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New magnetotelluric data through the boundary between the Ossa Morena and Centroiberian Zones

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ABSTRACT

The south-western part of the Iberian Peninsula, including the southern branch of the Iberian Massif, has recently been the subject of several magnetotelluric (MT) studies. This area is made up of three different tectonic terranes: the South Portuguese Zone (SPZ), the Ossa Morena Zone (OMZ) and the Central Iberian Zone (CIZ). The boundaries between these zones are considered to be sutures, which appear as high electrical conductivity anomalies in the MT surveys. The OMZ is characterised by a conductive layer at middle-lower crustal levels. To investigate the continuity of this conductive layer into the CIZ, a new MT profile was carried out. This 75-km long ENE profile goes through the boundary between the OMZ and the CIZ. The results of a two-dimensional magnetotelluric inversion revealed a high-conductivity anomaly in the transition OMZ/CIZ (the so-called Central Unit), which is interpreted as due to interconnected graphite along shear planes. High-conductivity anomalies appeared in the middle crust of the CIZ, whose geometry and location are consistent with the conductive layer previously found in the OMZ, thus confirming the prolongation of the conductive layer into the CIZ. The top of this layer correlated spatially with a broad reflector detected by a seismic profile previously acquired in the same area. This, together with other geological and petrological evidence, points to a common origin for both features.

KEYWORDS **Variscan. SW Iberia. Crustal structure. Graphite. Magnetotellurics.**

INTRODUCTION

The SW of the Iberian Peninsula is the southern branch of the Iberian Massif, the best-exposed fragment of the Variscan Fold Belt in Europe. It was formed by an oblique collision between three terranes: the South Portuguese Zone (SPZ), the Ossa Morena Zone (OMZ) and the Central Iberian Zone (CIZ). Suture zones containing rocks with oceanic chemical signature separate these terranes. The boundary between SPZ/OMZ is a northwarddipping, highly metamorphosed zone with ophiolitic inclusions, the Beja-Acebuches Ophiolitic complex (BAOC, Silva et al., 1990; Dallmeyer et al., 1993; Quesada et al., 1994) associated with the Pulo do Lobo accretionary prism (Fig. 1). The boundary between OMZ/CIZ is a left lateral subvertical ductile shear zone (Tomar-Badajoz-Córdoba Shear Zone, Burg et al., 1981; Quesada and Dallmeyer, 1994). Along its NW-SE trend, there is a blastomylonitic inner core called the Central Unit, which are strongly deformed and highly metamorphosed middle and lower crustal rocks (metasediments, orthogneisses and amphibolites) that were transpressionally exhumed in the Devonian and Carboniferous periods (Azor et al., 1994; Simancas et al., 2001).

The SW Iberian Peninsula has recently been the subject of a number of geophysical studies. Two previous magnetotelluric (MT) profiles (profiles I and II in Fig. 1) across the three Variscan terranes (Monteiro Santos et al., 1999; Almeida et al., 2001; Pous et al., 2004) provided the first images of the sutures at depth in the form of high-conductivity anomalies. The OMZ is characterised by a conductive layer at mid-lower crustal depth (10-25 km) that includes blobs of higher conductivity. A deep seismic reflection profile (IBERSEIS, Simancas et al., 2003; Carbonell et al., 2004) partially coinciding with the MT profile II (Fig. 1) revealed the presence of a broad band (1 to 2 s thick) of high-amplitude reflectivity called the Iberseis Reflective Body (IRB). The IRB is located at mid-crustal depth between 4 and 6 s TWT and extending more than 140 km along the whole OMZ and CIZ. The IRB correlates spatially with the top of the conductive layer where the deep seismic reflection IBERSEIS and the MT profile II overlap (Fig. 1). A mantle-derived intrusion, related to the plume activity that took place in Europe during the Carboniferous and Permian periods, has been suggested as the source of both high conductivity and high reflectivity (Carbonell et al., 2004). In this context, an alternative explanation for the high-conductivity blobs is the heterogeneous emplacement of the mafic intrusion. While the conductive layer does not appear in the CIZ, the IRB spans, in addition to the whole OMZ, most of the CIZ investigated. However, the seismic profile changes in direction towards the east (Fig. 1), whereas the MT profile II crosses late Variscan massive plutonic intrusions that cut the previous structures. To investigate the continuity of the conductive layer into the CIZ, far from the local plutonic intrusions, a new MT profile (profile L in Fig. 1) for the eastward deviation of the seismic profile was carried out. In this paper we report the results of this new MT profile L.

GEOLOGICAL SETTING

The southern branch of the Iberian Variscan Massif is divided into three tectono – stratigraphic terranes (Julivert et al., 1974; Ribeiro et al., 1990): the South Portuguese Zone to the south, the Central Iberian Zone to the north and the Ossa Morena Zone between the other two.

The basement of the OMZ consists mainly of Precambrian rocks with variable metamorphism, some of them showing high-pressure metamorphism (Fonseca et al., 1993). Most of this Precambrian basement is made up of late Precambrian dark schists and meta-greywackes known as the Serie Negra Fm. (Eguiluz, 1987; Simancas et al., 2001). This formation also includes black quartzites, amphibolites and volcanic rocks and is characterized by its high graphite content. Laboratory measurements with electron microprobe of Serie Negra Fm samples reveal the high connectivity of the graphite grains (Pous et al., 2004). These graphite-rich beds would have been produced by regional metamorphism of the organic sediments of the Serie Negra Fm. due to its deformation during the Cadomian orogeny (Neoproterozoic) and the accretion to the ancestral Iberian margin of Gondwana (Quesada, 1990a; Quesada, 1990b; Abalos et al., 1991).

