DISCUSSION ON «U-PB GEOCHRONOLOGY FOR THE BARREIROS TECTONISED GRANITOIDS AND ARRONCHES MIGMATITIC GNEISSES: TOMAR CORDOBA SHEAR ZONE, EAST CENTRAL PORTUGAL» by D.P.S. de Oliveira, M. Poujol and L.J. Robb

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M. Francisco Pereira would like to thank de Oliveira and co-workers for the opportunity to review and comment their earlier version of this recent paper. But, since this new version (de Oliveira *et al.*, 2002) contains significant omissions and misinterpretations of the constructive suggestions and of the data presented in our and others published articles, we consider appropriate to discuss here the contents of their present paper. First, we will deal with the correction of misleading statements related to the characterization of the structure of the Northeast Alentejo sector of the Coimbra-Cordoba shear zone and then we will discuss the U-Pb geochronological results and geodynamic implications in the context of the complex tectonic evolution of this region.

The location of the Ossa-Morena Zone - Central-Iberian Zone boundary

The exact location of the Ossa-Morena Zone (OMZ) / Central-Iberian Zone (CIZ) boundary has been discussed in several studies mostly by Iberian geologists (e.g. Ribeiro *et al.*, 1979; Burg *et al.*, 1981; Chacón *et al.*, 1983; Julivert, 1987; Apalategui *et al.*, 1990; Oliveira *et al.*, 1991; Abalos and Eguiluz, 1992; Azor *et al.*, 1994; Eguiluz *et al.*, 1995, 2000; Pereira and Silva, 2001a; Simancas *et al.*, 2001). In the Northeast Alentejo region this limit has been referred to be a tectonic boundary: the Portalegre thrust which represents the northern limit of the Blastomylonitic corridor or belt (Ribeiro *et al.*, 1979; Oliveira *et al.*, 1991). The Blastomylonitic belt has been considered the Portuguese extension of the Badajoz-Cordoba shear zone defined in Spain (Abalos and Eguiluz, 1992), both segments of the Coimbra-Cordoba shear zone (CCSZ as defined by Burg *et al.*, 1981).

It is assert by de Oliveira *et al.* (2002, p.102) that Pereira and Silva (2000) defined the OMZ/ CIZ limit in South-Central Spain within the Tomar-Cordoba shear zone. This reference is wrong because we never said anything similar regarding the OMZ/CIZ boundary in Spain. In our paper (Pereira and Silva, 2000) we pointed out that the OMZ/CIZ boundary exhibit a extended geodynamic evolution during the Paleozoic and cannot be simplified as a single Variscan overthrust (Portalegre thrust) of the OMZ over the CIZ. We also suggested that the OMZ/CIZ boundary present-day geometry is the result of the penetrative Variscan shearing, which overturned and obliterated a regional lower Paleozoic paleogeographic boundary, as can be described within the Portalegre-Esperança shear zone (e.g. Pereira and Silva, 2001b).

The structure of the Coimbra-Cordoba shear zone (CCSZ) in the Northeast Alentejo region (Portugal)

The description of the Northeast Alentejo region structural setting by de Oliveira *et al.* (2002) contains significant omissions, errors and misinterpretations.

Figure 1 of de Oliveira *et al.* (2002) present a general geological map of the Northeast Alentejo with the following serious errors:

(1) The authors ignored recent detailed structural studies developed in this region (e.g. Pereira, 1999; Pereira and Silva, 1997, 2000, 2001b) and suggest that the Urra Formation only comprises metapelites and greywackes attributed to Proterozoic age which is not correct; This formation is made of distinct volcaniclastic units and considered to be of Lower Paleozoic age (Cambrian/Ordovician), in the same stratigraphic position of similar formations overlained by the Arenigian Armorican quartzites found in other areas of the CIZ (the Bojas Formation in the Marão region, Coke and Gutiérrez-

