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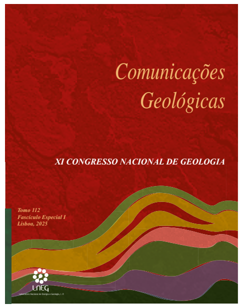
Ordovician – Silurian transition in the Central-Iberian Zone: Just a stratigraphic boundary or a major element in the evolution of the Iberian Variscides?

Transição Ordovícico - Silúrico na Zona Centro-Ibérica: Apenas um contacto estratigráfico ou um elemento estruturante do Varisco Ibérico?



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Abstract: The Ordovician-Silurian boundary in the Central-Iberian Zone is often considered a normal stratigraphic transition. Nevertheless, in studies carried out in Portugal (e.g. Espinhosela, São Mamede and Buçaco areas) and Spain (e.g. Alcañices Synform) this contact is marked by the development of shear zones subparallel to the lithostratigraphic units. Ongoing structural mapping in Celorico de Basto (Marão region) shows that near Campanhó, the Ordovician (Pardelhas Formation) and the Silurian (Campanhó Formation) units are bounded by a regional shear zone with a normal kinematics (the Covelo do Monte Fault, here presented). Although their origin is debatable, the intraorogenic normal faults are common mechanisms active during Variscan times in the Central-Iberian Zone. In the case of the Ordovician-Silurian boundary, these detachments could be facilitated by shale and organic materials prone to control the development of shear zones.

Keywords: Central-Iberian Zone, Ordovician-Silurian Boundary, Marão region, Iberian Variscides

Resumo: O limite Ordovícico-Silúrico na Zona Centro-Ibérica é frequentemente considerado uma transição estratigráfica normal. No entanto, estudos realizados em Portugal (e.g. áreas de Espinhosela, São Mamede e Buçaco) e Espanha (e.g. Sinforma de Alcañices), mostram que este contato é frequentemente marcado pelo desenvolvimento de zonas de cisalhamento subparalelas às unidades litostratigráficas. Cartografia estrutural de pormenor em curso em Celorico de Basto (região do Marão) mostram que, próximo a Campanhó, as unidades do Ordovícico (Formação de Pardelhas) e do Silúrico (Formação de Campanhó) são limitadas por uma falha normal (a Falha de Covelo do Monte, aqui apresentada). Embora a sua génese seja controversa, a instalação de falhas normais intra-orogénicas é um mecanismo comum ativo durante o orógeno Varisco na Zona Centro-Ibérica. No caso do contacto Ordovícico-Silúrico, estas falhas parecem ter sido controladas por material orgânico e argiloso suscetível de desenvolver superfícies de descolamento.

Palavras-chave: Zona Centro-Ibérica, Transição Ordovícico-Silúrico, região do Marão, Varisco Ibérico

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1. Introduction

The Ordovician and Silurian units of the Central-Iberian Zone (CIZ; Figura 1a) have been strongly deformed during the Variscan Orogeny. They are the result of sedimentation in a passive margin environment, related to the extensional processes associated to the birth of the Rheic Ocean (Gutiérrez-Marco *et al*., 2019). In particular, the Silurian sequences are often composed of lithologies contrasting with previous Ordovician strata, such as black shales, phosphate nodules and other lithotypes that suggest the transition of oxic to anoxic or euxinic depositional conditions (Gutiérrez-Marco *et al*., 2019, and references therein). In the northern CIZ the boundary between Ordovician and Silurian sequences has been usually mapped as a normal stratigraphic contact (*e.g.* Pereira, 1987, 1989, 2000; Dias *et al*., 2022), or the result of a cartographic discordance and hiatus observed in the basal Silurian (Pereira, 1987, Pereira, 1989). Nevertheless, in some areas this contact has been considered as tectonic. In the Spain counterpart of the CIZ, Vacas and Martínez Catalán (1987) followed by Antona and Martínez Catalán (1990), initially reported the absence of a gradual transition between the Ordovician and Silurian sequences in the Alcañices Synform, which led to the mapping of the limit as a thrust between the Campillo and Manzanal del Barco formations (although the possibility of being a discordance was not ruled out). More recently, in the Espinhosela region, the Ordovician-Silurian boundary has been considered an important tectonic contact, defining the Ribeira de Silos overthrust, marked by phyllonites, cataclasites and ferruginous breccias (Meireles *et al*., 2006, Meireles, 2011).