During the Cambrian–Ordovician, the opening of the Rheic Ocean resulted in a mainly detritic rift sequence, followed by a passive margin evolution in the Ordovician – Devonian periods (Robardet et al., 1990; Sanchez-García et al., 2003). The OMZ was affected by the collision between Laurassia and Gondwana (Matte, 2001).

Igneous intrusions of various kinds are found in the OMZ: subduction-associated rocks emplaced during the Cadomian orogeny, tholeiite/alkaline rocks from the Cambrian-Ordovician rifting stage, and finally syn- to post-Variscan intrusions (Sanchez-Carretero et al., 1990; Castro et al., 2002; Sanchez-García et al., 2003).

The OMZ/CIZ boundary is partially covered by the Guadiana basin, a shallow basin with clastic sediments from the Neogene period. The boundary between the OMZ and the CIZ is a left-lateral subvertical ductile shear zone (Tomar–Badajoz–Córdoba Shear Zone; Burg et al., 1981) with NW-SE trending. The inner core of the shear zone (known as the Central Unit) is strongly deformed and mainly composed of highly metamorphosed rocks, including metasediments, orthogneisses and amphibolites (Simancas et al., 2001). The Central Unit was exhumed in Devonian-Carboniferous times in a transpressive tectonic regime (Quesada and Dallmeyer, 1994). Displacement along this intra-continental shear zone accommodated the greatest part of the Variscan escape of the OMZ towards the SE, coeval with the subduction of the Rheic Ocean occurring in the southern margin of OMZ and prior to the collision with the SPZ Zone.

More to the northwest, the CIZ includes some formations also present in the OMZ, such as the precambrian

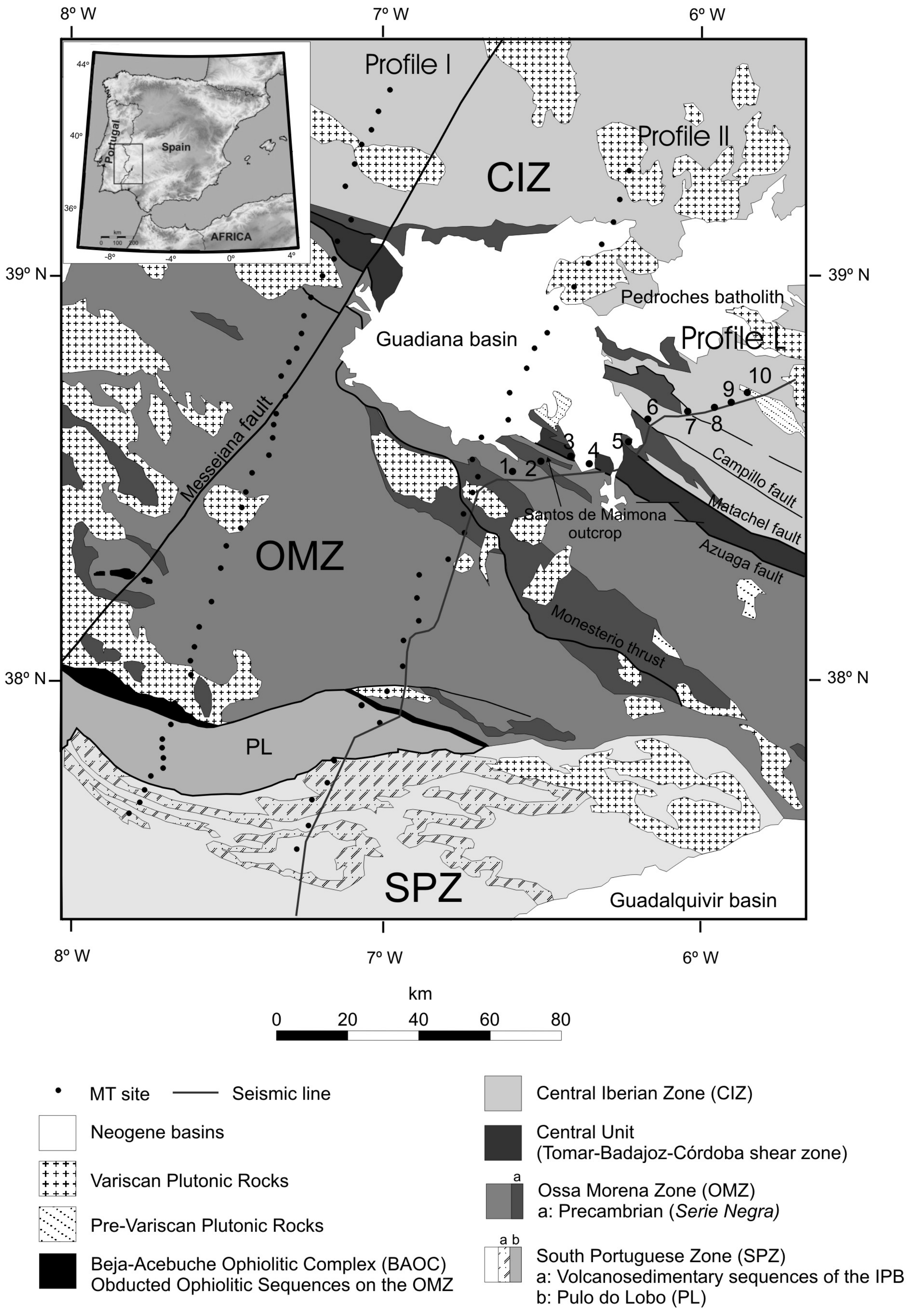

FIGURE 1 | **Simplified geological map with selected tectonic elements. Numbered MT sites are from the profile carried out in this study (Profile L). Western sites are from previous MT profiles (Profile I: Almeida et al., 2001; Profile II: Pous et al., 2004).**