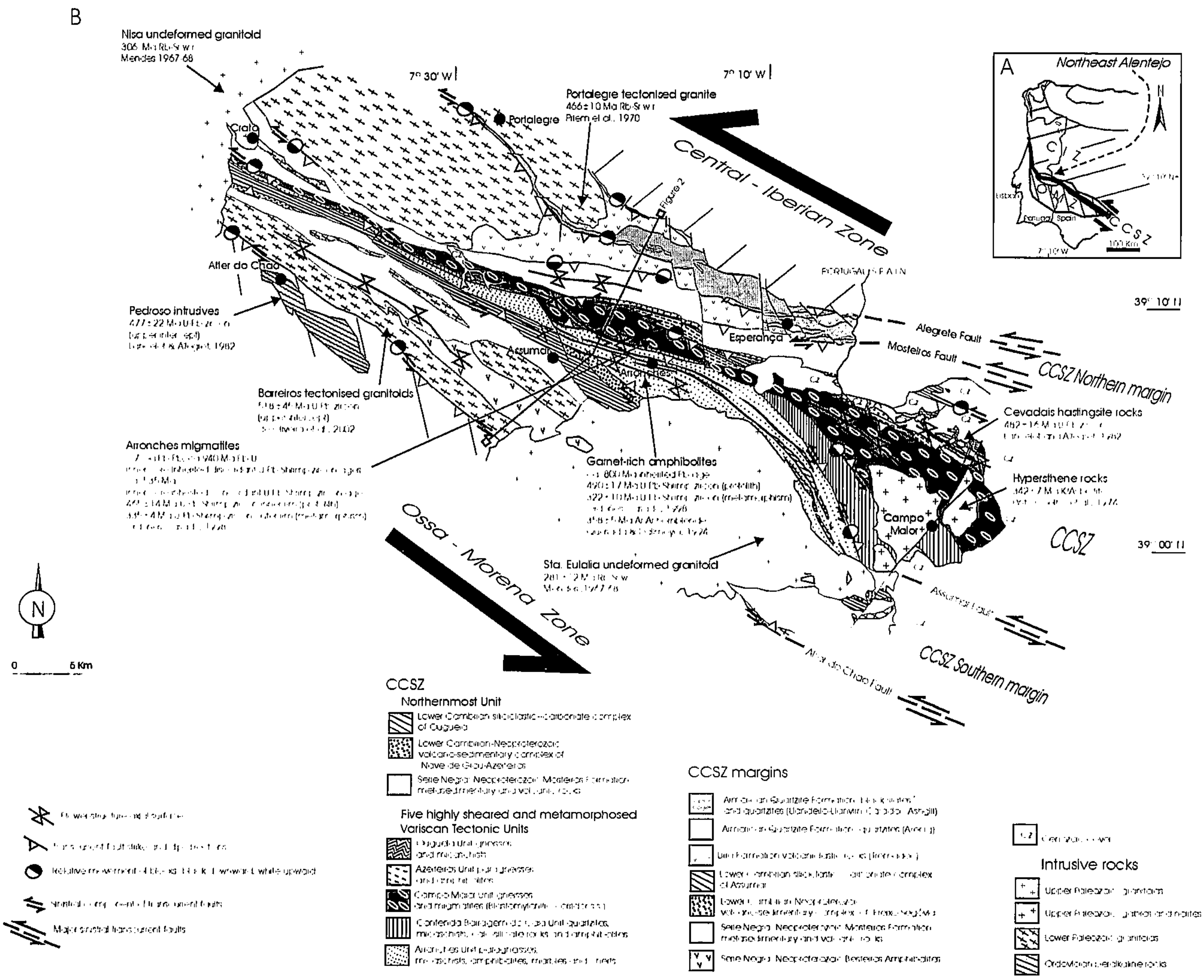

Figure 1 – Geological map of the Northeast Alentejo region (northernmost domains of the Ossa-Morena Zone in Portugal) showing the major units of the Coimbra-Cordoba shear zone and adjacent margins (the Portalegre-Esperança shear zone at North, and the Megastructure of Assumar at South) and existent radiometric dates; Modified from Pereira and Silva, in press).

