plagioclase, quartz, K-feldspar and subordinate content of biotite.

Diatexites have characteristics of crustal melts plus restitic material and, according to peraluminous character and εNdi values ranging from −8.9 to −9.3, indicate anatexis of Ediacaran metasedimentary rocks. Foliated granitoids (Leuco1; slightly peraluminous character and εNdi values of −3.9 and −5.5) and trondhjemitic veins (transitional between metaluminous and peraluminous compositions and with εNdi ranging from −3.8 to −6.1) have calc-alkaline signatures and may be related to each other by crystal fractionation processes; however, the mixing between mafic (mantle-derived) and felsic (diatexitic melt) magmas revealed by the isotopic data may also explain their genesis (Moita et al., 2009).

CL imaging of zircon from a sample of foliated granitoid (Leuco 1) shows that the internal pattern of morphologically complex zircon consists basically of a variable-width dark-CL rim surrounding a bright-CL core. The $^{206}Pb/^{238}U$ ages obtained range from ca. 348 to ca. 331 Ma, yielding a weighted mean age of 341.4 ± 2.0 Ma (MSWD=1.3), which seems to represent the best estimate of the crystallization age of the granitoid. This range of ages can also be divided into two age clusters with $^{206}Pb/^{238}U$ ages, yielding a weighted mean of 344.1 ± 2.1 Ma (MSWD=0.4) and of 335.6 ± 3.0 Ma (MSWD=0.45) probably representing two transient stages of zircon crystallization (Pereira et al., 2015).

Figure 4.- Dyke of foliated granitoid (Leuco1 containing inclusions of diatexite) intruding the diatexite (Host).

Stop 2

Montemor-o-Novo

Location: on the road N2 from Montemor-o-Novo to Mora (next to highway access)

Description: This is a stop in the Hospitais pluton hosted in the Évora high-grade metamorphic terrains. This pluton is mainly composed by a light coloured medium to coarse-grained quartz–diorite/tonalite with leucocratic lavers and few microgranular mafic enclaves.

Goal: We intend to discuss relationships between the quartz-diorite, leucocratic layers and microgranular mafic enclaves. Quartz-diorite shows a magmatic foliation, defined by the alignment of mafic minerals and by the preferred orientation of elongated mafic microgranular enclaves (some of them are bordered by felsic halos). Locally, are recognized more leucocratic irregular layers commonly parallel or slightly oblique to the magmatic foliation, or occurring as anastomosed structure and pockets.

Interpretation: Petrography reveals essentially the same mineral assemblage for the quartz-diorite, leucocratic layers and microgranular mafic enclaves (admitting variations in the percentage of mafic minerals in relation to felsic ones), consisting of plagioclase (dominantly andesine), amphibole (hornblende and cummingtonite–grunerite), biotite, alanite and quartz (Moita, 2007; Moita et al., 2005a; 2015).

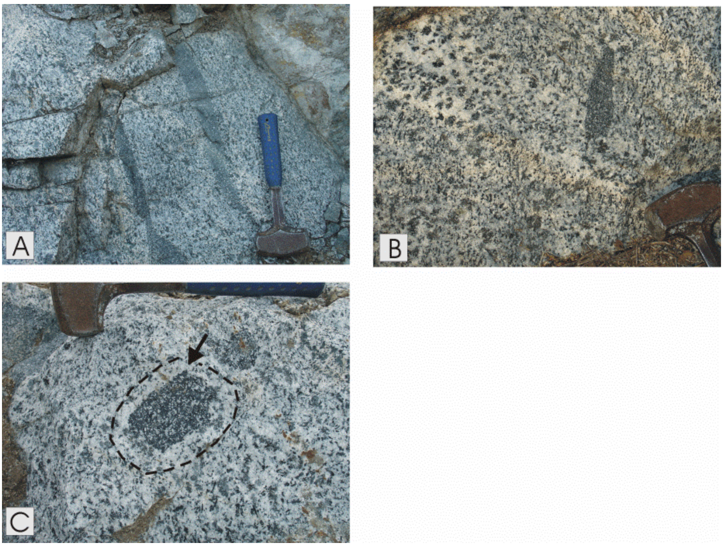

Figure 5.- A) Microgranular mafic enclaves within the foliated quartz-diorite; B) Discordant leucocratic layer; C) Leucocratic halo of a microgranular mafic enclave (from Moita et al., 2015a)

The Hospitais pluton has a metaluminous character and calc-alkaline signature suggesting a genetic relationship with mafic rocks (I-type granitoid; Moita, 2007; Moita et al., 2005b). This magma was probably generated through fractional crystallization from basic magmas. The εNdi values of quartz-diorite, leucocratic layers and microgranular mafic enclaves range from −1.87 to −3.22 (Moita et al., 2015).