Recent works on the geological mapping of Portugal at 1/200.000 scale (Sheet 6, Ferreira and Piçarra, 2020, from Portalegre; Sheet 3 - ongoing, from Buçaco) show that this contact is tectonic, as can be observed in the synclines of São Mamede and Buçaco: (1) in the southern limb of the São Mamede syncline, the Ordovician quartzites overlay the Silurian shales through a NW-SE thrust with cinematic transport to the NE; (2) in the SW side of the Buçaco syncline, the Silurian shales truncate several units of Ordovician, from the base to the top through a tectonic contact. The displacement of the Silurian shales over Middle Ordovician strata is also found in the NE side of this syncline.

These structural features on the Ordovician-Silurian boundary suggest that the Lower Silurian units of the CIZ could have been a decisive element in the evolution of the Iberian Variscides, as black shales are known for favouring the displacement of units in orogens (Morley *et al*., 2017).

In Celorico de Basto (Marão region, northern CIZ), southern from Campanhó (Figura 1b), detailed structural studies along the Ordovician-Silurian contact developed in sediment levels rich in organic matter are

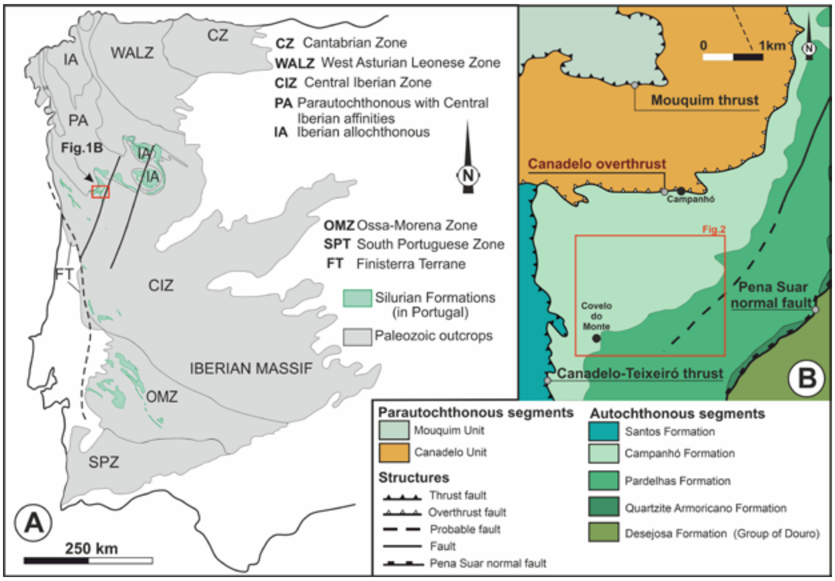

Figure 1. (A) Iberian Massif with the main Variscan tectonostratigraphic units and the location of the Silurian sequences in Portugal (adapted from Lotze, 1945; Julivert et al., 1974; Ribeiro, 2013a). (B) General geological map of the Campanhó segment (adapted from Pereira, 1987 and Dias et al., 2022).

Figura 1. (A) Maciço Ibérico com as principais unidades tectonostratigráficas variscas e a localização das sequências do Silúrico em Portugal (adaptado de Lotze, 1945; Julivert et al., 1974; Ribeiro, 2013a). (B) Mapa geológico geral do segmento de Campanhó (adaptado de Pereira, 1987 e Dias et al., 2022).

currently conducted to understand if the transition in this segment of the CIZ is either a continuous contact or is overprinted by the tectonism of the Variscan Orogeny, as suggested by the aforementioned cases. In this sector, although previous mapping (1:50.000 and 1:200.000 maps of Portugal; Pereira, 1989; 2000), considered it a stratigraphic boundary, the upper limit of Ordovician (Pardelhas Formation) truncates some lithologies interlayered in the Lower Silurian Campanhó Formation (Figura 2).