Marco, 1995; the Vale do Grou Group in the Mação region, Romão and Oliveira, 1995).

(2) de Oliveira *et al.* (2002) erroneously considered a Proterozoic age for the gneisses and migmatites included in the "Blastomylonitic belt" (see discussion for details); Recent U-Pb SHRIMP data pointed for the occurrence of a migmatization event within this strongly sheared CCSZ high-grade metamorphic unit during the Upper Paleozoic (Ordoñez-Casado *et al.,* 1997; Ordoñez-Casado, 1998); These results confirm that this high-grade tectonic unit is much younger than previously thought.

(3) The description of the Serie Negra Neoproterozoic successions omits the reference to a very characteristic rock, the black metacherts, which presence is an essential diagnostic feature to the recognition of this formation all over the OMZ (e.g. Carvalhosa, 1965; Gonçalves, 1971, 1978; Gonçalves and V. Oliveira, 1986; Oliveira *et al.,* 1991; Gonçalves and Carvalhosa, 1994; Pereira and Silva, 2001 b,c);

(4) The classification as thrusts of the major faults of this region was abandoned after detailed structural studies (Pereira, 1999). Nowadays these faults are considered as transcurrent faults with strike- and oblique-slip movements parallel to the orogen-trend (Pereira and Silva, 2000, 2001 b, in press);

(5) The references cited in the legend of the same Fig.1 of de Oliveira *et al.* (2002) inflate the importance of the contributions made by Oliveira *et al.,* (1992), Moreira (1994) and Solá (1996-1999) for the mapping of this sector of the OMZ in Portugal, and fail to acknowledge the extremely important contributions made by others field geologists who mapped and studied this complex region during the seventies as Torre de Assunção and Gonçalves (1970), Pinto Coelho and Gonçalves, 1971; Gonçalves (1971), Gonçalves *et al.,* (1972, 1978) and Gonçalves and Fernandes (1973).

In their paper de Oliveira *et al.,* (2002) also raise a number of cited statements to described the CCSZ structure, as references to Gonçalves (1971) and Pereira (1999), that are not correct:

(1) The authors quote (p.107): "The distribution of several of (...) thrust fault-bounded lithological packages creates a (asymmetric) flower structure-like

