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Lithostratigraphy of the "Schist-Greywacke Domain" in Portugal: a reappraisal

Litoestratigrafía del "Dominio Esquisto-Grauváquico" en Portugal: una reevaluación

Carlos A. P. MEIRELES[1]*, Paulo F. CASTRO[1], Nuno VAZ[2,3], Carlos ÂNGELO[1], Narciso FERREIRA[1], António J. D. SEQUEIRA[1], Artur A. SÁ[2,3]

[1]Laboratório Nacional de Energia e Geologia, Rua da Amieira, Apartado 1089 - 4466-901, S. Mamede de Infesta, Portugal
[2]Departamento de Geologia, Universidade de Trás-os-Montes e Alto Douro (UTAD), Quinta dos Prados, 5000-801, Vila Real, Portugal
[3]Polo da UTAD do CGeo – Centro de Geociências da Universidade de Coimbra, Quinta dos Prados, 5000-801, Vila Real, Portugal

*Correspondent author: carlos.meireles@lneg.pt

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Abstract

A synthesis of the knowledge of the Schist-Greywacke Domain (SGD) in Portugal is here presented. Until recently, this sequence assumed the designation of Dúrico-Beirão Supergroup composed by the Douro Group (DG) and the Beiras Group (BG). The DG is considered of Neoproterozoic – Cambrian age and the BG is of Neoproterozoic age. The identification and mapping in the BG of an unconformity as the Cadomian unconformity identified in Spain, which splits the Neoproterozoic in "lower Alcudian" and "upper Alcudian", is a turning point for the understanding and establishment of consistent stratigraphic sequences that now compose the Fróia and the Lousã groups assembled in the Beiras Supergroup. These new groups are correlated with the Neoproterozoic sequences currently recognized in Spain: the Lousã group is equivalent to the Ibor Group (upper Alcudian) and the Fróia Group is equivalent *pro parte*, to the Domo Extremeño Supergroup.

Keywords: Central Iberian Zone; Metasedimentary sequences; Beiras Supergroup; Douro Group; Iberian correlation

Resumen

En este trabajo se presenta una síntesis del conocimiento actual del Dominio del Complejo Esquisto-Grauváquico en Portugal. Hasta al presente esta secuencia ha sido designada como Supergrupo Dúrico-Beirão, compuesto por el Grupo Douro (GD) y por el Grupo Beiras (GB). El GD se consideraba de edad Ediacárico superior – Cámbrico inferior y el GB era atribuido al Neoproterozoico. La identificación y cartografía en el GB de una discordancia correlacionable con la del Cadomiense identificada en España, que divide el Neoproterozoico en "Alcudiense inferior" y "Alcudiense superior", es un punto de inflexión para la comprensión y el establecimiento de secuencias estratigráficas consistentes, que ahora componen los grupos Fróia y Lousã reunidos en el Supergrupo Beiras. Estos nuevos grupos se correlacionan con las secuencias neoproterozoicas actualmente reconocidas en España: el Grupo Lousã es equivalente al Grupo Ibor (Alcudiense Superior) y el Grupo Fróia es equivalente, *pro parte*, al Supergrupo Domo Extremeño.

Palabras clave: Zona Centro Ibérica, secuencias metasedimentarias, Supergrupo Beiras, Grupo Douro, correlación ibérica

1. INTRODUCTION

In Portugal, the pre-Ordovician metasedimentary sequences of Central Iberian Zone (CIZ) were referred traditionally as "Schist-Greywacke Complex" (CARRINGTON DA COSTA, 1950; TEIXEIRA, 1955). These sequences were later considered with the hierarchy of Dúrico-Beirão Supergroup (DBS) (PEREIRA, 1987; SOUSA and SEQUEIRA, 1989; SILVA *et al.*, 1989). The DBS (Fig. 1) was divided into *i*) Douro Group (DG), composed of flysch-like alternations of metagreywackes, slates and minor metaconglomerates, with carbonates levels at the base. This lithological sequence was considered of upper Ediacaran to lower Cambrian age (SOUSA and SEQUEIRA, 1993 and references therein); *ii*) Beiras Group (BG), a monotonous flysch-like succession of metagreywackes, slates and metaconglomerates, considered as deep-water turbidite-like sediments without carbonate intercalations (SOUSA, 1981, 1982, 1984; SILVA *et al.*, 1995). However, studies in the Caramulo and Lousã sectors (Fig. 1) of the BG (Central Portugal) revealed that more shallow-water sandy depositional environments also occur (MEDINA *et al.*, 1998a; ALONSO-GAVILÁN *et al.*, 2001; SILVA, 2013). Based on regional correlations with the Spanish sectors (SOUSA, 1984; RIBEIRO *et al.*, 1990; SOUSA and SEQUEIRA, 1993; RODRÍGUEZ ALONSO *et al.*, 2004) on paleontological evidence (SEQUEIRA, 2011) and geochronologic data (TASSINARI *et al.*, 1996; TEIXEIRA *et al.*, 2011; PEREIRA *et al.* 2012; CRISPIM *et al.*, 2021), a Neoproterozoic age is currently assumed for the BG.

Regarding the BG, until recently the current geological knowledge was the result of the profusion of local and partial studies carried out according to different mapping criteria. An example of this reality was the proposal for the creation of the "Arda-Marofa Group" by SILVA (2013). This work assumed that the deposition of the Beiras, Douro and "Arda-Marofa" groups occurred in distinct broadly contemporaneous basins (Fig. 2). The "Arda-Marofa Group" *sensu* SILVA (2013, 2014) would include several units which clearly belong to the DG, as it is the case of the Desejosa and S. Domingos formations (SOUSA, 1983), local units ascribed to the DG as 'Excomungada fm.' (SOUSA, 1989) and even to the Lower Ordovician units, as is the case of 'S. Gabriel formation' (SILVA and RIBEIRO, 1991; COKE *et al.*, 2001). So far, the vast amount of data obtained during our field studies described below, showed that lithostratigraphic model is not scientifically well supported and, for this reason, we suggest that it should be updated.

Meanwhile, a regional scale angular unconformity was mapped dividing the BG in two distinct lithostratigraphic sequences – Fróia and Lousã, respectively – correlated with the "lower Alcudian" and "upper Alcudian" sequences in Spain (MEIRELES *et al.*, 2014 and references therein). This unconformity corresponds to the Cadomian unconformity previously recognized in Spain (GONZÁLEZ LODEIRO *et al.*, 2004). In the present revision, the BG assumes the rank of Beiras Supergroup (BSG), as described below.

In the context of the preparation of the Geological Map of Portugal, sheet No. 4, scale 1:200 000 (Fig. 1), an effort has been made during the last several years by the authors

to achieve a better knowledge and understanding of the lithostratigraphy of these pre-Ordovician sequences (MEIRELES, coord., 2020). A significant number of revisions, some already published (MEIRELES *et al.*, 2013; MEIRELES *et al.*, 2014; SÁ *et al.*, 2014) allowed the present overview of the Portuguese "Schist-Greywacke Domain" (SGD) state of the art.

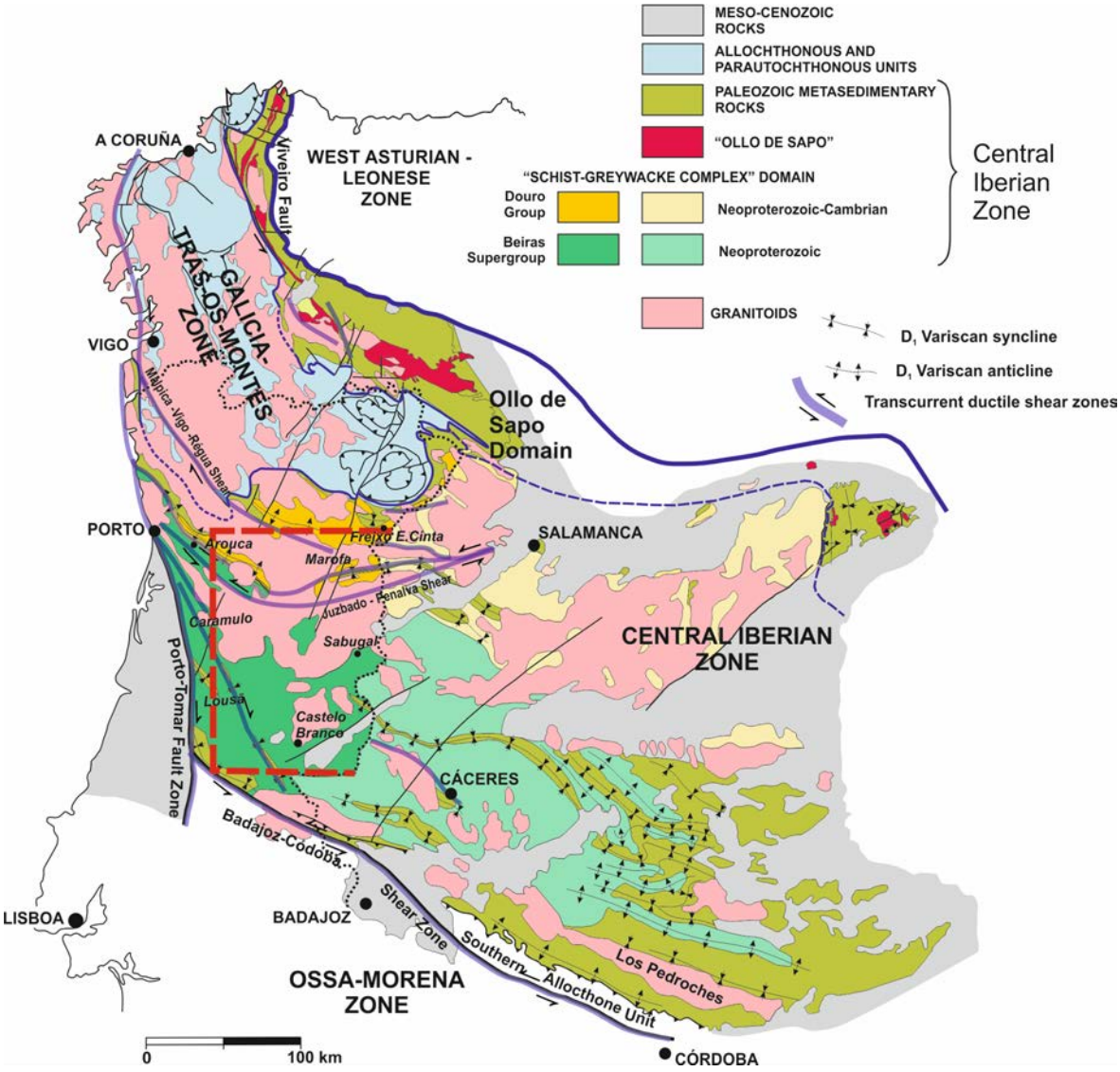

Figure 1. Location of the area (framed area with dashed red line and the Portugal-Spain border black dotted line) in the geologic context of the Central Iberian Zone (adapted from MARTÍNEZ-CATALÁN *et al.*, 2004 and from RODRÍGUEZ-FERNÁNDEZ, 2004).