There are gabbroic bodies within the Évora high-grade metamorphic terrains spatially associated with quartz-dioritic/tonalitic bodies. Major elements trends and trace elements patterns of the quartz–diorites and gabbros suggest that they can be co-genetic (Moita, 2007). This is supported by εNdi values ranging from −1.62 to −1.98 values obtained in gabbroic rocks, closer to those obtained in the quartz-diorites, indicating that parental mafic magmas formed in a strongly metasomatized mantle source (a mantle wedge above a subducted slab; Moita et al., 2015). However, εNdi values of +3.63 obtained in gabbros require either that quartz-diorites probably derived from mixing between mafic melts from a depleted mantle source and crustal melts (melting of Cambrian calc-alkaline metaluminous orthogneisses; Moita et al., 2015).

Zircon fractions of a quartz-diorite and a microgranular mafic enclave yield $^{206}Pb/^{238}U$ weighted average ages of 337.0 ± 2.0 Ma and 336.5 ± 0.5 Ma (Moita et al., 2015), representing the best estimate of the crystallization age of the Hospitais pluton, coincident with the second stage of zircon crystallization obtained in the foliated granitoid sampled in the Almansor stream (stop 1).

Stop 3

Arraiolos

Location: Near the castle of Arraiolos

Description: This is a stop in the Lower Gneiss Unit (LGU) of the Évora medium-grade metamorphic terrains (northern hanging wall of the dome-like structure). Amphibolites, and micaschists (Cambrian-Ordovician? protoliths) are strongly deformed. These metamorphic rocks have a pervasive S_2 foliation and tight D_2 folds. This fabric is cut by syn-D_2 dykes of granitic pegmatite-aplite and granites. Later, a contractional deformation phase (D_3) produced a structure controlled by upright D_3 folds with N150º-160º-trending to N120-130º-trending axial planes. The D_2 structures are folded, become steeper, and locally developed a pervasive D_3 crenulation cleavage.

Goal: We intend to discuss the interplay between D_2 extensional structures and D_3 contractional structures, interference patterns produced by the superposition of folds, and timing of emplacement of granitic dykes.

Figure 7.- Interference pattern of D2 and D3 folding in amphibolites, and discordant leucogranitoid veins.

Interpretation: Three tectonic units related to the D_2 extensional deformation and related decrease of metamorphic grade were distinguished in the northern hanging-wall block of the Évora Massif, from bottom-to-top: the Lower Gneiss Unit (LGU), the Intermediate Schist Unit (ISU) and the Upper Slate Unit (USU) (Dias da Silva et al., 2016):

- LGU exposed at south and north of the Pavia granite (ca. 324 Ma; Lima et al., 2011) includes meta-sedimentary and meta-igneous rocks strongly deformed under the highest metamorphic grade (H/MT-LP), as indicated by the garnet-fibrolite-biotite mineral assemblage found in gneisses. Amphibolites and gneisses have a pervasive (originally low-dipping) S_2 foliation and are associated to syn-D_2 dykes of granitic pegmatite-aplite and granites. Both top-to-the-ESE and top-to-the-SE shear senses are indicated by asymmetric intrafoliar folds, C/S fabric, C'-type shear bands and sigmoidal shapes of boudinaged quartz veins, granitic dykes and leucocratic layers of gneisses and amphibolites.

- ISU makes the transition to the uppermost structural levels that define the USU. The southern limit of the ISU is gradual, being marked by the continuing replacement of gneisses and amphibolites for biotite-rich schists and by the progressive decrease of the number and volume of granitic dykes. Towards the top of this tectonic unit S_2 is represented by a crenulation cleavage, parallel to the bedding and representing the axial plane of centimetre-scale tight folds. These D_2 structures are folded by D_3 and later intruded by granitic dykes that include foliated xenoliths of the host rock. On top, the metassediments are mica schists with a pervasive S_2 crenulation cleavage, parallel to the bedding that represent the axial plane of tight folds.

- USU represents the highest structural level with the lowest metamorphic grade. The mica schists are gradually replaced by laminated slates, metamorphosed basic igneous rocks and marbles. S_2 crenulation cleavage is still very pervasive and usually sub-parallel to bedding, and later folded by D_3.

The superposition of N150-160º-trending D_3 open upright folds resulted in complex fold pattern that is more pronounced within the N120-130º-trending late D_3 strike-slip shear zones.