Serie Negra Fm. (Delgado et al., 1977; Simancas et al., 2001). Overlying this, a calc-alkaline volcano-sedimentary sequence, the Malcocinado Fm., is found, locally covered by Cambrian detrital and carbonate formations. In most of the zone, Ordovician strata are found unconformably overlying the Serie Negra and the Malcocinado formation (Gutiérrez-Marco et al., 1990; Robardet, 2002).

More to the north, the pre-orogenic series are mainly formed by the Schist-greywacke complex (Teixeira, 1955). This is a Cambrian sequence made of alternating greywackes and slates with interbedded volcanic rocks, limestone and conglomerates. There are also a number of granite intrusions, mainly of late Variscan age, the largest being the Los Pedroches batholith (which prolongs to the east outside of Fig. 1).

MAGNETOTELLURIC DATA

The MT method is based on the measurement of naturally occurring transient electric and magnetic fields at several periods. The relations between these fields at different periods are used to define an impedance tensor whose components provide information about the electrical resistivity distribution at depth. In two dimensional models (2D), the equations describing the electromagnetic fields can be uncoupled in two independent modes: TE mode (or E-polarisation), in which the electrical currents flow perpendicular to the strike, and TM mode (or H-polarisation), in which the currents flow parallel to the strike. General information on the method can be found in Vozoff (1972) and Jones (1992).

Ten MT soundings with a site spacing ranging from 5 to 10 km were carried out along the new 75 km-long ENE profile coinciding with the eastward deviation of the IBERSEIS seismic line (Fig. 1). This profile crosses the boundary between the OMZ and CIZ. The four components of the electrical and magnetic fields were recorded in EW and NS directions in periods ranging from 0.004 s to 4000 s. The vertical magnetic component was recorded at seven sites (see Fig. 2B and 3). The impedance tensor components and geomagnetic transfer functions were calculated using standard robust processing techniques (Egbert and Booker, 1986). Figure 2 shows the apparent resistivities and phases for the ten sites (Fig. 2A) as well as the magnetic transfer functions for those sites at which the vertical magnetic component was recorded (Fig 2B).

The real induction arrows for three selected periods (20 s, 200 s and 2000 s) are shown in Fig. 3. The thick lines display the vertical to horizontal magnetic field ratio and the real part points away from the high-conductivity zones. It can be observed that for long periods the arrows are predominantly NE. At 20 s and 200 s (Fig. 3) there is a change in direction between sites 5 and 7 (roughly to the south at site 5 and roughly to the north at site 7), which reveals the presence of high conductivity between them. At periods less than 10 s (not shown in Fig. 3), the arrows are small and scattered. The dimensionality was analysed by multi-site, multi-period analyses (McNeice and Jones, 2001). We found that with the exception of site 4, for a strike direction between 105º and 125º, the error lay within the 95% confidence interval for periods higher than 50 s. We chose 125º since the agreement showed better stability at periods between 1-20 s (depending on the site) and 50 s. This direction fairly coincides with the strike directions of profiles I and II. The ambiguity of 90º was resolved by considering the directions of the induction arrows.

The impedance tensor components were rotated 35º and static shift levelling was determined as part of the inversion procedure. The induction arrows were projected onto the direction perpendicular to the strike. A two-dimensional joint inversion of rotated apparent resistivities and phases for both modes and projected geomagnetic transfer functions was carried out using the REBOCC algorithm (Siripunvaraporn and Egbert, 2000). As usual, first we inverted the geomagnetic transfer function from a uniform half space. Then, the final model of this inversion was used as an initial model for the joint inversion for TM and geomagnetic transfer functions. Finally the resulting model was used as an initial model for the joint inversion of the three kind of data. In the last step, the levelling of the static shift of those sites with poor fit was inverted. Figure 2 shows the data and model responses for the final inversion model. The RMS misfit for the final model was 3.77, using an error floor of 6% for the apparent resistivities, 5º for phases and 0.01 for the geomagnetic transfer functions.

A sensitivity study on the final inversion model investigated to what extent the structures were really required by the data. The deepest part of the conductive bodies in the model was checked by a forward modelling algorithm (Wannamaker et al., 1987) and subsequently removed to the minimum depth required by the data. Figure 4A shows the final 2D model.

