

Superposition of shear zones during orogenic development: an example from the NW Variscan Belt (Viana do Castelo, NW Portugal)

Jorge Pamplona ^{a,*}, Gabriel Gutiérrez-Alonso ^b, António Ribeiro ^c

^a Centro de Investigação Geológica, Ordenamento e Valorização de Recursos, Universidade do Minho, 4710-057 Braga, Portugal

^b Departamento de Geología, Universidad de Salamanca, 37008 Salamanca, Spain

^c Departamento de Geologia e Laboratório de Tectonofísica e Tectónica Experimental, Universidade de Lisboa, 1749-016 Lisboa, Portugal

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Abstract

The Viana do Castelo region of NW Portugal is the only domain in the West Variscan where the transition from the D₁ strike-slip structures to the D₁ east vergent flat-lying structures, formed during Devonian–Carboniferous continental collision, has been recognized. Although intrusion of voluminous granite bodies has resulted in extensive recrystallization of host rocks, kinematic analysis of these rocks, using mesoscopic criteria and quartz CPOs (crystallographic preferred orientation) reveals shear senses coherent with the field evidence and suggests that D₁ deformation was partitioned into transpressional and compressional components. We also interpret the strain patterns to the effects of non-cylindrical superposed shear zones. The above aspects can be useful to understand the complex tectonic evolution of the most internal zone of the Variscan Belt and of other internal zones of collisional orogenic belts with similar characteristics.

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1. Introduction

Multi-phase development of the internal zones of orogenic belts is characterized by the superposition of ductile structures, mainly shear zones, with different kinematic components developed under different metamorphic conditions. Within the internal zones, shear zone development is commonly coeval with granitoid generation and emplacement and both processes record the evolution of the different deformation regimes in space and time. The sequential record of shear fabric generation and related structures is commonly obscured by subsequent tectonothermal events that result in partial annealing of these fabrics. As a result of these complexities, it is commonly very difficult to unravel the kinematic significance of earlier structures.

The NW Iberian Variscan arcuate belt is a classic orogenic belt where the multi-phase development of the Variscan structures in its internal zones has been recognized and described (Ribeiro et al., 1990a,b; Martínez-Catalán et al.,

1996; Dallmeyer et al., 1997). The orogenic development of the Variscan Belt is the result of the Devonian–Carboniferous collision between Gondwana and Laurentia that caused the major, shortening-related structures with displacements normal to the general strike of the belt. In addition, the arcuate shape of the belt suggests that crustal-scale strike-parallel structures may accommodate some of the across-strike shortening (Matte and Ribeiro, 1975; Iglesias and Choukroune, 1980; Ferreira et al., 1987; Llana-Fúnez and Marcos, 2001; Gutiérrez-Alonso et al., 2004). Based on paleomagnetic evidence in the external zones, such structures have been interpreted to have originated during the latest stages of the collision (Weil et al., 2001). The strike-slip crustal shear zones have been also interpreted to have facilitated the emplacement of many of the granitoid bodies present in NW Iberia (Aranguren and Tubía, 1994).

In this study, we describe and interpret the structures present in the studied area and the sequence of deformational events causing them, in a region where the aforementioned major deformation phases existing in the NW Iberian Variscan Belt show their geometric and kinematic relationships. The mentioned structures are recognized along a NNW–SSE-trending deformation corridor located in the proximity of Viana do Castelo (NW Portugal) (Fig. 1). We present a detailed structural analysis of the region emphasizing the kinematics of the shear zones and the relationships among them and the

* Corresponding author. Tel.: +351 253 604307; fax: +351 253 678206.

E-mail address: jopamp@dct.uminho.pt (J. Pamplona).