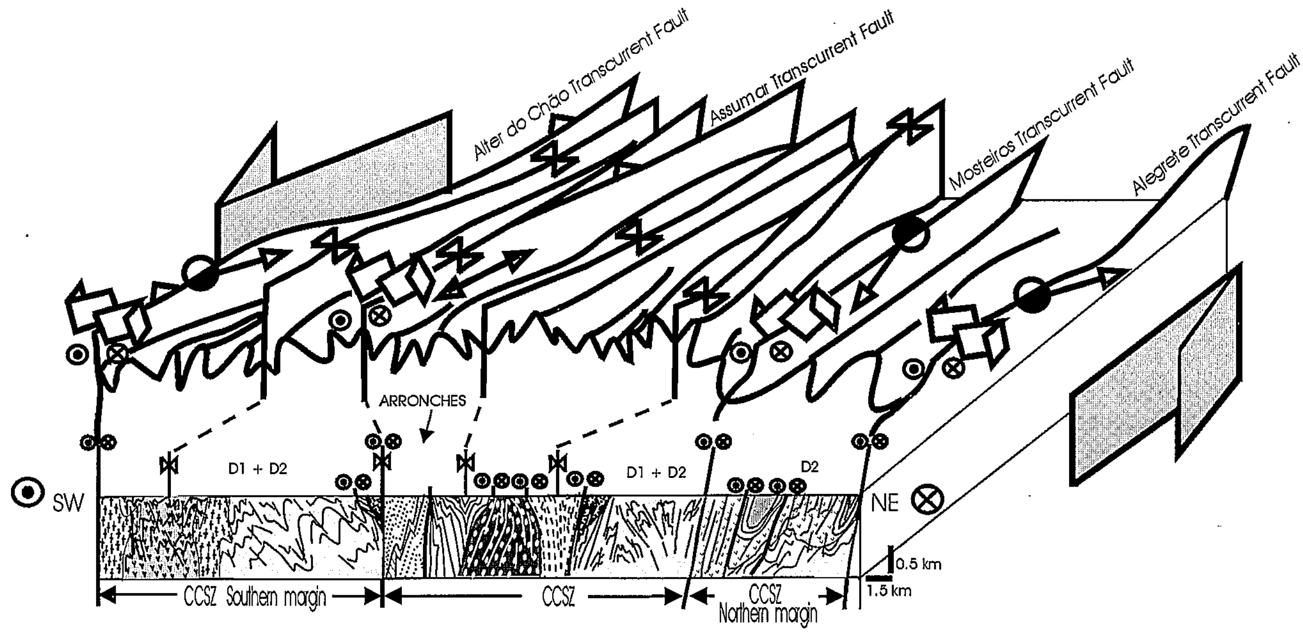

Figure 2 – Schematic tri-dimensional representation of the structure of the Northeast Alentejo region, showing an interpretative cross-section with localization on Fig. 1; Modified from Pereira and Silva, in press.

morphology (Gonçalves, 1971)" or "The CM Unit refers to the migmatitic gneisses, (...) form the core of the flower structure proposed by Gonçalves (1971)". Gonçalves never used the term flower structure in his PhD thesis to define the complex geometry of the Northeast Alentejo region.

(2) The description of the internal complex structure of this sector of the CCSZ by de Oliveira *et al.*, (2002) misinterpret the data presented on my PhD thesis (Pereira, 1999). First, when they mentioned (p.107) the terms "Campo Maior Formation", "Morenos Formation", "Mosteiros Formation" and "Urra Formation" to describe the internal structure of the CCSZ, they use abandoned interpretations based on the existence of a major anticlinorium with Riphean highly metamorphosed and deformed gneisses and migmatites in the core and Vendian less metamorphosed sedimentary and volcanic rocks on the northern and southern limbs (e.g. Gonçalves and V. Oliveira, 1986; Oliveira *et al.*, 1991). It is now generally accepted that structural complexity should not be used as the base criteria for assigning rocks to older ages when compared with adjacent less deformed and metamorphosed rocks.

More, we consider the subdivision of the CCSZ in a northernmost unit where the weakly deformed and metamorphosed Neoproterozoic-Lower Cambrian stratigraphic sequence is recognised and in five highly sheared and metamorphosed Variscan tectonic units (Figs. 1 and 2). This is not what de Oliveira and co-workers state as a quote (p.107): "There are four tectonostratigraphic subdomains defined by Pereira (1999) that make up the TCSZ (...) the Assumar Subdomain or Megastructure, the Arronches-Morenos-Caia Subdomain, the Degolados-Campo Maior subdomain and finally the Urra-Mosteiros-Ouguela Subdomain, last latter three making up the Crato-Arronches-Campo Maior Megastructure." or "Pereira (1999) has divided the CAC Megastructure into three units, namely Campo Maior (CM), Contenda-Barragem do Caia (CBC) and Arronches (ARR) Units (...)".