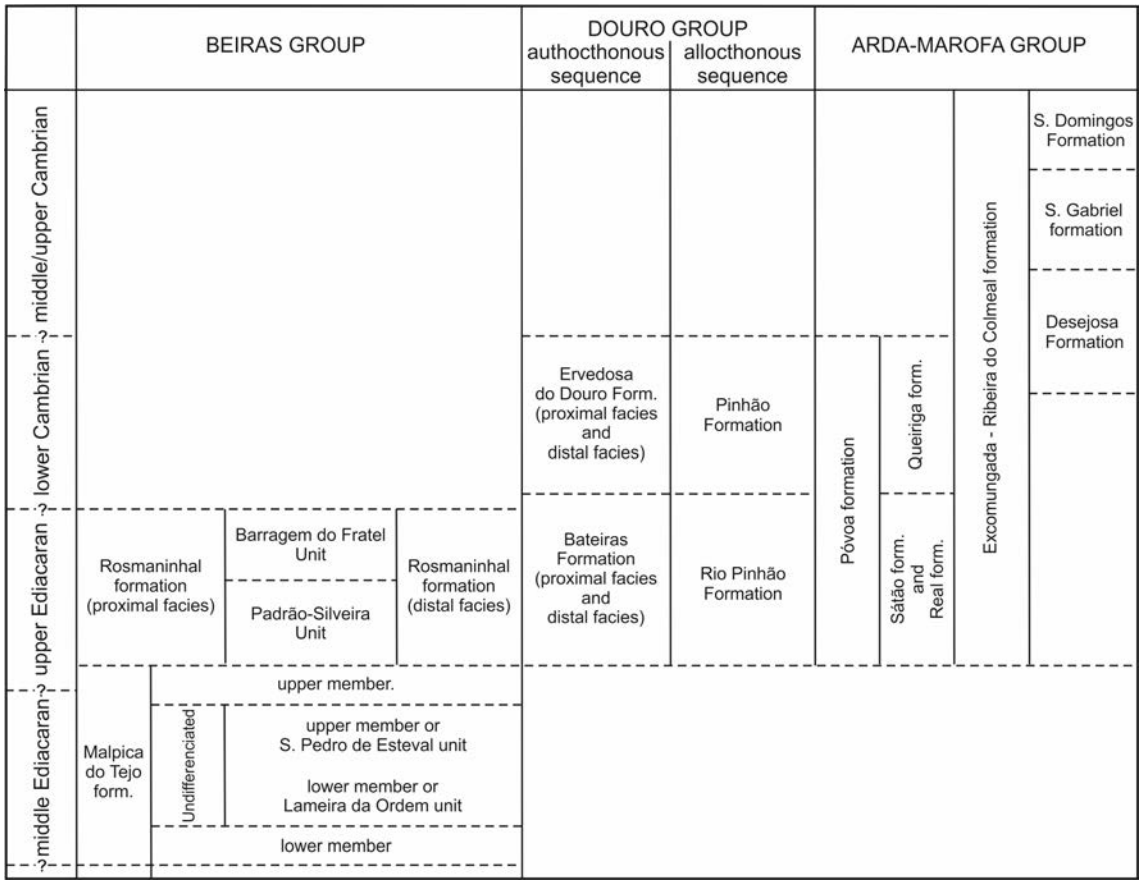

Figure 2. The proposal of A. F. Silva for the "Schist-greywacke Domain" in Portugal (adapted from SILVA, 2013).

2. THE DOURO GROUP

The first and most complete study of the DG was made by SOUSA (1982, 1983a) who defined the following formal lithostratigraphic units, from bottom to the top (Fig. 3):

- Bateiras Formation - formed from bottom to top by two informal members: *i*) black graphitic slates and metagreywackes; *ii*) grey slates, metagreywackes, and metalimestones. The estimated thickness is 800±100 m (SOUSA, 1982, 1983a). Recent field revisions confirmed this thickness.
- Ervedosa do Douro Formation – composed by thin alternations of green slates and metasiltstones. Magnetite-rich levels are interpreted as reference horizons. It has an estimated thickness of about 250±50 m.
- Rio Pinhão Formation – this unit shows predominance of thick metagreywackes alternating with thin dark slates. Its thickness is about 250±50 m.
- Pinhão Formation – this unit is lithologically and sedimentologically similar to the Ervedosa do Douro Formation, including the presence of magnetite-rich levels. It has a thickness of ca. 350±50 m.

- Desejosa Formation – represented by siliceous slates with fine metasiltstone intercalations and sparse metagreywacke levels. The estimated thickness is about 250±50 m.
- São Domingos Formation – it is characterized by polymictic metaconglomerates and metaquartzarenites, with an estimated thickness of ca. 50 m.

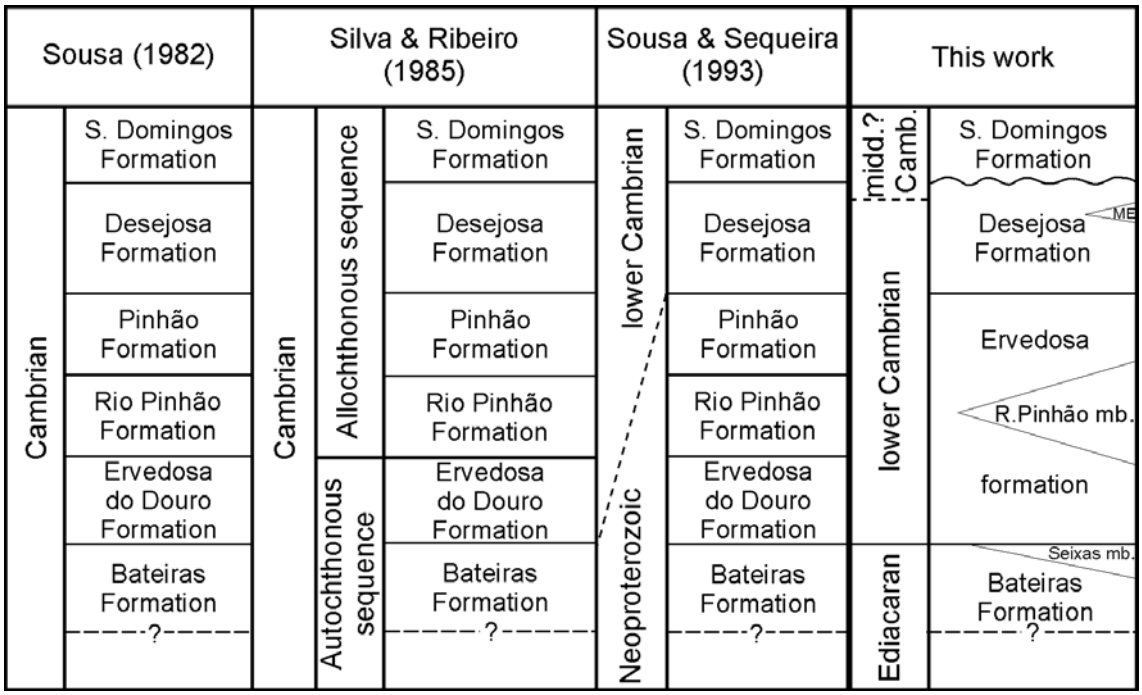

Figure 3. Correlation chart showing the knowledge evolution of the lithostratigraphic sequence of the Douro Group. Legend: Wavy line, erosional unconformity; midd.? Camb., middle? Cambrian; R. Pinhão mb., Rio Pinhão member; ME, Montes Ermos member; Seixas mb., Seixas member.

According to SOUSA (1982, 1983b), the lithologies and sedimentary structures are those of a classical turbiditic sequence with a continuous filling up of submarine fans.

More recently, in the Freixo de Espada à Cinta region (Fig. 1), a new informal unit was mapped, the Montes Ermos fm., which according to the authors conformably overlies the Desejosa Formation (DIAS DA SILVA, 2014; DIAS DA SILVA *et al.*, 2014). This unit, identified so far only in this area, is made up of thin alternations of grey fine-grained metasandstone and metasiltstone beds with a total thickness not greater than 150 m. The fieldwork carried out for the present revision and preliminary geochemical data recently obtained by the authors showed that this unit is a local facies variation of the Desejosa Fm., sharing the same geochemical signature (Fig. 4). For these reasons, the lithostratigraphic rank is here changed to Montes Ermos member (Fig. 3).

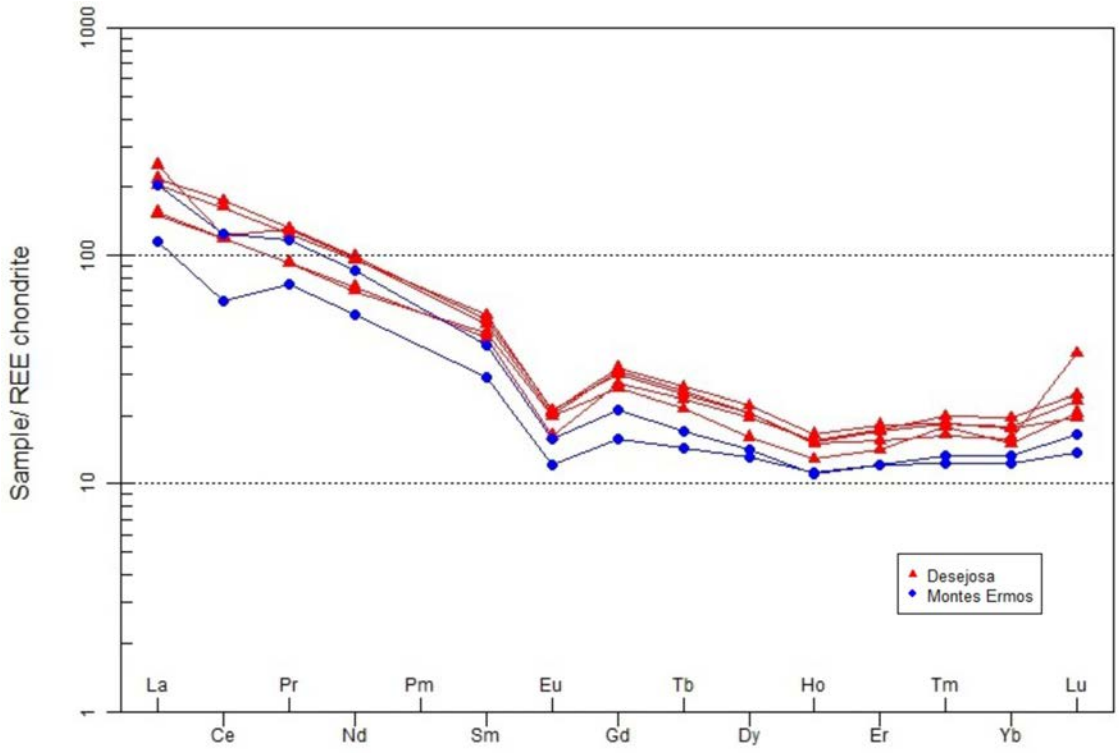

Figure 4. REE spider plot of Desejosa and Montes Ermos units. For the calculations and the plot diagram (REE chondrite Boynton 1984) was used the program GCDkit 6.0 (JANUSEK *et al.*, 2006).