2. Geological setting

The CIZ is characterized by a set of metasedimentary units, accompanied by large granite intrusions all representing the extensional and collisional stages of the Variscan Cycle on the Iberian Massif (Ribeiro *et al*., 2007).

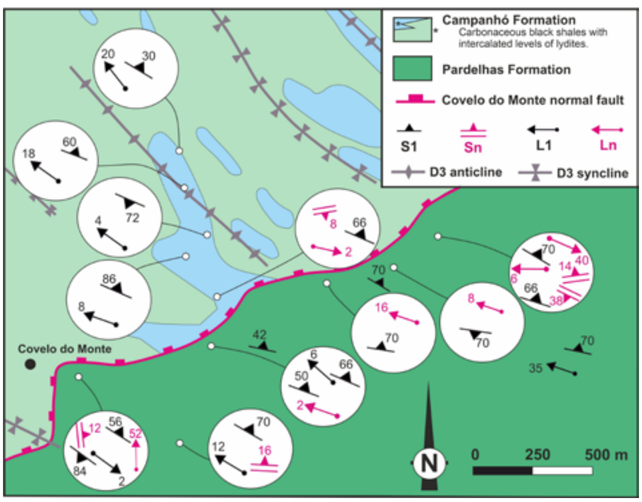

Figure 2. Structural and map of the Campanhó area (adapted from Pereira, 1987) and the tectonic contact between the Ordovician and Silurian, as interpreted in this work.

Figura 2. Mapa estrutural e geológico da área da Campanhó (adaptado de Pereira, 1987) e o contacto tectónico entre o Ordovícico-Silúrico, como interpretado neste trabalho.

This zone is limited to the south by the Tomar – Badajoz – Córdoba shear zone and to the west by the Porto – Tomar – Ferreira do Alentejo shear zone (*e.g.* Romão *et al*., 2013). The main structural pattern of the CIZ is due to the superposition of several tectonic events, highly disputed (*e.g.* Ribeiro *et al*, 2007; Dias da Silva, *et al*., 2020) in what concerns the number and kinematics (*i.e.* compressional and /or extensional). As the characterization of the these tectonic events are not fundamental for this work, we are going to use the succession of tectonic events recently considered in the nearby Marão mountain (Dias, *et al*., 2022): first deformation phase (D1) that generates a pervasive S1 cleavage axial planar of subvertical to overturned folds; second deformation phase (D2) usually expressed by sub-horizontal thrusts being more intense close to the allochthonous complexes; and third deformation phase (D3) consisting of discrete folds with subvertical axial planes that cut through these previous structures, well expressed due to the first order folds of the D2 thrusts (*e.g.* Ribeiro, 2013b).

In Campanhó (Figura 1B), the tectonostratigraphy is defined by autochthonous and parautochthonous units (Pereira, 1987; Pereira 1989). The autochthonous sequences are represented by metassediments of the Desejosa Formation (Middle to Upper Cambrian, upper part of the Douro – Beiras Super Group; Silva *et al*., 1987/89), sequentially overlaid by the Armorican Quartzite Formation (Lower Ordovician), the Pardelhas Formation (Middle Ordovician), the Campanhó Formation (Upper Silurian) and the Santos Formation (Lower Devonian). The parautochthonous segment contains the Mouquim and Canadelo Units (Upper Silurian-Devonian) composed of metassediments isolated from the autochthonous by the Canadelo overthrust (Pereira and Ribeiro, 1983; Pereira, 1987; Pereira, 1989; Figura 1B).

3. Structural Mapping in Covelo do Monte region

As stated, the contact between the Ordovician and Silurian sequences in the Marão region, represented by the interface of the Pardelhas and Campanhó formations (Figura 1b) may provide valuable insights into the geodynamic meaning of this boundary during the tectonic events related to the Variscan orogeny. This way, the thorough characterization of the structural features should help to discern whether the contact between them is characterized by normal stratigraphic sequences or by tectonic activity features and, in this case, what could be its kinematics.