We argue that the CCSZ represents a complex Variscan ductile sinistral shear zone superposed to a Neoproterozoic-Paleozoic geological record (Cadomian volcanic arc and Lower Paleozoic basins and magmatism). It is characterised by the heterogeneous distribution of Variscan deformation (D2) and metamorphism (M2) with the developed of a steep mylonitic foliation and a subhorizontal to gently dipping stretching lineation under high- to low-grade metamorphic conditions. The above mentioned five strongly deformed and heterogeneously metamorphosed Variscan tectonic units, bounded by major transcurrent faults (Pereira and Silva, in press), are from north to south (Figs.1 and 2):

- The Ouguela Unit composed of feldspar-rich blastomylonitic gneisses (P-T estimates: 600-700°C / 7-9 kbar; Pereira and Apraiz, 2002), leucocratic segregations, sillimanite-biotite-rich paragneisses and garnet-kyanite-sillimanite-andalusite-biotite micaschists;
- The Azeiteiros Unit with feldspar-biotite-chlorite paragneisses and hornblende-actinolite amphibolites;
- The Campo Maior Unit (high-grade blastomylonitic corridor *s.s.*) made by sillimanite-biotite paragneisses, migmatitic gneisses (rocks sampled, nearby the Arronches village, for geochronological studies by de Oliveira *et al.*, 2002 and by Ordoñes-Casado, 1998), quartz-feldspar-sillimanite blastomylonitic gneisses (P-T ~ 650-750°C / 6-7 kbar),

garnet-rich amphibolitic gneisses, garnet-rich amphibolites and leucocratic segregations;

- The Contenda-Barragem do Caia Unit composed of mylonitised quartz-feldspatic gneisses and quartzites, garnet-rich amphibolites (P-T estimates: 550-700ºC / 8-10 kbar; Pereira and Apraiz, 2002), calk-silicate rocks, epidote-rich amphibolites, garnet-biotite micaschists and alkaline blastomylonitic gneisses;

- The Arronches Tectonic Unit with garnet-rich micaschists, marbles, black metacherts, amphibolites, garnet-rich amphibolites, alkaline-peralkaline blastomylonitic gneisses, staurolite-garnet-rich micaschists (P-T ~ 550-600ºC / 5-6 kbar), biotite-garnet metapelites and metapsammites.

The present geometry of this complex region reflects the structure developed during the Variscan transcurrent movements parallel to the orogen-trending. Is made up of a system of composite flower-like structures with opposite northeasterly or southwesterly verging narrow asymmetric folds with steep axial planes, superposed to previous Variscan and Cadomian tectonic fabrics.

The traditional section of a fan-like geometry for the OMZ northern domains with opposite vergences of nappes and recumbent folds rooted in a central high-grade blastomylonitic belt (Matte, 1991) is not recognised in this sector of the CCSZ.

Discussion on "U-Pb geochronology for the Barreiros tectonised granitoids and Arronches migmatitic gneisses"

The geochronological data presented by de Oliveira *et al.*, (2002) is, in part, an important contribution to constrain the character of Cadomian metamorphism (M1) and timing of deformation (D1) observed in this region. The assignation of the amphibolitic facies metamorphism (M1) and ductile deformation (D1), which affects the Neoproterozoic Serie Negra succession in the Northeast Alentejo region (Megastructure of Assumar), to the Cadomian orogeny suggested by field data (Pereira and Silva, 1999) is now confirmed and supported by the geochronological data presented by de Oliveira *et al.* (2002) for the Barreiros granitoids (518±45 Ma: U/Pb multi-grain technique on zircons, interpreted as the Middle Cambrian to Lower Ordovician protolith age).

Contrariwise, we believe that the interpretation of the geochronological data applied to the Arronches migmatitic gneisses by de Oliveira and co-workers which is used to assign this rocks to the Palaeoproterozoic, is not supported by the presently accepted geological setting for this region.

First, we don't consider appropriate to believe that the CCSZ high-grade blastomylonitic corridor (*s.s.*) is composed by the oldest Proterozoic rocks of this region as suggested by de Oliveira *et al.*, (2002) in their geological map (p. 106). It is clear that they are mixing distinct geological concepts when they present an interpretation for the obtained Arronches migmatitic gneisses ages (p.110): "(...) 2146±91 Ma (...) age is interpreted as the minimum age of protolith formation" and "(...) the age of 431.2±6.4 Ma (...) identical within error to the age of 442.6± 2.6 obtained for the Barreiros tectonised granitoids (...) points towards a leucosome formation event (partial melting) (...)". How can it be possible to consider a Paleoproterozoic age for the tectonic unit that includes the Arronches migmatitic gneiss when it is assumed, by the same authors, a Paleozoic age for the partial melting and leucosome formation reported on this rocks? We would like to remember that the main criteria to define this tectonic unit is the character of the high-grade metamorphism and not the protolith ages of different kind of strongly sheared and highly metamorphosed Neoproterozoic to Paleozoic rocks which can be distinguished within it.