The first fossils found in the DG belongs to the Desejosa Formation and corresponds to trilobite remains (REBELO, 1985). Unfortunately, "the specimens are incomplete and poorly preserved to allow identification or a meaningful description" (REBELO and ROMANO, 1986). Due to these limitations, it was then only possible to assign a Cambrian age to the upper part of the DG. Posteriorly, DIAS DA SILVA *et al.* (2014) noticed the discovery of the trace fossils *Rosselia* and *Teichichnus* in the Desejosa Fm., which allowed assigning a Cambrian, Series 2, Stage 3 age to the upper part of this unit. Moreover, the occurrence of the trilobite aff. *Paradoxides* in the upper part of the same unit, identified by A.A. Sá near Freixo de Espada à Cinta, can extend the age up to lower Miaolingian. In addition, a metaconglomerate of the São Domingos Fm. provided a U-Pb detrital zircon age of 524±20 Ma, framed in the Ediacaran-Cambrian (up to Miaolingian) (TEIXEIRA *et al.*, 2012). In this context, these data demonstrate the possibility that the youngest age of the Desejosa Fm. corresponds to the Miaolingian Epoch.

The recent fieldwork allows identifying a new quartzitic /metasandstone level in the transition between Bateiras Fm. and Ervedosa fm. (Fig. 3), the Seixas member. These alternations of quartzwacke and slates were previously referred as metagreywackes in the top of Bateiras Fm. (SOUSA and SEQUEIRA, 1989). Its thickness reaches up to 400 m near Seixas village. The Seixas member contains the ore exploited in the Numão gold mine. The quartzwackes are highly mineralized too.

To explain the similarity between the Ervedosa do Douro and Pinhão formations a tectonic duplication, caused by the *"*Senhora do Viso inferred syn-sedimentary thrust*"*, was suggested by SILVA and RIBEIRO (1985). According to these authors, an allochthonous sequence (Rio Pinhão, Pinhão, Desejosa and São Domingos formations) was thrusted over an autochthonous sequence formed by the Bateiras and Ervedosa do Douro formations (Fig. 3). However, previously SOUSA (1982, 1983a), SOUSA and SEQUEIRA (1993) noticed that in the south-eastern area of the Douro valley was not possible to distinguish Ervedosa do Douro from Pinhão formations, as well as it was also noted that Rio Pinhão Fm. disappears laterally both to the NE and to the SW (cross-section Pinhão-Tabuaço). Our field observations and interpretations are in accordance with these last assertions. In effect, the Rio Pinhão unit disappears not only to the NE and the SW but also to the SE, in a lateral facies transition. The lithological similarity between the Ervedosa do Douro and Pinhão formations already pointed by SOUSA (1982, 1983a) and the data already collected allow us to conclude that both correspond to the same unit, re-named as Ervedosa fm. in the present work (Fig. 3). The "Rio Pinhão Fm.", which corresponds to a sandy fan deposition, is now considered as a member of the Ervedosa fm. The basal contact of the São Domingos Fm. is irregular and corresponds to an erosional unconformity over the Desejosa Fm. or even over the Pinhão member as already suggested by SOUSA (1982, 1983a). This situation is also observed in the Arouca sector (SÁ *et al.*, 2014). The meaning of this erosional unconformity is an open question needing further research.

Initially, SOUSA (1982, 1983b) suggested a lower Cambrian age for the Bateiras Fm. Later, SOUSA and SEQUEIRA (1993) proposed the Precambrian – Cambrian boundary somewhere in the sequence Ervedosa, Rio Pinhão, and Pinhão Fms. According to SAN JOSÉ *et al.* (1990), the Bateiras Fm. is correlated with the limestones of the lower part of the Aldeatejada Fm. in the Salamanca sector (DÍEZ BALDA, 1986) and the Fuenteguinaldo limestone in the Ciudad Rodrigo sector (RODRIGUÉZ ALONSO, 1982), both ascribed to the late Ediacaran. In this sense, the Ediacaran – Cambrian boundary in the Douro valley must be placed between the Bateiras and Ervedosa formations and so, the lateral correlation with the Spanish sectors is here followed. The age of the DG is therefore placed between the Ediacaran and the middle(?) Cambrian (Miaolingian).

The stratigraphic criteria of SOUSA (1983a), elaborated in the areas of Alijó and S. João da Pesqueira (Fig. 7), were extended to other adjacent sectors of the Douro valley, namely Marofa and Arouca – Castro Daire areas (Fig. 1). In the Marofa sector, SOUSA (1989) distinguished two informal units. The lower one, Ponte de Chinchela fm., lithologically similar to the Bateiras Fm., and the Excomungada fm. correlated with the set Ervedosa do Douro, Rio Pinhão and Pinhão units. Those informal designations must be abandoned, only prevailing the terms Bateiras Fm. and Ervedosa fm.

The geological context in the Arouca – Castro Daire sector is more complex (Fig. 5). The Valongo anticline is a major Palaeozoic structure whose overturned limb is affected by the left lateral top to SW of the Douro – Beira shear zone, a branch of the Porto –

Viseu tectonometamorphic belt (REAVY, 1987; BENTO DOS SANTOS *et al.*, 2021). These structures have their eastern expression in the Juzbado – Penalva do Castelo shear zone (Fig. 1). There is still some controversy about this structure alternatively viewed as a Variscan structure (VALLE AGUADO *et al.*, 1993, 2000; PEREIRA *et al.*, 2013, 2014; DÍEZ FERNANDEZ and PEREIRA, 2016) or an older one, reactivated during the Variscan Orogeny (PONCE DE LÉON and RIBEIRO, 1981; DIAS *et al.*, 2013; RODRIGUES *et al.*, 2013; BENTO DOS SANTOS *et al.*, 2021).

On the other hand, it has been reported near Sátão (Fig.5) the occurrence of metamorphic rocks (amphibolite schists and diopside marbles) whose protolith could be limestone and dolomite (SCHERMERHORN, 1956). In this context, SOUSA (1982, 1983b) ascribed these occurrences to the Bateiras Fm. However, the metamorphism, tectonic complexity, and the destruction of most of the key outcrops preclude a clear interpretation.

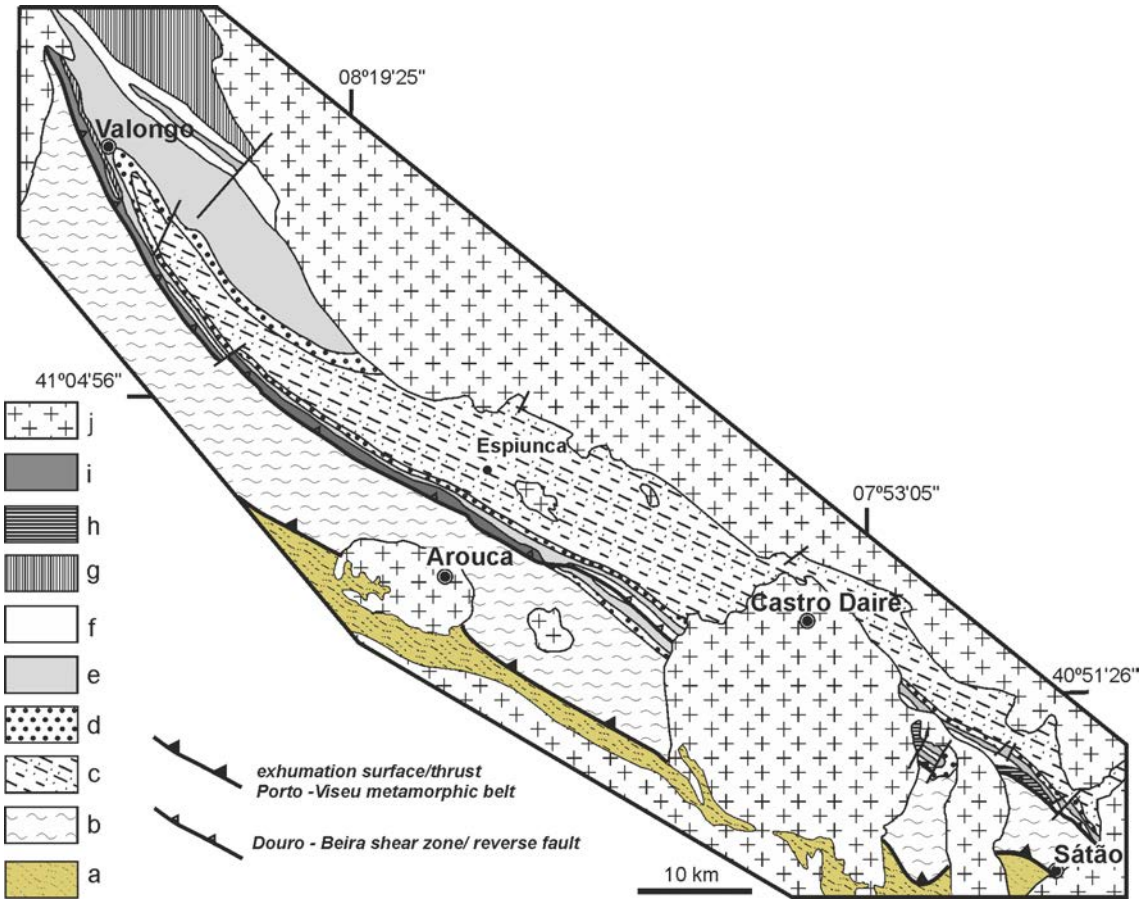

Figure 5. Schematic geological map of the Valongo – Arouca – Sátão sector (Adapted from PINTO DE JESUS, 2001; SÁ *et al.*, 2014). Legend: a, Lithodemic units of Porto – Viseu metamorphic belt; b, Beiras Supergroup (Fróia group); c, Douro Group; d, Lower Ordovician; e, Middle and Upper Ordovician; f, Silurian; g, Devonian; h, Pennsylvanian (Moscovian); i, Pennsylvanian (lower Gzhelian); j, Palaeozoic granitoids.

Recent field observations indicate that the core of the Satão-Valongo anticline has clear affinities with the DG sequence. This is shown by the presence of, from top to bottom, conglomerates filling erosional channels over the Desejosa Fm. or even over the Ervedosa fm., in a stratigraphic position similar to that of the São Domingos Fm. in the Douro valley; the Ervedosa fm. with its characteristic green chlorite slates with magnetite-rich disseminations (SÁ *et al.*, 2014). According to the geological map (Fig.5) it is highly suggestive that the boundary between the DG and the BG in this sector is marked by the Douro-Beiras shear zone with the Douro Group to the north and the Beiras Group to the south of this structure.

Figure 6. Unconformity observed in the Arouca UNESCO Global Geopark. Road Espiunca - Donim. (WGS84/UTM Datum: -8°11’23.33’’W; 40°59’30.60’’N). Paulo Castro is 1,73 m tall (adapted from SÁ *et al.*, 2014).