Granitoid dykes with meters thick to bodies several hundreds of meters wide are distributed along the three tectonic units. Some dikes cut S_2 foliation in the amphibolites and gneisses and crenulation cleavage in mica schists and slates. Granitoids dated at ca. 328 Ma (close to São Geraldo; Lima et al., 2012) include amphibolite xenoliths showing S_2 foliation, and show a S_3 foliation. The Pavia granite (ca. 324 Ma; Lima et al., 2012) is strongly deformed at its northern and southern contacts by late D_3 strike-slip shear zones.

The crystallization age obtained for the Arraiolos biotite granite that cut the S_2 foliation of LGU amphibolites and micaschist indicate that D_2 extensional deformation was active before ca. 337 Ma (Pereira et al., 2009). This age is coincident with the second stage of zircon crystallization that was obtained in the Almansor foliated granitoid (stop 1) and with the crystallization age of the Hospitais pluton (stop 2).

The age of the São Geraldo tonalite (ca. 328 Ma; Lima et al., 2012) and the Pavia granite (ca. 324 Ma; Lima et al., 2012) define a later magmatic pulse. These plutonic rocks are deformed by late D_3 strike-slip shear zones.

Stop 4

Évora

Location: Alto de São Bento mills and quarry (Évora).

Description: This is a stop in the Évora pluton hosted in Évora high-grade metamorphic terrains. In the outcrop where the mills are located is possible to observe a porphyritic granitoid with microgranular mafic enclaves in contact with a two-mica leucogranite. The quarry allows the observation of a two-mica leucogranite spatialy associated with low dipping tabular bodies of porphyritic granite with granular mafic enclaves, foliated granodiorites, tonalites and gabbros. These granitoids are associated with a granitic pegmatite-aplite complex.

Goal: We intend to discuss relationships between the different types of granitoids, the nature of enclaves, magmatic fabrics defined by the orientation of K-feldspar phenocrysts, mixing and mingling of compositionally distinct melts and the association with a granitic pegmatite-aplite complex.

Interpretation: The mineral assemblage of the two-mica leucogranite includes quartz, K-feldspar, plagioclase, muscovite and biotite, and minor tourmaline. Two elongated foliated tonalitic bodies (xenoliths?) are surrounded by the two mica leucogranite (Moita, 2007).

The porphyritic granitoids contain phenocrysts of K-feldspar, surrounded by a groundmass of K-feldspar, plagioclase, quartz, biotite and minor muscovite (Ribeiro, 2006). These granitoids contain mafic enclaves with tonalitic composition (Moita et al., 2009).

Figure 5.- Mafic enclaves in the porphyritic granitoid.

The porphyritic granitoid (monzogranite-granodiorite) has a weak peraluminous nature (I-type: A/CNK = 0.9; with microgranular enclave- εNdi = −1.1) distinct from the strongly peraluminous nature of two-mica leucogranites (S-type: A/CNK = 1.19–1.2; εNdi = −7.2). Trace element patterns of porphyritic granitoids indicate enrichment of the most incompatible elements and negative Nb and Ti anomalies consistent with a calc-alkaline signature (Moita et al. 2009).

A set of U-Pb data (Pereira et al., 2015) with significant scattering obtained from the porphyritic granitoid yield a weighted mean $^{206}Pb/^{238}U$ age of 345.0 ± 5.7 Ma (with an unacceptable MSWD = 16). Two age clusters were defined giving a weighted mean $^{206}Pb/^{238}U$ age of 342.8 ± 2.0 Ma (MSWD = 0.24) and of 336.7 ± 3.2 Ma (MSWD = 0.115), similar to those recognized in the foliated granitoid from the Almansor stream (stop 1).

References

Chichorro, M., 2006. A Evolução Tectónica da Zona de Cisalhamento de Montemor-o-Novo (Sudoeste da Zona de Ossa Morena – Área de Santiago do Escoural – Cabrela). Unpublished PhD thesis, Universidade de Évora, 521p.

Chichorro, M., Pereira, M.F., Díaz-Azpiroz, M., Williams, I.S., Fernández, C., Pin, C., Silva, J.B. (2008): Cambrian ensialic rift-related magmatism in the Ossa-Morena Zone (Évora–Aracena metamorphic belt, SW Iberian Massif): Sm–Nd isotopes and SHRIMP zircon U–Th–Pb geochronology. Tectonophysics 461: 91–113.

Dias da Silva, I.F., Pereira, M.F., Silva, J.B., 2016. Interplay between Variscan extension and contraction in the Ossa-Morena Zone (Iberia): Structure of the northern hanging-wall block of the Évora Massif. IX Congreso Geologico de Espãna. Geotemas

Lima, S.M., Corfu, F., Neiva, A.M.R., Ramos, M.F., 2012. Dissecting complex magmatic processes: an in-depth U–Pb study of the Pavia pluton, Ossa-Morena Zone, Portugal. Journal of Petrology 53 (9), 1887–1911.