The Ordovician Pardelhas Formation (Figura 1b), corresponds to a detrital-pelagic basal layer, composed essentially of micaceous shales and pelites, accompanied by slates (ardosiferous shales) at the top, with a relatively low metamorphic grade (evidenced by the presence of chiastolite) (Pereira, 1989 and references therein).

The Silurian Campanhó Formation (Pereira 1987; Pereira 1989) is characterized by black carbonaceous shales, with some levels of lydites. The northern boundary of the Campanhó Formation is the Canadelo Overthrust, underlined by a decimetric layer of black shales, graphite levels and sigmoid structures in the Devonian strata, indicating detachment towards SE.

In the Covelo do Monte sector, the only penetrative structure is a well manifested steep WNW-ESE S1 cleavage coeval of a L1 intersection lineation with an average plunging of 15º to 20º to WNW, though with some wavy pattern (Figura 2). This cleavage, often underlined by millimetre quartz veins, shows a continuous deformation process, often leading to the transposition of the bedding. Although it is axial planar to the D1 folds, which could suggest a coaxial deformation, sigmoidal structures indicate a sinistral kinematics (Figura 3A), subparallel to the main structural trend. This feature, which is common in the northern sectors of the CIZ, indicates a more complex behaviour with strain pertitioning during D1 (Moreira, *et al*., 2010; Dias, *et al*., 2022 and references herein).

The D1 structures are refolded by centimetric to metric WNW-ESE ascribable to the D3 regional event (Figura 3B), refolding previous

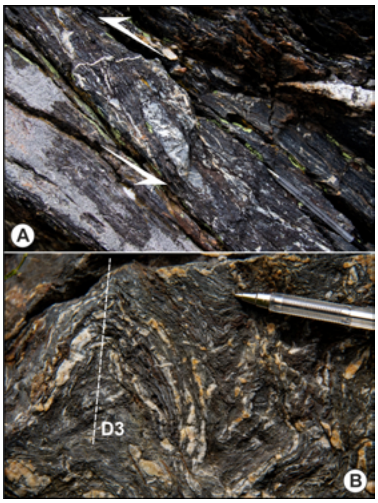

Figure 3. (A) Sigmoidal quartzitic lenses indicative of a sinistral kinematic. (B) D1 centimetric folds refolded during D3 tectonic event.

Figura 3. (A) Lentículas de quartzito sigmoidais evidenciando uma cinemática esquerda. (B) Dobras D1 centimétricas afectadas por um dobramento D3.

lithostratigraphic and tectonic contacts (Figs. 1B and 2) and coeval with a discrete S3 cleavage.

In the vicinity of the Ordovician-Silurian contact can be observed the development of a weak subhorizontal to low dipping cleavage (Sn; Figura 2), better observed in the shaly layers that produces the crenulation of the S1 cleavage. This Sn cleavage is folded by the D3 structures (Figura 4) indicating that it was developed after the S1 cleavage event and before the D3 regional one.

As the Sn and Ln structures become less clear away of the boundary between the Ordovician and the Silurian units, this contact must have been active before the D3 tectonic event, developing the mentioned Sn and Ln structures.

4. Discussion

The development of a post-S1 crenulation cleavage (Sn) only observable in the vicinity of the Ordovician-Silurian contact, prove that this boundary is tectonic, which explains the observed truncation of some of the Silurian layers, by the Ordovician formation. The subhorizontal to low dipping geometry of Sn, coupled with the steeper behaviour of the coeval fault contact (30º to 35º to NW according to the map pattern of Pereira, 1989), show that this must be considered a normal fault. Along this Covelo do Monte normal fault, the Campanhó Formation sequences (hanging-wall) moved downwards in relation to the Pardelhas Formation (foot-wall).

Concerning the age constraints of the Covelo do Monte normal fault development, the coeval Sn cleavage crenulated the S1 penetrative cleavage and it is folded by the regional third tectonic event (D3). Concerning the geodynamic meaning of this fault, it appears included in a set of discrete NE-SW normal faults dipping towards NW developed in the autochthon of the Marão region (the Pena Suar - Figura 1B - and Seixinhos faults; Dias *et al*., 2022). This restricted development strongly suggests that they should be considered a local process of the Variscan deformation.