However, near Espiunca village (Figs. 5 and 6), the Desejosa Fm. rests unconformably on dark quartzites (SÁ *et al.*, 2014). This type of quartzites, which are absent in the DG, have similar lithological characteristics to the quartzites that frequently occur in the upper part of the BSG sequence (see the BG description below). The stratigraphic interpretation of the Espiunca quartzites remains an open question needing further research. According to VALLE AGUADO and MARTÍNEZ CATALÁN (1994), on the SW side of the reverse limb of this anticlinal structure the units were correlated to the

DG. Nevertheless, our field observations do not confirm this affinity, but instead demonstrate that they should be correlated with the “lower Alcudian” sequences of the “Beiras Group”. Recent published and independent work confirms our field observations about this correlation (JACQUES *et al.*, 2021). In fact, these authors considered that the CXG lithologies on this SW flank are correlated with the "Lower Alcudian" due to the same structural features described for infra-Cadomian sequences, *e.g.*, consistent steep to subvertical plunge of fold hinge lines and axis and steep to subvertical intersection lineations.

2.1. Regional tectonic setting of the Douro Group

All the DG units are affected by a main D_1 Variscan episode of tectonic deformation, which generated folds and associated cleavage. A characteristic of this tectonic arrangement is the occurrence of large hectometre-thick bands of cylindrical folds separated by metric-thick bands of small-scale folds associated with shear zones. The tectonic trend changes from E-W in the region close to Spanish border (Moncorvo and Foz Côa regions), where the fold axis are sub-horizontal, to NW-SE, to the nearby of Porto, where the structures are dipping to the NW. The DG units are integrated in the SW virgation of the Ibero-Armorican Arc that resulted from the Laurussia-North Gondwana collision (MATTE and RIBEIRO, 1975). This generated a pervasive shearing with a left lateral component parallel to the fold axis (SOUSA and SEQUEIRA, 1989; RIBEIRO *et al.*, 1990; DIAS and RIBEIRO, 1995; COKE, 2000; BÚRCIO, 2004; DIAS *et al.*, 2010; MOREIRA *et al.*, 2010). The change in the tectonic structure along the DG exposure depends on the geographic position along the arc virgation.

In this context, the so-called “Senhora do Viso inferred syn-sedimentary thrust*”* (SILVA and RIBEIRO, 1985) is just one D_1 WNW-ESE sinistral shear bands (Fig. 7). Near Senhora do Viso chapel (Figs. 7 and 8B), the northern slope of the hill is marked by a N110° shear affecting the contact between the metagreywackes of the Rio Pinhão mb. and the green phyllites of Ervedosa fm. The same kinematic feature is observed near Seixas geodetic landmark (Figs. 7 and 8A). A second shear band was recognized south of Senhora do Viso hill, approximately with the same N100°–110°strike and left lateral sense of movement given by drag folds with fold axis 80°/240° and axial planes N100°/80°S (Figs. 7 and 8C).

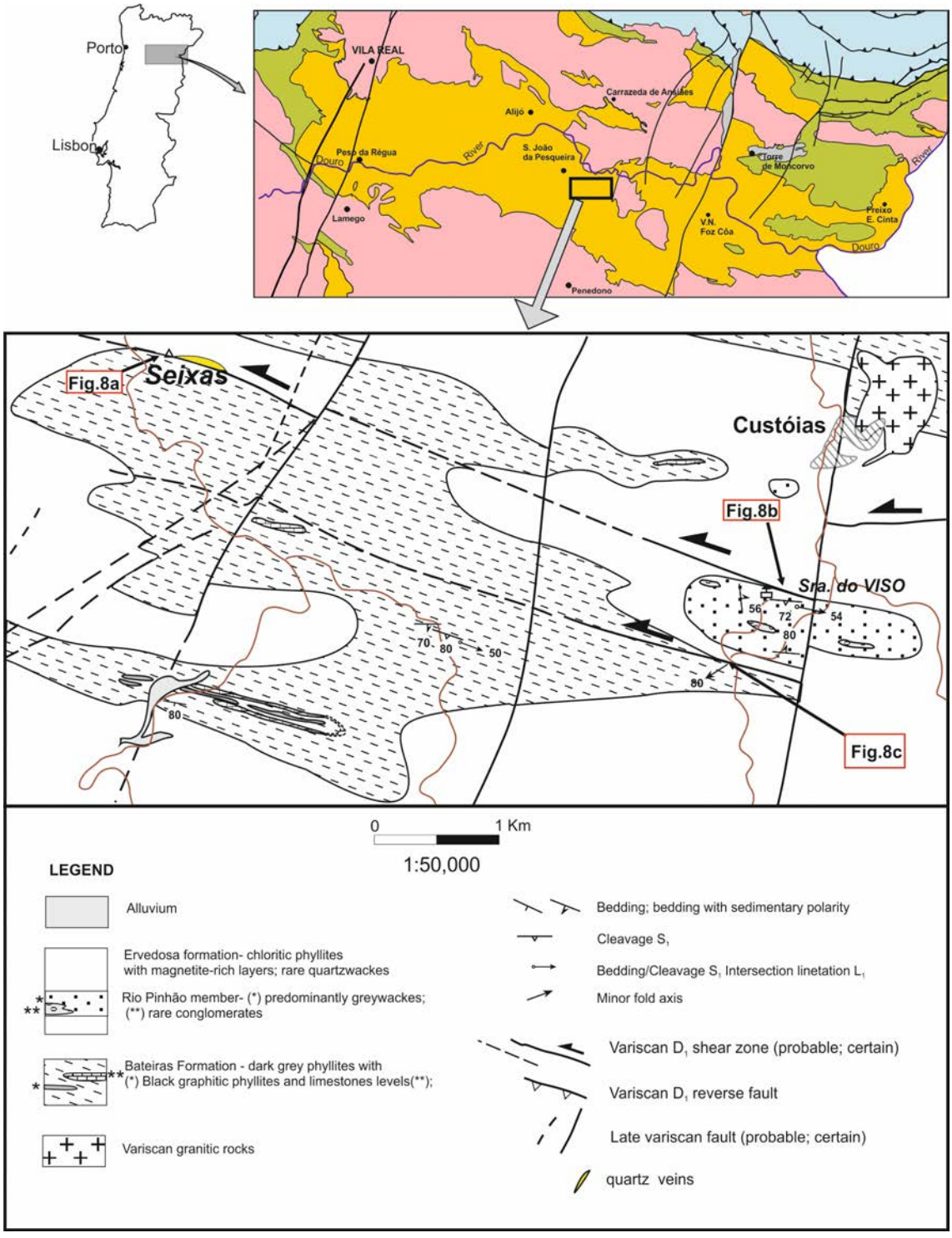

Figure 7. Geology of the Senhora do Viso sector and its variscan D_1 shear.

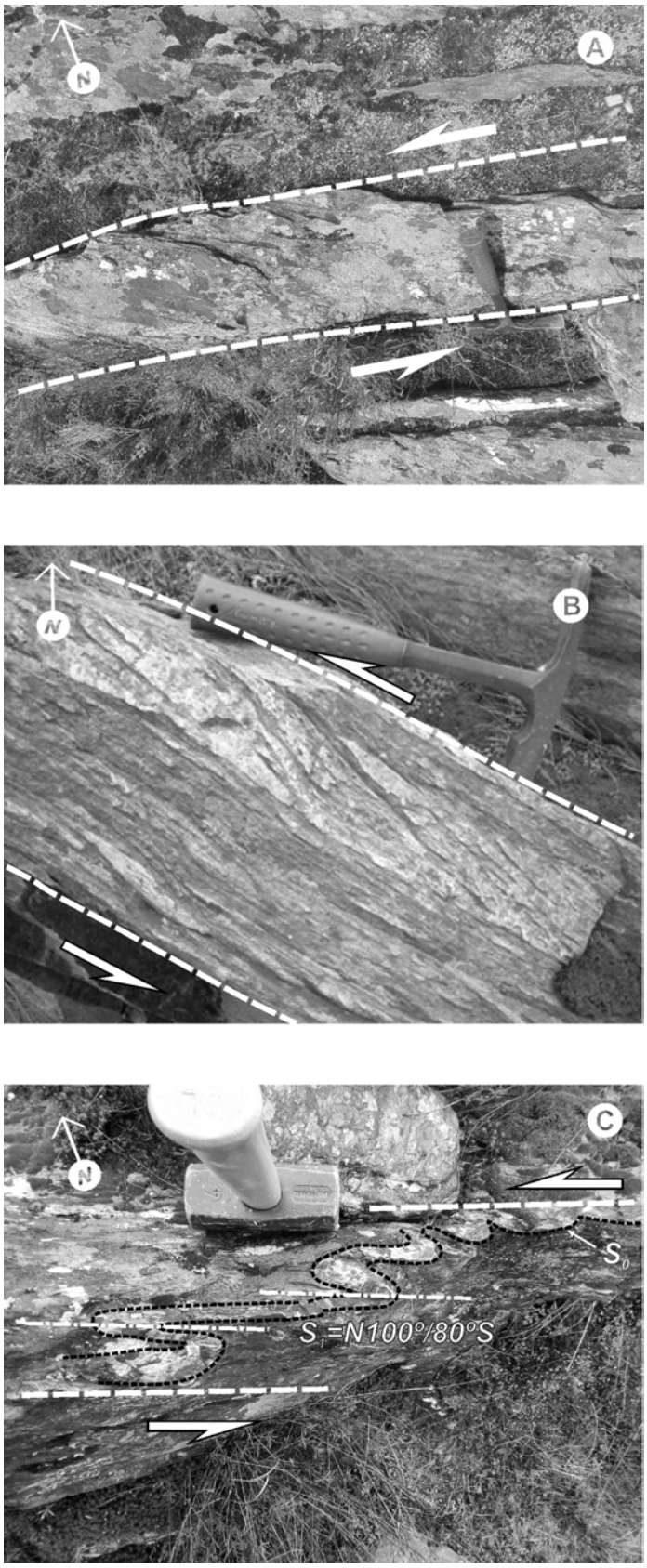

Figure 8. Detailed areas pointed out in Fig. 7. A) Seixas geodesic point; B) “Sra. do Viso chapell”: in (A) and (B) it is notorious the bending of the cleavage with left component; C) minor folds associated to the shear band.

2.2. The boundary between Douro Group and "Beiras Group"

The location of boundary between the Douro and the Beiras sedimentary basins has been the matter of discussion (Fig 9). The criteria used by different authors to establish this boundary is beyond the scope of this synthesis. Despite already discussed complexities in the Arouca-Castro Daire sector, our proposal coincides with that of Fig. 9B, in which the boundary is placed broadly at Douro-Beiras Carboniferous Trough. However, in relation to the Beiras and Douro sedimentary basins, our field observations points to independent basins, not contemporaneous. The Douro basin was opened after the filling of Beiras basin. After our field observations in the Sabugal area (Figs. 1 and 9A) it is understandable the option of SOUSA (1982) as Bateiras-like black shales occur. This reality shows the need for more studies, currently in progress, to fully clarify these inter-basin relationships.