RESISTIVITY STRUCTURE

The upper 4 km of the final 2D model (Fig. 4A) show high resistivity along the whole profile with the exceptions of small northeast-dipping shallow conductors, below sites 2, 4 and 6-7. Below, at middle crustal levels (between 5 and 25 km), the crust is mostly highly conductive with three major conductive zones that show the characteristic sequence of higher-conductivity blobs previously found in the Ossa Morena Zone (Fig. 4B, Pous et

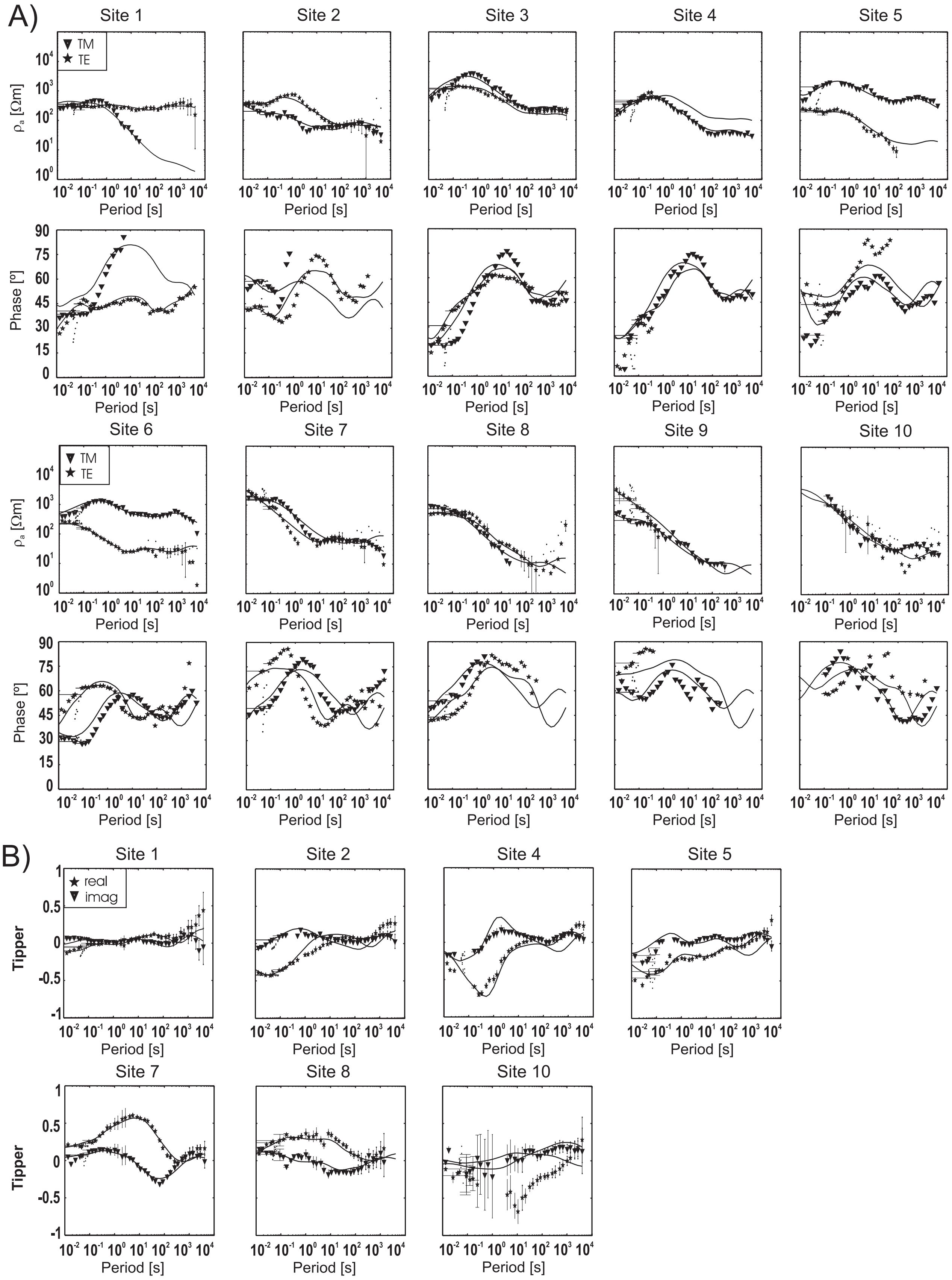

FIGURE 2 **Data and model responses in the ten MT soundings analysed along the profile L. A) Apparent resistivities and phases (TE and TM polarizations). B) Projected geomagnetic transfer functions.**