Secondly, it most be also referred that other studies, on rocks from this high-grade metamorphic blastomylonitic unit (besides of that one from the Arronches migmatites by Ordoñes-Casado, 1998) indicated by de Oliveira *et al.*, (2002, p.108-109), pointed for the presence of different ages from the zircon populations:

(1) High-grade calc-silicate gneiss of La Cardenchosilla (Spain): 2253+211/-194 Ma (upper intercept, U-Pb multi-grain technique on zircon) interpreted as average-age of provenance and 418±2 Ma (lower intercept, U-Pb multi-grain technique on zircon) interpreted as a presumed granulite-facies overprint (Schäfer, 1990); 343±5 Ma (overgrown rims, U-Pb SHRIMP zircon age) interpreted as partial melting (Ordoñes-Casado, 1998);

(2) Paragneiss of La Cardenchosilla (Spain) (Ordoñes-Casado, 1998): 2.4 – 2.5 Ga ($^{207}Pb/^{206}Pb$, inherited discordant U-Pb SHRIMP zircon age); 600-700 Ma (inherited concordant U-Pb SHRIMP zircon age); 566±8 Ma ($^{206}Pb/^{238}U$, oscillatory rim U-Pb SHRIMP zircon age) interpreted as the maximum age of deposition; 341± Ma (U-Pb SHRIMP zircon age) interpreted as the age of metamorphism;

(3) Azuaga gneiss from Arroyo Argallón (Spain) (Ordoñes-Casado, 1998): 2.4 Ga (inner core, inherited concordant U-Pb SHRIMP zircon age); 0.86 and 1.9 Ga ($^{206}Pb/^{238}U$, inner core, inherited discordant U-Pb SHRIMP zircon age); 1.0 and 2.2 Ga ($^{207}Pb/^{206}Pb$, inner core, inherited discordant U-Pb SHRIMP zircon age); 500-700 Ma (inherited concordant U-Pb SHRIMP zircon age); 509±8 Ma (U-Pb SHRIMP zircon intercept age) interpreted as the formation of the igneous protolith; 341± Ma (U-Pb SHRIMP zircon age);

These heterogeneous zircon ages seem to indicate recycling processes during the Variscan orogeny of zircons formed during the Lower Paleozoic magmatic events, the Cadomian orogeny and of detritical variably old Proterozoic or Archean contributions from different provenances.

The poly-orogenic evolution reported within the CCSZ is a well-established fact. Despite of the controversy on the possibility to determine the tectonometamorphic characteristics of the Cadomian events within the CCSZ (Azor *et al.*, 1993; Abalos *et al.*, 1993; Eguiluz *et al.*, 2000; Simancas *et al.*, 2001), there are several data sources leading to think that the Variscan orogeny played an important role in defining the structural and metamorphic major divisions recognised at present (Pereira and Silva, 2001, in press).

As a final point, the U-Pb multi-grain zircon dating technique can achieve accurate results if is it applied to simple zircon systematics (magmatic rocks that not suffered complex overprint processes) but to obtain reliable radiometric data from high-grade metamorphic rocks it is crucial to use the SHRIMP U-Pb dating of zircon crystals assisted by detail cathodoluminescence studies. This analytical technique allows the recognition of distinct zircon records related to complex geologic histories involving combined effects of the presence of inherited grains and distinct zircon growth or Pb-loss, which is crucial to avoid interpretations with non realistic geological significance.

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