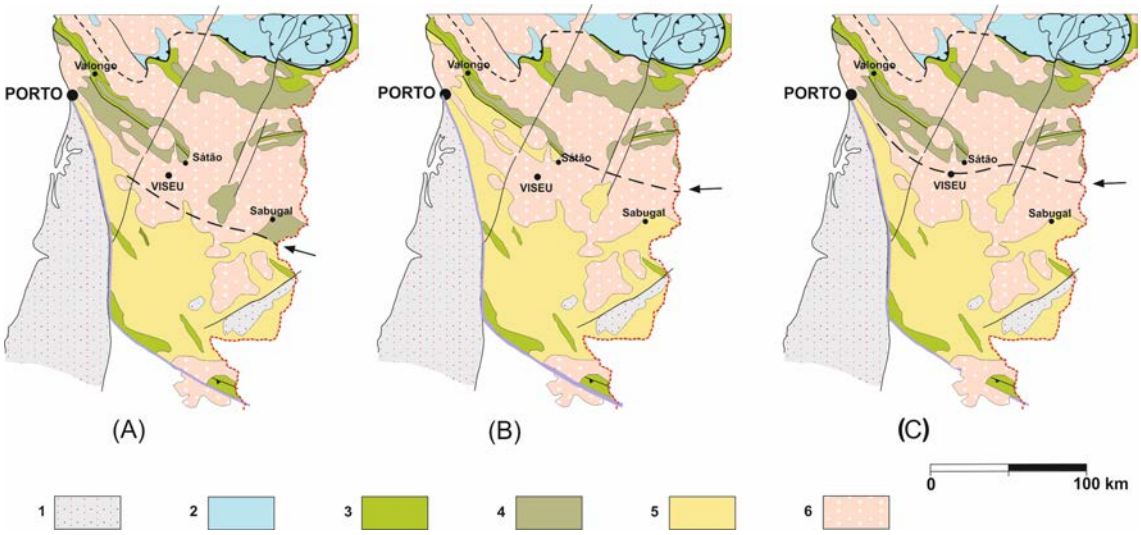

Figure 9. Proposals for possible boundaries (dashed line marked by the arrow) between the Douro and Beiras sedimentary basins. (A) – SOUSA, (1982); (B) – OLIVEIRA, coord., (1992); (C) - RODRIGUÉZ FERNANDEZ, (2004). Legend: 1 - Meso-Cenozoic rocks; 2 - Allochthonous and Parautochthonous units (Galicia – Trás-os-Montes Zone); 3 - Palaeozoic metasediments; 4 - Douro Group; 5 – "Beiras Group"; 6 – Granitoids.

3. "BEIRAS GROUP". HISTORICAL REVIEW

The first attempt to establish the "Beiras Group" (BG) lithostratigraphic sequence was made by SILVA *et al.* (1988), who defined two informal units: *i*) Malpica do Tejo fm., composed mainly by metagreywackes and subordinate metapelites, overlaid by *ii*) Rosmaninhal–Perais fm., consisting mostly of metapelites with intercalations of metaconglomerates. Later, ROMÃO (1991) suggested the existence of another unit, the Almaceda fm., at the upper part of the BG succession, also composed of dominant metagreywackes and metapelites. In the Geological Map of Portugal at the scale

1:500,000 (OLIVEIRA, coord., 1992), the BG was subdivided, from bottom to top, in Malpica do Tejo, Perais, Rosmaninhal and Almaceda fms., a stratigraphic succession that was up to now informally accepted (SILVA *et al.*, 1995). Posteriorly, the Malpica do Tejo fm. was subdivided into a "lower member", with a predominance of shales, psammites and scarce metagreywackes, and an "upper member" where metagreywackes predominate (ROMÃO *et al.*, 2010).

In the Poiares - Lousã sector (Figs. 10 and 11), two new units were defined: the Caneiro fm., composed essentially of metagreywackes, overlaid by the Boque–Serpins fm., consisting mostly of metapelites and intercalations of metagreywackes (SEQUEIRA and SOUSA, 1991). A revision of this last unit showed that quartzwackes and quartzites occur at its upper part and were deposited in a siliciclastic platform (ALONSO-GAVILÁN *et al.*, 2001). These quartzwackes and quartzites were later proposed as a new lithostratigraphic unit – the Colmeal Formation – overlapping the Boque–Serpins fm. (MEIRELES *et al.*, 2013).

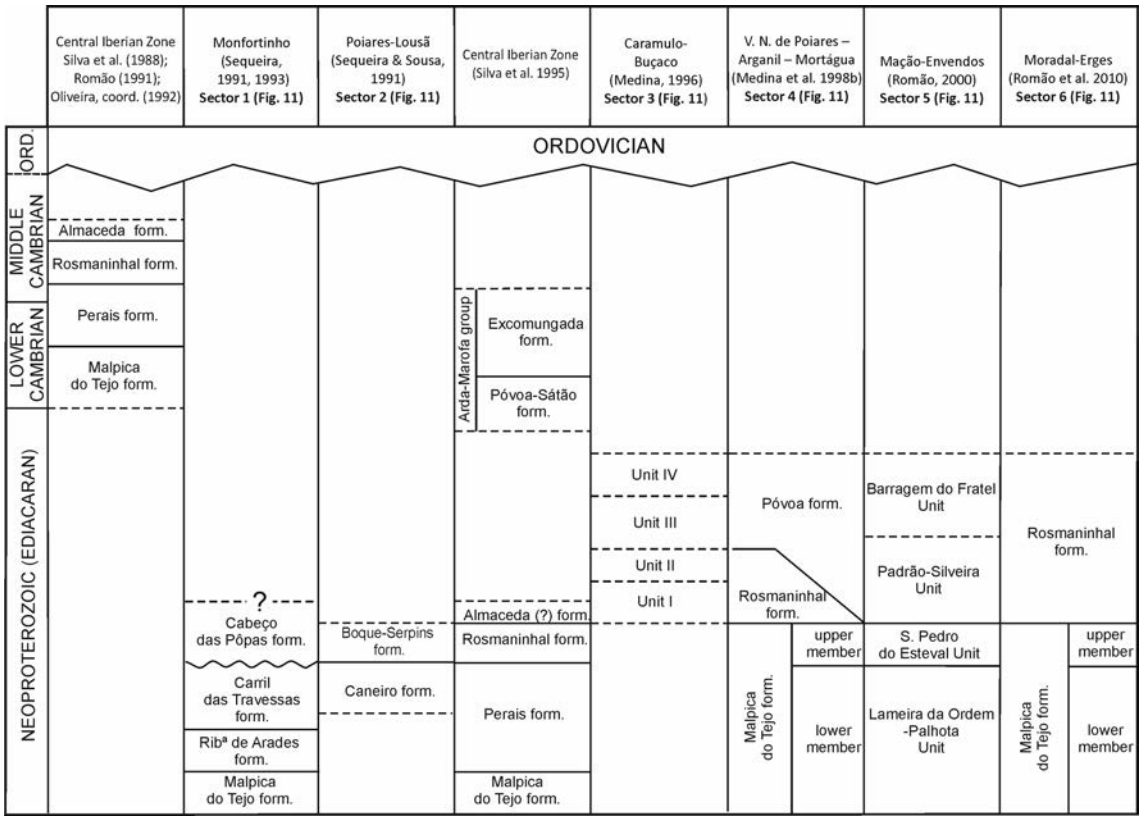

Figure 10. Correlation chart showing historical interpretations of the "Beiras Group" lithostratigraphic sequences. Major wavy line, Toledanian unconformity. Minor wavy line in Monfortinho sector, lower Alcudian-upper Alcudian unconformity *sensu* SEQUEIRA (1993).

In the Caramulo-Buçaco sector (Fig. 10), was recognized a succession of four units where metasandstones and shales predominate in different proportions (MEDINA *et al.*, 1989; MEDINA and RODRIGUEZ ALONSO, 1991; MEDINA, 1996; MEDINA *et al.*,

1998a, 1998b). According to MEDINA *et al.* (1998b), "unit I", "unit II" and "unit III" have a dominant shale composition, while "unit IV" have prominent intercalations of metasandstones and quartzites within the shales. This last unit is now correlated with the Colmeal Fm. (MEIRELES *et al.*, 2013). The fieldwork evidenced that some of the other units may belongs to lower Alcudian (Fig. 13).

Another succession of units was established in the Monfortinho region (Central Portugal, close to the Spanish border) as follows, from base to top (Fig. 10): Malpica do Tejo, Ribeira de Arades, Carril das Travessas and Cabeço das Pôpas formations. The Cabeço das Pôpas unit overlies unconformably the Ribeira de Arades fm., with dominant pelites and scarce metagreywackes, and the Carril das Travessas fm., composed mostly of metagreywackes. (SEQUEIRA, 1993; SEQUEIRA *et al.*, 1996). Finally, in the Mação – Envendos sector (60 km SE of Castelo Branco; Fig. 11) the following sequence was erected, from bottom to top: Lameira da Ordem unit, composed of metapelites; S. Pedro de Esteval unit, dominated by metagreywackes; Padrão–Silveira unit, with dark metapelites with intercalations of conglomerates and metagreywackes; and Barragem de Fratel unit, with metapelites and metagreywackes (ROMÃO, 2000; ROMÃO *et al.*, 2013 and references therein).

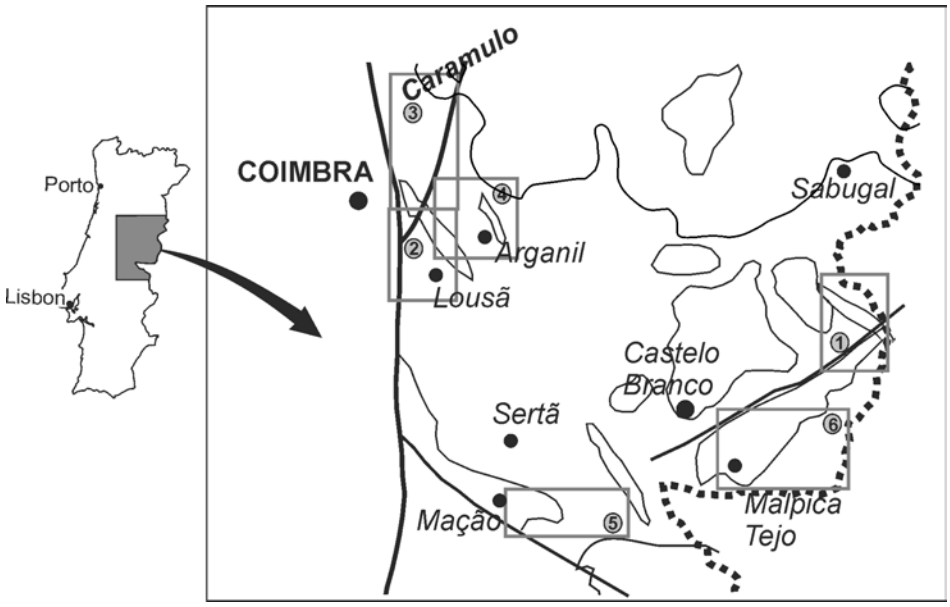

Figure 11. Location of the sectors referred in figure 10.