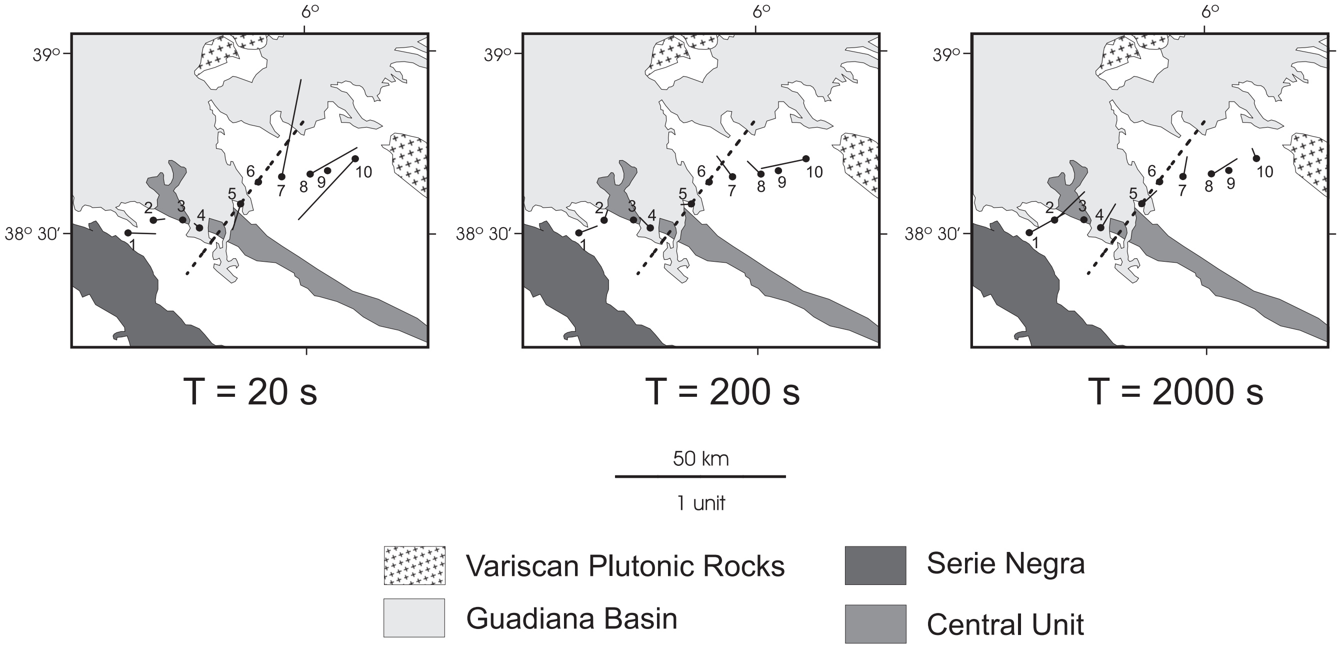

FIGURE 3 **Real induction arrows for 20, 200 and 2000 s. The dashed line is the projected profile corresponding to the two-dimensional electrical resistivity model shown in Fig. 4.**

al., 2004). Conductive zone C1, below site 1, extends from the surface down to a depth of about 25 km and correlates with the main outcrop of the graphite rich Serie Negra Fm. in the Ossa Morena Zone. Conductive zone C2 is located beneath the surface occurrence of the Central Unit. Its top is 5 km deep and extends down to 20 km. Note the North-east-dipping behaviour of its south-westernmost part. A striking result is the presence of a conductive body (C3) along the whole Central Iberian Zone. This conductive zone ranges from 7 to 25 km in depth. Below these three conductive zones the whole lower crust is moderately resistive (100 – 200 Ωm).

DISCUSSION

The two tectonic terranes sampled by the new profile L (OMZ and CIZ) do not differ in terms of electrical resistivity. In both zones, the upper 4-5 km show high resistivity, with the exception of the three small shallow northeast-dipping conductors. The conductor beneath site 2 is correlated with the surface trace of a strongly NE-dipping fault that bounds the Carboniferous outcrop of Los Santos de Maimona and the conductor below site 4 is associated with the late variscan Azuaga fault (see Fig. 1). The cause of the enhanced conductivity in these areas has been interpreted as the presence of fluids along these faults. By contrast, there is no major outcropping fault between sites 6 and 7. In this case, the conductor could be associated with a shallow strip of Serie Negra Fm. or with the NW prolongation of the Campillo fault found more to the SE (Fig. 1).

At middle crustal levels, at the southwestern end of the model, the major conductive body C1, with a depth ranging from the surface down to about 25 km, has resistivity values and geometry consistent with the resistivity structure found by Pous et al. (2004) in the same area, i.e. with the northernmost end of the conductive layer found along the whole OMZ middle crustal levels (conductor A5 in Fig. 4B). The behavior of the conductivity of this layer was explained by interconnected graphite from the Serie Negra Fm. at this depth, well below the schistosity front.

Conductor C2 is located beneath the surface occurrence of the Central Unit and provides an image of this suture at depth. The metamorphic conditions of the Central Unit (high pressure, high temperature 15 kbar and 700ºC, (Abalos et al., 1991; Azor et al., 1994) favor the graphitization of the Serie Negra Fm. in shear planes. Therefore, the area of enhanced conductivity related to the suture is presumably produced by the presence of interconnected graphite associated with the transpressive deformation along the Tomar–Badajoz–Córdoba Shear Zone. Conductor C2 can be seen as having two parts: a south-westernmost part merging with the shallow conductor below site 2 and relating to the Los Santos de Maimona fault; and a north-eastern part, with a width of no more than 15 km and gently south-dipping. The latter cor-