Moita, P., 2007. Granitóides no SW da Zona de Ossa Morena (Montemor-o-Novo - Évora): Petrogénese e Processos Geodinâmicos. Unpublished PhD thesis, Universidade de Évora, 351 p.

Moita, P., Pereira, M., Santos, J., 2005a. Tonalites from the Hospitais massif (Ossa-Morena Zone, SW Iberian Massif, Portugal). I: geological setting and petrography. Geogaceta 37, 51–54.

Moita, P., Santos, J., Pereira,M.F., 2005b. Tonalites from the Hospitais massif (Ossa-Morena Zone, SW Iberian Massif, Portugal). II: geochemistry and petrogenesis. Geogaceta 37, 55–58.

Moita, P., Santos, J., Pereira, M.F., 2009. Layered granitoids: interaction between continental crust recycling processes and mantle-derived magmatism. Examples from the Évora Massif (Ossa-Morena Zone, southwest Iberia, Portugal). Lithos 111 (3–4), 125–141.

Moita, P., Santos, J.F., Pereira, M.F., Costa, M.M., Corfu, F., 2015. The quartz-dioritic Hospitais intrusion (SW Iberian Massif) and its mafic microgranular enclaves — Evidence for mineral clustering. Lithos 224-225, 78-100.

Pereira, M.F., Silva, J.B., Chicorro, M., 2003. Internal structure of the Évora high-grade terrains and the Montemor-o-Novo shear zone (Ossa–Morena Zone, Portugal). Geogaceta 33, 79–82.

Pereira, M., Silva, J., Chichorro, M., Moita, P., Santos, J., Apraíz, A., Ribeiro, C., 2007. Crustal growth and deformational processes in the northern Gondwana margin: constraints from the Évora Massif (Ossa-Morena Zone, SW Iberia, Portugal). Geological Society of America, Special Paper 423, 333–358.

Pereira, M.F., Chichorro, M., Williams, I.S., Silva, J.B., 2008. Zircon U–Pb geochronology of paragneisses and biotite granites from the SW Iberian Massif (Portugal): evidence for a paleogeographic link between the Ossa-Morena Ediacaran basins and the West African craton. In: JP Liégeois, E Nasser (eds) The boundaries of the West African Craton 297. Geological Society of London Special Publication, 385–408.

Pereira, M.F., Chichorro, M., Williams, I.S., Silva, J.B., Fernández, C., Díaz-Azpíroz, M., Apraiz, A., Castro, A., 2009. Variscan intra-orogenic extensional tectonics in the Ossa-Morena Zone (Évora-Aracena-Lora del Río metamorphic belt, SW Iberian Massif): SHRIMP zircon U–Th–Pb geochronology. Geological Society of London, Special Publication 327, 215–237.

Pereira, M.F., Chichorro,M., Silva, J.B., Ordóñez-Casado, B., Lee, J.K.W.,Williams, I.S., 2012. Early Carboniferous wrenching, exhumation of high-grade metamorphic rocks and basin instability in SW Iberia: constraints derived from structural geology and U–Pb and ^{40}Ar–^{39}Ar geochronology. Tectonophysics 558–559, 28–44.

Pereira, M.F., Chichorro, M., Fernández, C., Silva, J.B., Matias, F.V., 2013. The role of strain localization in magma injection into a transtensional shear zone (Variscan belt, SW Iberia). Journal of the Geological Society 170, 93-105.

Pereira, M.F., Chichorro, M., Moita, P., Santos, J.F., Solá, A.M.R., Williams, I.S., Silva, J.B., Armstrong, R.A. (2015): The multistage crystallization of zircon in calc-alkaline granitoids: U–Pb age constraints on the timing of Variscan tectonic activity in SW Iberia. International Journal of Earth Sciences, 104 (5): 1167-1183.

Pin, C., Fonseca, P.E., Paquette, J.-L., Castro, P., Matte, Ph., 2008. The ca. 350 Ma Beja Igneous Complex: a record of transcurrent slab break-off in the Southern Iberia Variscan Belt? Tectonophysics 461, 356–377.

Ribeiro, C., 2006. Cartografia de rochas ígneas: Análise da Orientação Preferencial de Fenocristais de Feldspato para Caracterização do Fluxo Magmático nos Granitóides Porfiróides do Alto de São Bento (Maciço de Évora, Zona de Ossa Morena). Unpublished MSc thesis, Universidade de Évora, 160 p.