3.1. The Beiras Supergroup stratigraphy

The unconformity identified by SEQUEIRA (1993) was confirmed, mapped and revised in the Monfortinho sector and in the studied area of the BSG (Figs. 12 and 13). It separates two sedimentary megasequences with distinct lithostratigraphic and structural characteristics: here named Fróia, for the lower sequence, and Lousã, the upper sequence. We propose that this unconformity is correlated with the Cadomian

unconformity defined in Spain between the lower and upper Alcudian (MEIRELES *et al.*, 2014 and references therein).

The criteria used for the identification of this angular unconformity and the distinction between these two stratigraphic series are the same as those used by the Spanish geologists (ORTEGA GIRONES and GONZÁLEZ LODEIRO, 1986; GONZÁLEZ LODEIRO *et al.*, 2004; ÁLVARO *et al.*, 2019).

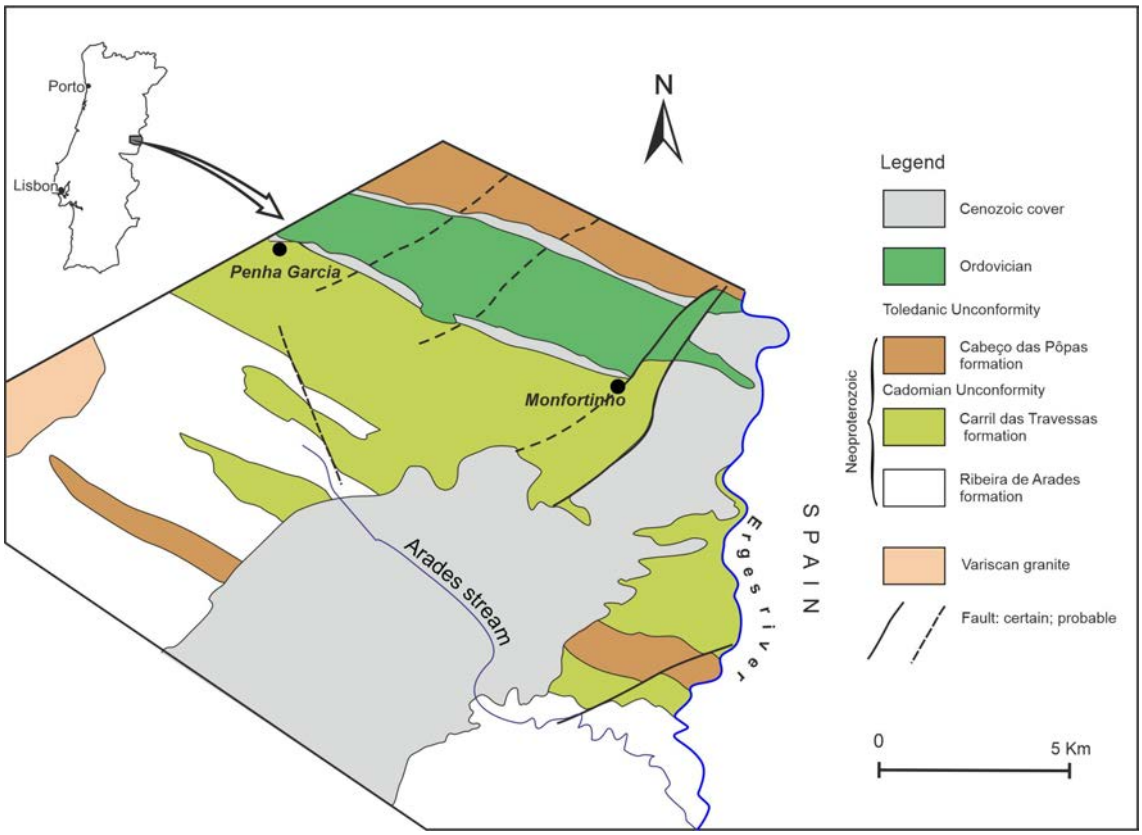

Figure 12. Geological sketch of Monfortinho – Penha Garcia area adapted from the original of SEQUEIRA (1993).

The recognition of this unconformity (Fig. 14) implies that new lithostratigraphic sequences must be reconsidered. In this sense, an effort of integration of the published geological maps of the Erges River sector (SEQUEIRA *et al.*, 1996; ROMÃO *et al.*, 2010) has been made. In the northern sector of the Erges River, a detailed lithostratigraphic research was done regarding the classification of Cabeço das Pôpas, Carril das Travessas and Ribeira de Arades formations (SEQUEIRA, 1993, SAN JOSÉ *et al.*, 1995; SEQUEIRA *et al.*, 1996). In the Arganil sector (Fig. 11, sector 4) the units mapped by PONTE and GAMA PEREIRA (2004) belongs to Fróia group, which is correlated to the Domo Extremeño Supergroup *pro parte* (ÁLVARO *et al.*, 2019). There is field evidence that the units I and II defined by MEDINA (1996) are correlated to Fróia group and the units III and IV to the Lousã group.

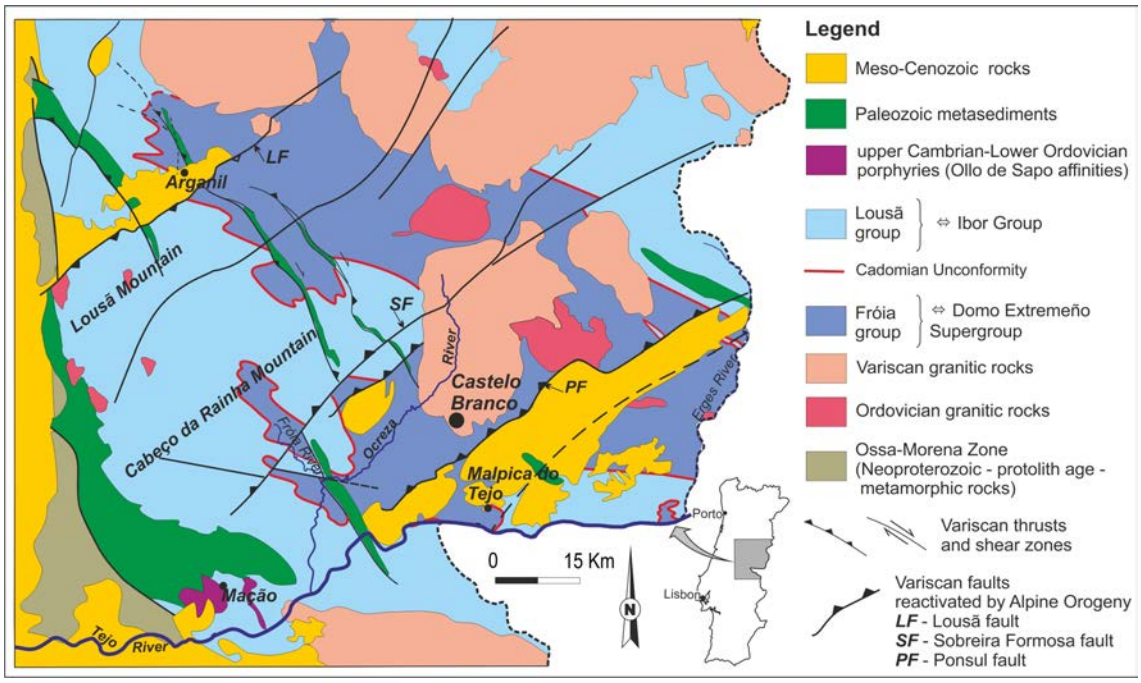

Figure 13. A general sketch of the Lousã and Fróia groups and their proposed correlation with the Ibor Group and Domo Extremeño Supergroup (*pro parte*).

In accordance with the above mentioned, it is now assumed that the Lousã and Fróia sequences have the rank of group. In this context, the hitherto named "Beiras Group", must rise the rank to Beiras Supergroup. Therefore, the "Dúrico-Beirão Supergroup" (DBS), as referred up to now, must be discarded giving place to the Beiras Supergroup and the Douro Group.

Across the Spanish border, in the Cáceres sector (Extremadura province, Spain), are only reported stratigraphic units ascribed to the Domo Extremeño Group (PALACIOS *et al.*, 2010, 2013). From the bottom to the top of the sequence: Guadiana Formation (shales and greywackes metric intercalations); Botija Formation (predominantly shales); Monroy Formation (shales and greywackes decametric intercalations) and Orellana Formation (shales with scarce clast- and matrix- supported conglomerates). In this context, must be noticed that in Spain the Neoproterozoic sequences were recently reappraised as Ibor Group and Domo Extremeño Supergroup (DESG), separated by the Cadomian angular unconformity. The DESG is composed by the Guadiana and Campanario Groups. The first one is subdivided into the La Coronada and Sta. Maria de Zújar formations. The Campanário Group is subdivided into the Botija, Monroy and Orellana formations (ÁLVARO *et al.*, 2019). It should be noted that the Orellana Fm. is correlated with the Cabeço das Pôpas fm.

Structural data recovered in the Fróia group, besides the strong influence of the D_1 Variscan phase more intense than in the Spanish side, show that the bedding has a general NE–SW orientation (Fig. 15). The Variscan slaty cleavage D_1 (N130°–140°) shows L_1 intersection lineation and fold axis close to the vertical (>60°) indicating previous folds prior to Variscan episode. Regarding the Lousã group, this is less

deformed than Fróia group (Fig. 15). The bedding strikes WNW–ESE and dips S or N. The D_1 Variscan episode exhibits open cylindrical folds with N100°–120°orientation, sub-vertical axial planes, axial planar slaty cleavage subparallel to the fold axial planes and fold axis dipping less than 50°. Cleavage bedding intersection lineation L_1 is parallel to the fold axis (MEIRELES *et al.*, 2014). These structural features were recognized in the Rosmaninhal area, being previously explained as a “tectonic thrust of sardic age” (ROMÃO and RIBEIRO, 1992). However, in accordance with the recent field data, this area represents a small erosive window that exposes the Fróia group.