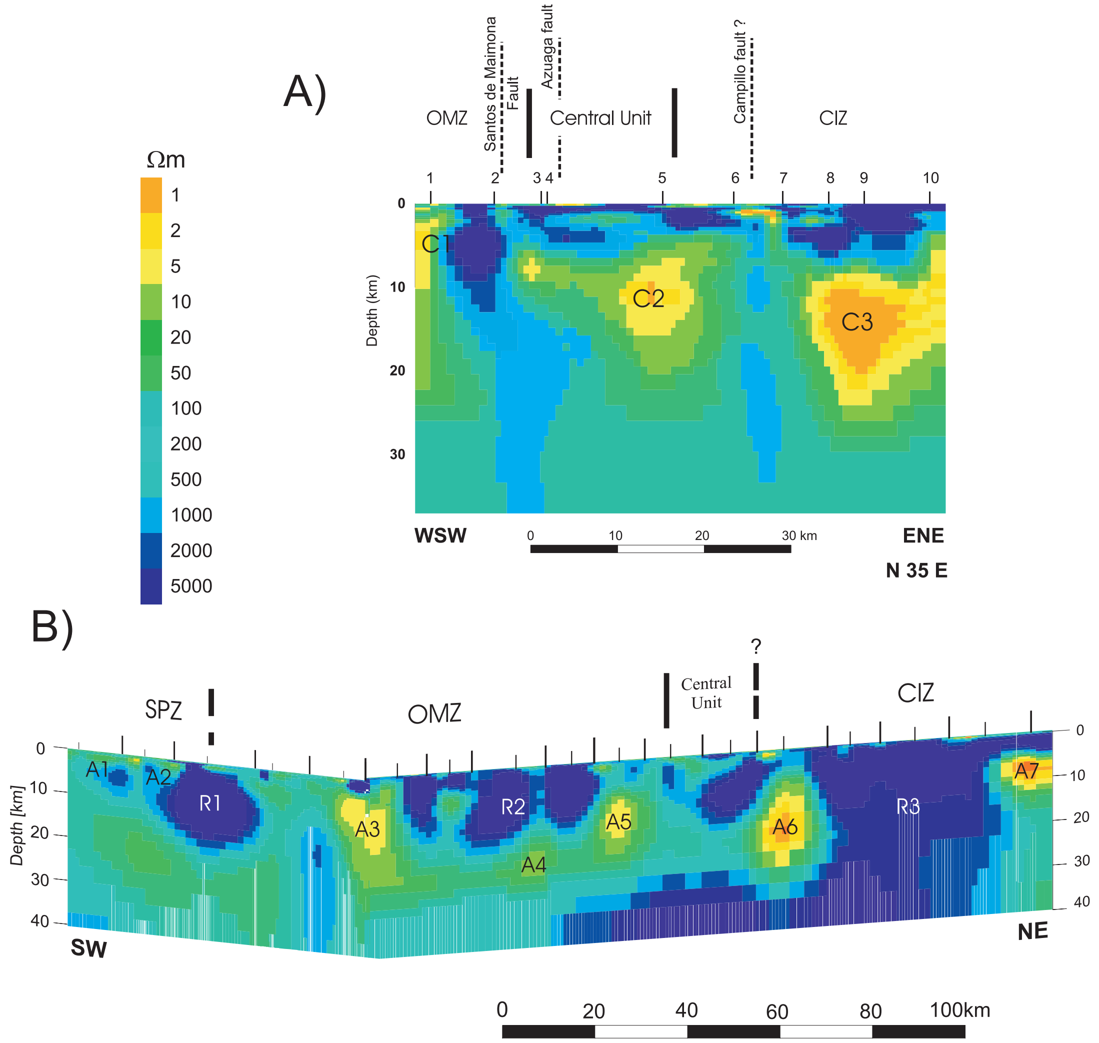

FIGURE 4 **A) Two-dimensional electrical resistivity model for profile L with some surface tectonic elements marked. See location in Fig. 3. C1, C2 and C3: high conductivity zones at middle-lower crustal levels; OMZ: Ossa Morena Zone; CIZ: Central Iberian Zone. B) Two-dimensional electrical resistivity model for profile II. See Pous et al. (2004) for a detailed discussion. Note that the resisitivity scale is the same for both figures.**

responds to the eastern prolongation of the high-conductivity body found more to the west in profile II (conductor A6 in Fig. 4B) and is related to the OMZ/CIZ suture, represented by the blastomylonitic core of this shear zone (Central Unit). This geometry agrees with the change of vergence in the shallow structures: south-verging south of the Central Unit, and north-verging north of this unit.

As explained before, in profile II of Pous et al. (2004), the conductive layer found at middle crustal depths along the whole OMZ (A4-A5-A6 in Fig. 4B) does not enter the CIZ. By contrast, in Profile L there is a large conductive body (C3) with depths ranging from 7 to 25 km in the CIZ. This is the most significant finding as it shows that the conductive layer found previously in OMZ prolongs into the CIZ. This confirms that the lack of conductor in the CIZ along profile II (R3) is due to late Variscan magma intrusions (such as the Los Pedroches batholith) that would have removed the graphite-rich materials. Presence of the Serie Negra Fm. at lower crustal depths is shown in the suture zones (SPZ/OMZ and OMZ/CIZ), where high-T amphibolite and granulite metamorphic grade Serie Negra Fm. rocks were exhumed during Variscan transpression. Thus, it is very likely that the Serie Negra occurs throughout the middle and lower crust of the OMZ (Simancas et al., 2003), as well as at the southernmost end of the CIZ.

The combination of the previous profile II and the present profile L creates an image of a conductive layer at mid-crustal depth along the whole OMZ and the CIZ. The top of this conductive layer correlates spatially with the Iberseis reflective body (IRB) along its whole length. Note that the top of the conductor C3 is at a shallower depth than most of the conductive layer in profile II (which was at about 10-15 km). This is consistent with the gentle dip of the IRB (deeper in the OMZ and shallower in the CIZ; Simancas et al. 2003).

This reinforces the view that high conductivity and high reflectivity have a common origin. The mantle-derived intrusion is corroborated by a number of geophysical and petrological evidence (Carbonell et al., 2004). Outcrops of high T and low P high-grade metamorphic rocks in the SPZ/OMZ transition (Bard, 1977; Crespo-Blanc and Orozco, 1988) are an indication of a heat source at middle crustal levels. The presence of calc-alkaline mafic intrusions from the Early Carboniferous period in some parts of the OMZ, that are related to Cu-Ni magmatic ore deposits, indicates intrusion of primitive mafic mantle-derived magmas into the crust (Tornos et al., 2001). This magma assimilated the Serie Negra black schists present and the resulting hybrid magma intruded into the upper crust. If this is so, high conductivity is due to the graphite-rich restites left by the intrusion and high reflectivity is due to the high density of the intruded materials.