The generation of localized normal faults during late D1 to D2 in the autochthonous units of the Marão region has been recently debated by Dias *et al.* (2022), where these intraorogenic faults were considered an uncommon feature of late D1 due to local heterogeneities. The authors interpret the Seixinhos – Pena Suar fault system (that comprises the Pena Suar fault, parallel to the proposed Covelo do Monte normal fault; Fig 1B), to be associated to major sinistral NW-SE shear zones (*e.g.* Manta, Amarante and Mondim-Murça-Moncorvo shear zones; Figura

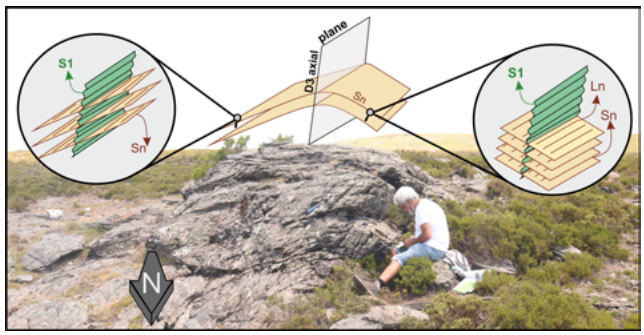

Figure 4. Mesoscopic D3 structure folding the S1 and Sn cleavages in Covelo do Monte region.

Figura 4. Estrutura mesoscópica D3 dobrando as clivagens S1 e Sn na região de Covelo do Monte.

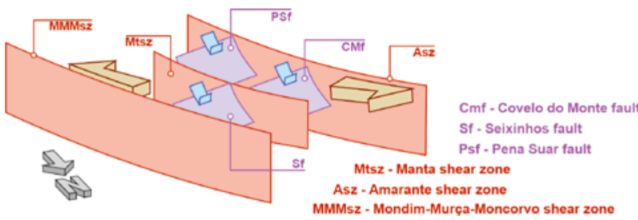

Figure 5. Schematic representation proposed for the normal fault system associated with the major shear zones of the Marão region (adapted from Dias et al., 2022).

Figura 5. Representação esquemática proposta para a geração do sistema de falhas normais associado às principais zonas de cisalhamento da região do Marão (adaptado de Dias et al., 2022).

4), developed through continuous compression with no significant shifts of the tectonic environment; this would ultimately lead to the local opening of releasing bends, accommodating extension prone to the generation of normal faults.

The model of the ductile-brittle normal faults of the Marão region proposed by Dias *et al*. (2022), regarding the emplacement of the Seixinhos – Pena Suar fault system is highly compatible with the generation of the Covelo do Monte fault (Figura 5). This work in Celorico de Basto also highlight the predominance of organic-rich shales in basal Campanhó Formation, making them prone to detachment when subjected to the extensional stresses associated with releasing bends.

5. Final remarks

Detailed structural mapping showed that in southern Campanhó (Celorico de Basto, Marão region) the Ordovician-Silurian boundary is marked by the Covelo do Monte normal fault, which is congruent to the emplacement mechanisms proposed to the Seixinhos – Pena Suar fault system, also observed elsewhere in CIZ (Dias *et al*., 2022). In order to better characterize the Ordovician – Silurian boundary, geological and structural mapping should be crossed with petrography and geochemistry to identify and quantify the presence of organic matter (or derivatives of its recrystallisation) in the horizons where detachments occur. The characterization of organic matter will help to understand its possible role in Silurian layers as a local constituent able to facilitate detachments (*e.g.* Parnell and Brolly, 2021). On a broader scale, Silurian lithotypes on the base of the sequences with such characteristics could be the common factor for the Ordovician-Silurian tectonic contact found throughout the CIZ, as commonly described in literature.

The proposed Covelo do Monte normal fault explain why in the 1/50 000 geological of Celorico de Basto (Pereira, 1989), the upper limit of the Ordovician (Pardelhas Formation) truncates some younger lithologies interlayered in the Lower Silurian Campanhó Formation (Figura 2).

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