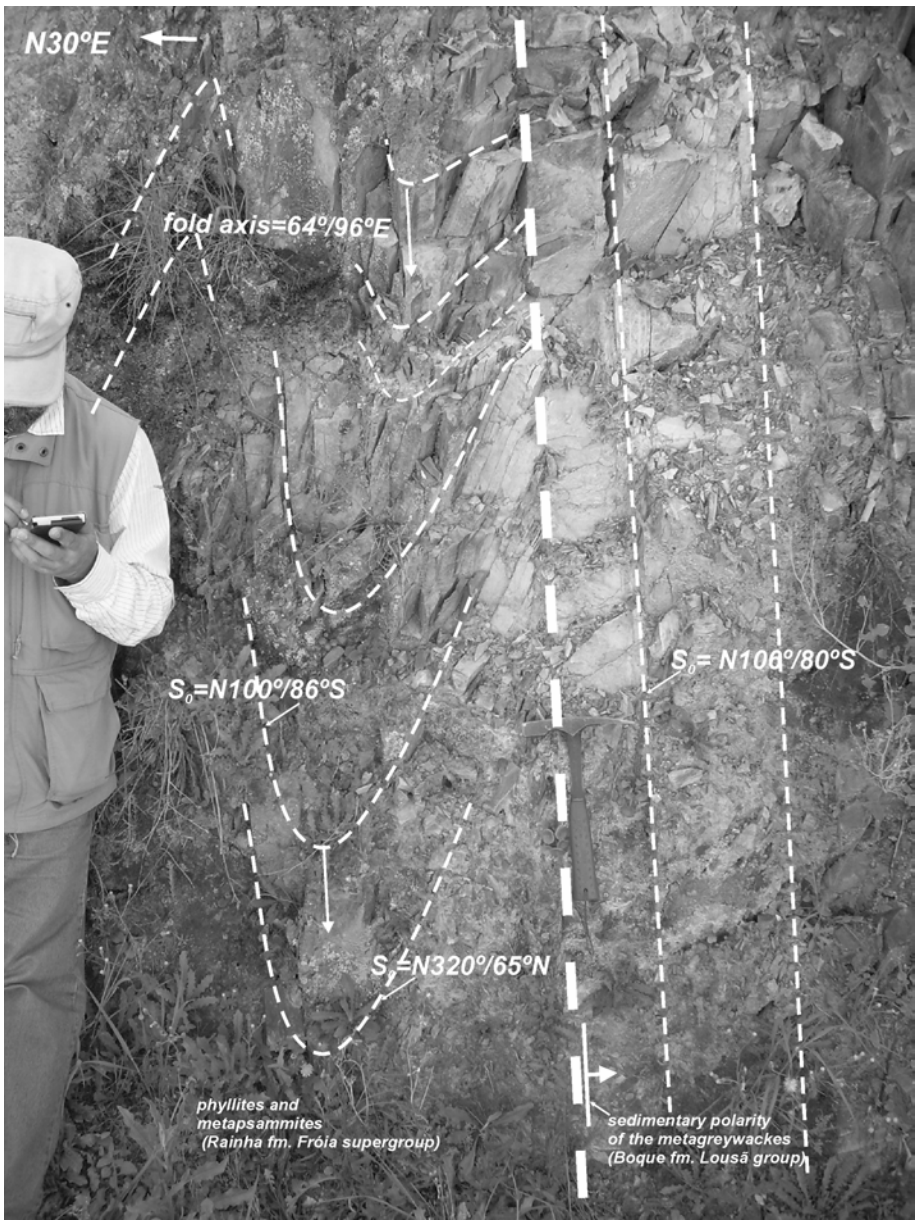

Figure 14. Cadomian unconformity between Lousã group and Fróia group. Road N 233, Sobreira Formosa – Castelo Branco (WGS84/UTM Datum: -07° 49' 43.936"W/39° 47' 20.597"N). Azimuth of the cross section, N30°E.

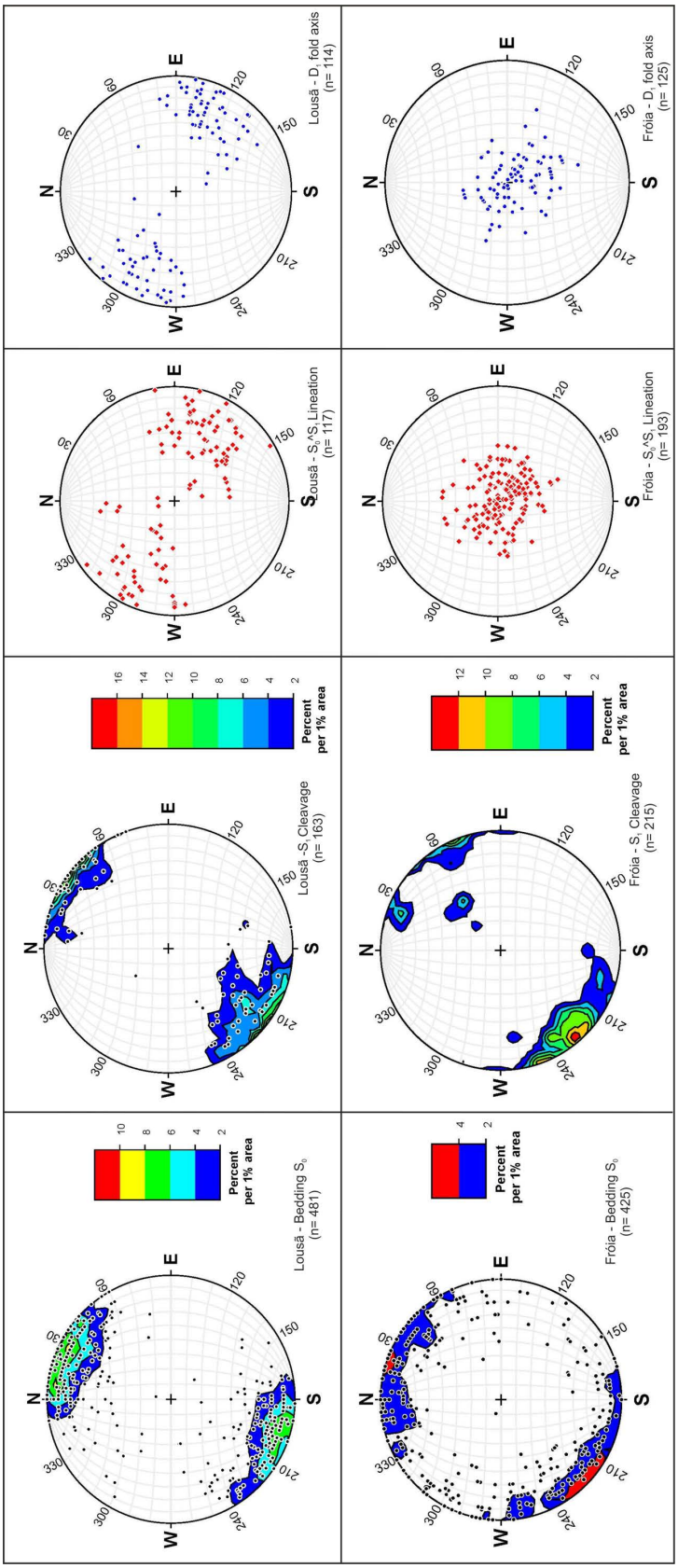

Figure 15. Stereographic representations of the Lousã and Fróia groups (adapted from Meireles *et al.*, 2014). Stereographic calculations in Stereonet 11 (ALLMENDINGER *et al.*, 2012; CARDOZO and ALLMENDINGER, 2013).

The evidence of folding prior to the Variscan deformation was already demonstrated in the Erges River sector (SEQUEIRA, 1993) and in the Arganil sector (PONTE and GAMA PEREIRA, 2004, and references therein). This last work clearly shows the Variscan folding interference over pre-Variscan deformation. The same features were recognized in a ubiquitous way in all the Fróia group. As described by PONTE and GAMA PEREIRA (2004), it is common a dextral Variscan shear striking N10°W running parallel to the Ordovician synclines and its conjugate N80°E shear. These structures were also recognized in all the area and locally produced chevron kink folds with vertical axis, which can be mistaken with the interference of Variscan episodes over Cadomian folds. The lithostratigraphic units that presently compose the BSG are shown in Fig. 16.

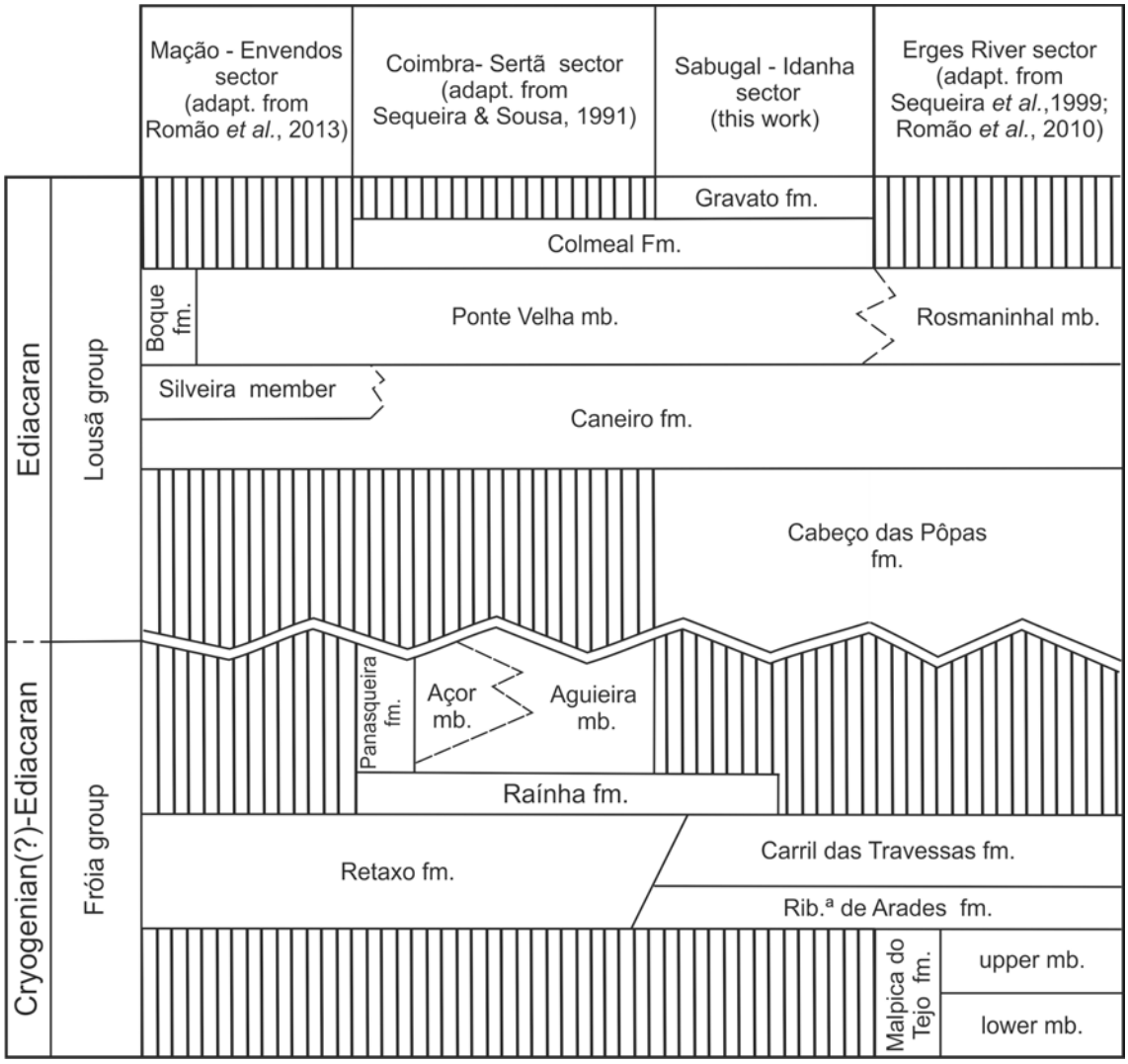

Figure 16. The new proposal for the stratigraphic sequence of the Beiras Supergroup (Coimbra – Sertã, Sabugal – Idanha and Erges River sectors) and correlation with Mação – Envendos sector (= sector 5, Fig. 11). Wavy line, unconformity; vertical ruling, stratigraphic gaps; dashed lines, possible lateral transitions.