CONCLUSIONS

The resistivity model obtained from a new MT profile along the northern portion of the Iberseis deep reflection seismic profile provides an image of the whole crust of the northern part of the Ossa Morena Zone (OMZ) and the Central Iberian Zone (CIZ). In the southernmost part of the model, in the Ossa Morena Zone, there is a conductive body (C1) coinciding with the conductive layer previously found in the OMZ (Pous et al., 2004). More to the northeast, another high-conductivity body (C2) appears beneath the surface occurrence of the Central Unit, inner core of the boundary between the Ossa Morena Zone and the Central Iberian Zone. The suture is imaged as a conductive zone about 15 km wide and extending from 5 km depth down to 20 km. This is consistent with the geometry of the suture found in previous studies (Pous et al., 2004), thus confirming that the OMZ/CIZ suture extends towards the SE in the studied area.

In the CIZ, a large conductive body (C3) extending from 7 to 25 km depth indicates the prolongation of the conductive layer across the suture into the CIZ which correlates with the Iberseis Reflective Body (IRB) along its whole extension. This proves that the lack of conductor in the CIZ in the previous profile II (Pous et al., 2004) was due to local effects, namely the presence of late Variscan plutonic intrusions. The correlation between the conductive layer and the Iberseis Reflective Body, together with geological and petrological evidence, confirms the hypothesis of a mantle-derived mafic intrusion of Early Carboniferous age into the area.

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REFERENCES

Abalos, B., Gil Ibarguchi, J.I., Eguiluz, L., 1991. Cadomian subduction/collision and Variscan transpression in the Badajoz-Córdoba shear belt, southwest Spain. Tectonophysics, 199, 51-72.

Almeida, E.P., Pous, J., Monteiro Santos, F.A., Fonseca, P., Marcuello, A., Queralt, P., Nolasco, R., Mendez Victor, L.A., 2001. Electromagnetic imaging of a transpressional tectonics in SW Iberia. Geophysical Research Letters, 28, 439-442.

Azor, A., González Lodeiro, F., Simancas, J.F., 1994. Tectonic evolution of the boundary between the Central Iberian and Ossa-Morena zones (Variscan belt, southwest Spain). Tectonics, 13, 45-61.

Bard, J.P., 1977. Signification tectonique des métatholéïtes d'affinité abyssale de la ceinture métamorphique de basse pression d'Aracena (Huelva, Espagne). Bulletin de la Societé Géologique de France, 19, 385-393.

Burg, J.P., Iglesias, M., Laurent, P., Matte, P., Ribeiro, A., 1981. Variscan intracontinental deformation: the Coimbra-Córdoba Shear Zone (SW Iberian Peninsula). Tectonophysics, 78, 161-177.

Carbonell, R., Simancas, F., Juhlin, C., Pous, J., Pérez-Estaún, A., González-Lodeiro, F., Muñoz, G., Heise, W., Ayarza, P., 2004. Geophysical evidence of a mantle derived intrusion in SW Iberia. Geophysical Research Letters, 31, L11601 doi:10.1029/2004GL019684.

Castro, A., Corretgé, L.G., De la Rosa, J., Enrique, P., Martínez, F.J., Pascual, E., Lago, M., Arranz, E., Galé, C., Fernández, C., Donaire, T., López, S., 2002. Palaeozoic Magmatism. In: Gibbons, W., Moreno, T. (eds.). The Geology of Spain, London, Geological Society, 117-153.

Crespo-Blanc A., Orozco, M., 1988. The Southern Iberian Shear Zone: A major boundary in the Hercynian folded belt. Tectonophysics, 148, 221-227.

Dallmeyer, R.D., Fonseca, P.E., Quesada, C., Ribeiro, A., 1993. ^{40}Ar/^{39}Ar mineral age constraints for the tectonothermal evolution of a Variscan suture in southwest Iberia. Tectonophysics, 222, 177-194.

Delgado, M., Liñán, E., Pascual, E., Pérez-Lorente, F., 1977. Criterios para la diferenciación de dominios en Sierra Morena Central. Studia Geologica Salmanticensia, 12, 75-90.

Egbert, G.D., Booker, J.R., 1986. Robust estimation of geomagnetic transfer functions. Geophysical Journal of the Royal Astronomical Society, 87, 173-194.

Eguiluz, L., 1987. Petrogénesis de rocas ígneas y metamórficas en el antiforme Burguillos-Monesterio. Macizo Ibérico Meridional. Doctoral thesis. Universidad del País Vasco, Bilbao, 694 pp.

Fonseca, P., Aráujo, A., Leal, N., Munhá, J., 1993. Variscan Glaucophane-Eclogites in the Ossa-Morena Zone. Terra Nova, 5, 11-12.

Gutiérrez-Marco, J.C., De San José, M.A., Pieren, A.P., 1990. Part IV (Central Iberia Zone): Post-Cambrian Paleozoic Stratigraphy. In: Dallmeyer, R.D., Martínez-García, E. (eds.). Pre-Mesozoic Geology of Iberia. Berlin, Springer-Verlag, 160-171.

Jones, A.G., 1992. Electrical conductivity of the continental lower crust. In: Fountain, D.M., Arculus, R.J., Kay, R.W. (eds.). Continental Lower Crust. Amsterdam, Elsevier, 81-143.