3.1.1. Fróia-group

The thicknesses of these units are difficult to estimate due to the interference of the D_1 Variscan phase over the pre-Variscan NE-SW folds. The group thickness may achieve a maximum of 6,000 m. Some of the units are described here for the first time. This group is subdivided in the following lithostratigraphic units, from bottom to top:

Malpica do Tejo formation – this unit comprises two members: lower member, *sensu* ROMÃO *et al.* (2010), characterized by alternations of metasiltstone and metapelites with rare metagreywackes; upper member, *sensu* ROMÃO *et al.* (2010), predominantly formed by metagreywackes with intercalations of metapelites, metasiltstones and metaconglomerates.

Ribeira de Arades formation – this unit has a large predominance of metapelites. Although foliated metagreywackes are described and mappable (SEQUEIRA, 1993; SEQUEIRA *et al.*, 1996).

Carril das Travessas formation – predominance of metagreywackes with metapelites and metaconglomerate intercalations (SEQUEIRA, 1991).

Retaxo formation (new unit) – it is a volcano-sedimentary sequence composed of black phyllites and metasandstones, with intercalations of metatuffites, acid metatuffs and rare mafic volcanic rocks. Dissemination of sulphides in all the lithologies is common. This lithological composition is compatible with an active margin geotectonic setting associated with an island arc (MEIRELES and CASTRO, 2014). In the nearby Ciudad Rodrigo – Hurdes – Sierra de Gata domain, RODRÍGUEZ-ALONSO *et al.* (2004) reported the same geotectonic interpretation for volcanic rocks in units ascribed to Lower Alcudian. It is assumed that Retaxo fm. is a distinct unit on the top of Ribeira de Arades and Carril das Travessas formations.

Raínha formation (new unit) – mostly formed by metapelite and metasiltstone alternations with some intercalations of metagreywackes. Quartzites occur in the lower part of the unit making the transition from the Retaxo fm..

Panasqueira formation (new unit) – this unit comprises two members*:* Açor member, characterised by dark grey to black slates with sparse centimetric-thick dark grey quartzite intercalations especially in the lower part of the unit; Aguieira member*,* composed of thick white quartzites with minor intercalations of grey slates. It occurs in the Arganil sector, north of Lousã fault (Fig. 13). A lateral stratigraphic equivalence between the Açor and the Aguieira members is interpreted, the later corresponding to more proximal facies of the former.

3.1.2. Lousã group

The total group thickness may range between 2,000 m and 6,000 m. Some units are described here for the first time.

The following lithostratigraphic units are recognized, in ascending order:

Cabeço das Pôpas formation (adap. from SEQUEIRA, 1993) – pebbly mudstones in the bottom and predominance of shales, metasiltstones, and scarce metagreywackes to the top of the sequence. The conglomerates are considered as glacigenic origin by SAN JOSÉ *et al.* (1995).

Caneiro formation - represented by metric-scale metagreywacke beds with minor pelitic intercalations. It corresponds to the S. Pedro de Esteval unit *sensu* ROMÃO (2000) and ROMÃO *et al.* (2013). A new member is recognized, Silveira member, former Padrão-Silveira unit *sensu* ROMÃO (2000) and ROMÃO *et al.* (2013).

Boque formation (new unit) – corresponds to the former Boque – Serpins fm., *sensu* SEQUEIRA and SOUSA (1991). The unit is subdivided in two members: Ponte Velha member, with predominance of shales and psammites, minor decimetric to metric-thick metagreywacke intercalations and scarce conglomerate levels with rare phosphate nodules (GAMA PEREIRA, 1984; MEIRELES *et al.*, 2013). The former Barragem do Fratel unit *sensu* ROMÃO (2000) and ROMÃO *et al.* (2013) is *pro parte* equivalent. The Rosmaninhal member, former Rosmaninhal fm. *sensu* ROMÃO *et al.* (2010), comprising shales and psammites with abundant conglomerates and phosphate nodules. We assume the possible lateral transition of lithofacies in between both members.

Colmeal Formation – represented by shales with intercalations of quartzwackes and quartzites (formalized in MEIRELES *et al.*, 2013).

Gravato formation (new unit) – with dark quartzites at the base followed upward by black shales, and grey shales with abundant stratabound basic lithologies. This new lithostratigraphic unit was identified for the first time in the Sabugal sector.

4. THE AGE OF THE BEIRAS SUPERGROUP

Samples recovered from the Caramulo – Buçaco region (Fig. 1), presently correlated with the Colmeal Fm. provided Sr and Nd isotopic signatures pointing to sediments deposition during the interval 600-550 Ma, in a tectonic passive margin (TASSINARI *et al.*, 1996). The same unit provided a detrital zircon U-Pb ages of 635-545 Ma (PEREIRA *et al.*, 2012).

Detrital zircons from metagreywackes ascribed to the Caneiro fm. in the Sabugal sector (Fig. 16) yielded the U–Pb age ca. 577 Ma (TEIXEIRA *et al.*, 2011) which is also consistent with the Ediacaran age of the bacterial microfossils *Bavlinella faveolata* (SHEPELEVA, 1962, VIDAL, 1976) and *Palaeogomphosphaeria cauriensis* (PALACIOS, 1989) described by SEQUEIRA (2011) in the Cabeço das Pôpas and Carril das Travessas forms.

The recent review of the trace fossils records in Spain confirmed the Ediacaran age for the Ibor Group units (JENSEN and PALACIOS, 2016) proving so the stratigraphic equivalence with the Lousã group.

Recent U-Pb zircon data was obtained in the Cabeço da Pôpas formation points to a maximum deposition age (MDA) of 589±6.4 Ma. The metagreywackes previously considered as belonging to Carril das Travessas form. by SEQUEIRA (1993), suggest an MDA of 560±10 Ma (CRISPIM *et al.*, 2021).

The glacigenic feature of Cabeço das Pôpas fm. (SAN JOSÉ *et al.*, 1995) is suggestive of its equivalence with the Ediacaran Weesenstein-Orellana glaciation in Spain (LINNEMANN *et al.*, 2018). This local glacigenic episode has now been integrated in the Upper Ediacaran Glacial Period (LINNEMANN *et al.*, 2021).

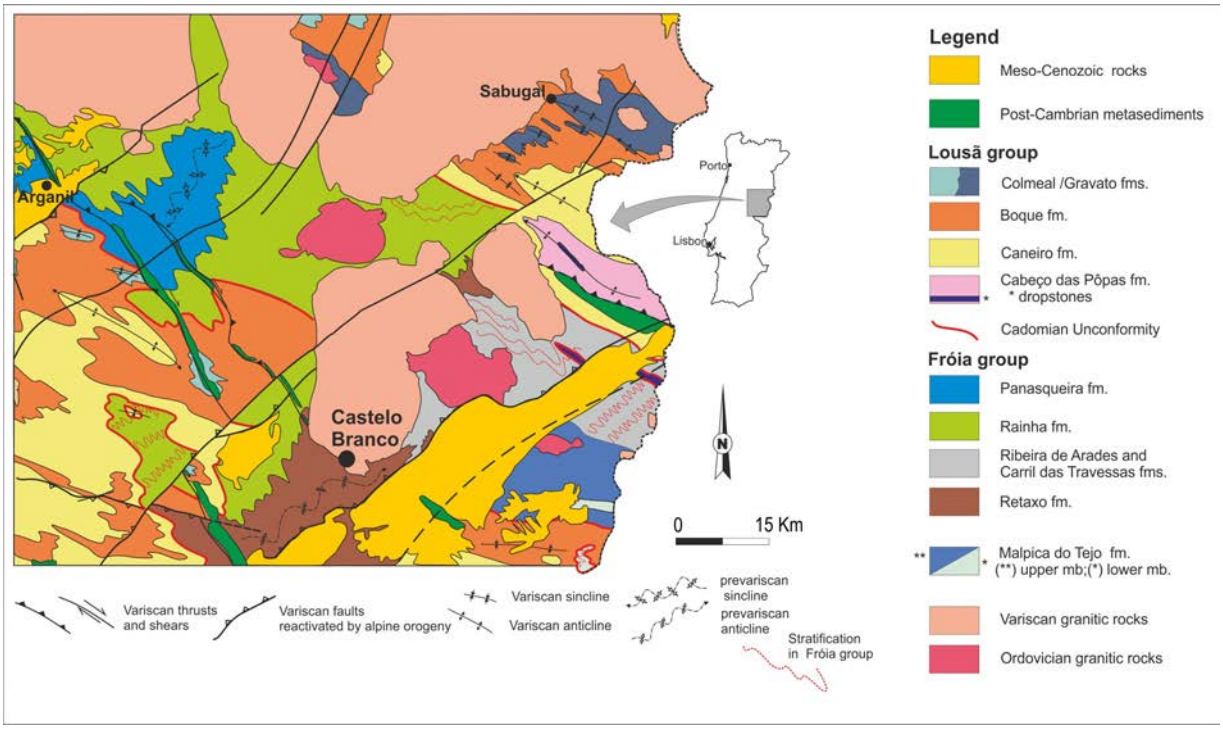

Figure 17. Geological sketch map of the units that compose the Lousã and Fróia groups.

5. CONCLUSIONS

The pre-Ordovician sequences of the Spanish CIZ reveal that tectonic events were responsible for sedimentary hypercycles. The present synthesis of the so-called "Schist-Greywacke Domain" in Portugal follows the same criteria as shown by geological mapping revisions. From now, it is possible to establish more accurate correlations with the Spanish sectors of the pre-Ordovician sequences.

The former "Schist-Greywacke Complex" is now proposed to be divided into Douro Group and Beiras Supergroup. The latter is formed by the Lousã and Fróia groups.

Scarce paleontological data and lithostratigraphic correlations with other sectors of the Spanish CIZ indicate a Neoproterozoic– middle(?) Cambrian age for the Douro Group. On the other hand, the identification and mapping of the Cadomian unconformity in the former “Beiras Group” allowed the separation of the lithostratigraphic units in two sedimentary hypercycles, presently composing the Lousã and Fróia groups. The “Beiras Group” is now ranked as Beiras Supergroup. Correlations with the Spanish CIZ suggests that the Lousã group is equivalent to the Ibor Group (upper Alcudian) and the Fróia Group is equivalent to the Domo Extremeño Supergroup. Both are of Ediacaran age.

This synthesis is a step forward concerning the knowledge of the old-named “Schist-Greywacke Complex”. We are aware that further research is needed, namely about the age, the sedimentological, and lithogeochemical characterization of these sequences considering the need to formalize the new stratigraphic units. This procedure is being carried out in another work in progress.

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