Julivert, M., Fontboté, J.M., Ribeiro, A., Conde, L., 1974. Mapa tectónico de la Península Ibérica y Baleares. Escala 1:1.000.000. Madrid, Instituto Geológico y Minero de España, 104 pp, 1 fold. map.

Matte, P., 2001. The Variscan collage and orogeny (480-290 Ma) and the tectonic definition of the Armorica microplate: a review. Terra Nova, 13, 122-128.

McNeice, G., Jones, A.G., 2001. Multisite, multifrequency tensor decomposition of magnetotelluric data. Geophysics, 66, 158-173.

Monteiro Santos, F.A., Pous, J., Almeida, E.P., Queralt, P., Marcuello, A., Mati, H., Mendes Victor, L.A., 1999. Magnetotelluric survey of the electrical conductivity of the crust across the Ossa Morena Zone and South Portuguese Zone suture. Tectonophysics, 313, 449-462.

Pous, J., Muñoz, G., Heise, W., Melgarejo, J.C., Quesada, C., 2004. Electromagnetic imaging of Variscan crustal structures in SW Iberia: the role of interconnected graphite. Earth and Planetary Science Letters, 217, 435-450.

Quesada, C., 1990a. Precambrian terranes in the Iberian Variscan Foldbelt. In: Strachan, R.A., Taylor, G.K. (eds.). Avalonian and Cadomian Geology of the North Atlantic. New York, Blackie, 109-133.

Quesada, C., 1990b. Precambrian successions in SW Iberia: their relationship to “Cadomian” orogenic events. Geological Society Special Publications, 51, 353-362.

Quesada, C., Dallmeyer, R.D., 1994. Tectonothermal evolution of the Badajoz-Córdoba shear zone (SW Iberia): characteristics and ^{40}Ar/^{39}Ar mineral age constraints. Tectonophysics, 231, 195-213.

Quesada, C., Fonseca, P.E., Munhá, J., Oliveira, J.T., Ribeiro, A., 1994. The Beja-Acebuches Ophiolite (Southern Iberia Variscan fold belt): geological characterization and geodynamic significance. Boletín Geológico Minero, 105, 3-49.

Ribeiro, A., Quesada, C., Dallmeyer, R.D., 1990. Geodynamic evolution of the Iberian Massif. In: Dallmeyer, R.D, Martínez-García, E. (eds.). Pre-Mesozoic Geology of Iberia. Berlin-Heidelberg, Springer-Verlag, 399-409.

Robardet, M., 2002. Alternative approach to the Variscan Belt in southwestern Europe: Preorogenic paleobiogeographical constraints. Geological Society of America, Special Paper 364, 1-15.

Robardet, M., Gutiérrez-Marco, J.C., 1990. Part V (Ossa Morena Zone): Passive Margin Phase (Ordovician-Silurian-Devonian). In: Dallmeyer, R.D., Martínez-García, E. (eds.). Pre-Mesozoic Geology of Iberia. Berlin-Heidelberg, Springer-Verlag, 267-272.

Sánchez-Carretero, R., Eguiluz, L., Pascual, E., Carracedo, M., 1990. Part V (Ossa Morena Zone): Igneous rocks. In: Dallmeyer, R.D., Martínez-García, E. (eds.). Pre-Mesozoic Geology of Iberia. Berlin-Heidelberg, Springer-Verlag, 292-313.

Sánchez-García, T., Bellido, F., Quesada, C., 2003. Geodynamic setting and geochemical signatures of Cambrian-Ordovician rift-related igneous rocks (Ossa-Morena Zone, SW Iberia). Tectonophysics, 365, 233-255.

Silva, J.B., Oliveira, J.T., Ribeiro, A., 1990. Part VI (South Portuguese Zone): Structural Outline. In: Dallmeyer, R.D., Martínez-García, E. (eds.). Pre-Mesozoic Geology of Iberia. Berlin-Heidelberg, Springer-Verlag, 348-362.

Simancas, F., Martínez Poyatos, D., Expósito, I., Azor, A., González Lodeiro, F., 2001. The structure of a major suture zone in the SW Iberian Massif: the Ossa-Morena/Central Iberia contact. Tectonophysics, 32, 295-308.

Simancas, F., Carbonell, R., González Lodeiro, F., Pérez Estaún, A., Juhlin, C., Ayarza, P., Kashubin, A., Azor, A., Martínez Poyatos, D., Almodóvar, G.R., Pascual, E., Sáez, R., Expósito, I., 2003. The Crustal Structure of the Transpressional Variscan Orogen of SW Iberia: The IBERSEIS Deep Seismic Profile. Tectonics, 22(6), 1062, doi:10.1029/2002TC001479.

Siripunvaraporn, W., Egbert, G., 2000. An efficient data-subspace inversion method for 2-D magnetotelluric data. Geophysics, 65, 791-803.

Teixeira, C., 1955. Notas sobre geología de Portugal: O complexo xisto-grauváquico ante-ordoviciano. Lisboa, Empresa Literaria Fluminense Lda., 50 pp.

Tornos, F., Casquet, C., Galindo, C., Velasco, F., Canales, A., 2001. A new style of Ni-Cu mineralization related to magmatic breccia pipes in a transpressional magmatic arc, Aguablanca. Mineralium Deposita, 36, 700-706.

Vozoff, K., 1972. The magnetotelluric method in the exploration of sedimentary basins. Geophysics, 37, 98-141.

Wannamaker, P.E., Stodt, J.A., Rijo, L., 1987. A stable finite element solution for two-dimensional data. Geophysics, 88, 277-296.

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