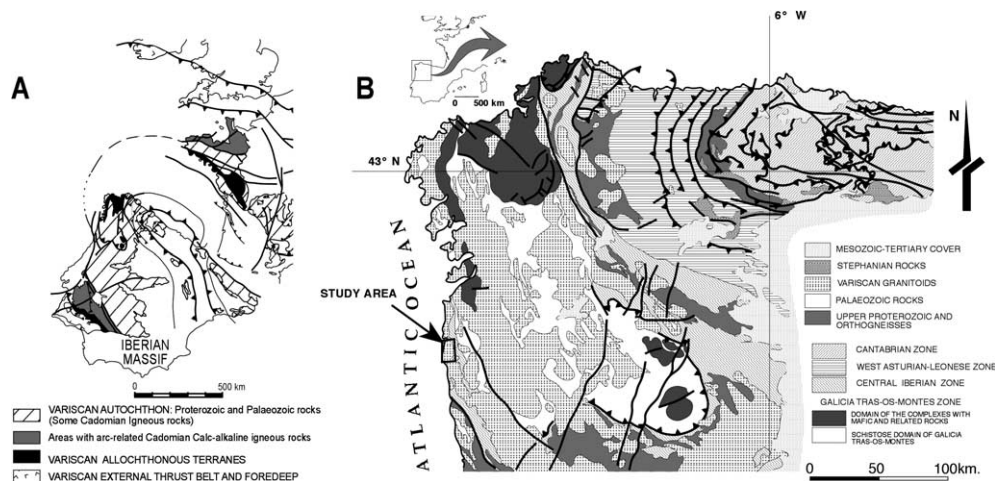


Fig. 1. (A) Map of the West European Variscan Belt prior to Biscay Bay opening depicting its marked arcuate shape. (B) Sketch map depicting the geological framework of the internal zones of the NW Variscan and the studied area. The allochthonous, parautochthonous and autochthonous units are highlighted as well as the main thrusts and strike slip faults.

regional structure. The kinematic analysis has been done using both mesoscopic structural criteria and quartz CPOs (crystallographic preferred orientation). In this corridor, the dating of granitic intrusions provides precise time constraints that enable different deformational episodes found in this area to be placed in chronological sequence.

The presence of a large volume of granitic intrusions has recrystallized the host rocks to varying different degrees, limiting the information provided by the quartz CPOs in the studied region. However, we propose a kinematic and structural sequence in the region and correlate these events with those described in the surrounding areas. We also interpret the relationship between the superposed shear zones and the different intrusive modes of the granite bodies. Taken together, these features constrain the tectonic evolution of the internal zone of the Variscan Belt and provide insights into processes occurring in other collisional orogenic belts.

2. Geological setting

NW Iberia Variscan geological framework (Fig. 1) consists of a structural stack of thrust slices that can be grouped into three main structural units. The uppermost thrust slice, known as the allochthonous unit, sits above the Variscan suture and the subducted terranes of Gondwanan affinity (Arenas et al., 1986, 1995; Ribeiro et al., 1990a; Martínez-Catalán et al., 1999; Fernández-Suárez et al., 2003). The allochthonous unit is variously interpreted to be composed either of Laurentian affinity rocks or of rocks with an Armorican affinity (Marques et al., 1996). The latter interpretation implies that the suture with Laurentia must exist further west. Below it, and separated by a large thrust, the parautochthonous unit contains Silurian and Devonian sediments from the Gondwanan margin that were located in the most seaward position and that were not subducted during orogenesis (Iglesias et al., 1983; Farias, 1990; Ribeiro et al., 1990a; Martínez-Catalán et al., 1999). The lowermost unit is autochthonous and consists of Upper Proterozoic sedimentary rocks unconformably overlain by

Paleozoic strata that were deposited along the Gondwana shelf (Gutiérrez Marco et al., 1990; Pereira and Ribeiro, 1992; Sequeira, 1993).

The studied area is located in the Variscan kilometre-scale Viana do Castelo–Caminha antiform (Fig. 2), which is developed in the lower Paleozoic rocks located within the autochthonous unit in the most internal zone of the Variscan Belt, in the Central Iberian Zone (CIZ) (Fig. 1), which is characterized by the abundant Variscan granitoids and the widespread ductile deformation of the same age (Diez Balda et al., 1990; Dias, 1994). The main geological features of the study area, as described by Pereira et al. (1989), Cathileneau et al. (1993), Toyos (1995, 2003) and Pamplona (2001), are shown in a synthetic cross-section of the Viana do Castelo–Caminha antiform (Fig. 3) and will be described in detail.

The rocks that crop out in the study area are mainly Variscan syn-orogenic granitoids (Fig. 2A) that intrude Upper Proterozoic shales and a sequence of Lower Paleozoic rocks (see synoptic lithostratigraphic column in Fig. 2B) composed of sandstones and conglomerates of the Cambrian Desejosa Formation, which is unconformably overlain by the Arenigian Armorican Quartzite (Santa Justa Fm.) and shales of Lanvirn–Llandeilian age (Valongo Fm.). All host rocks have undergone LP–HT contact metamorphism related to the intrusion of the Variscan granitoids and have developed a paragenesis of garnet, andalusite (chiastolite up to 7 cm long), cordierite and scarce sillimanite. This LP–HT metamorphism (Hébert, 1997) masks most of the features of a previous Barrovian episode (Martínez et al., 1990; Ribeiro, 1992; Pamplona, 2001).

The structural evolution of the CIZ has been classically described to be comprised of three major deformation phases that occurred following each other along the Variscan Belt evolution (Dallmeyer et al., 1997 and references therein). According to some authors, the first deformation phase (D_1) and the D_1 pervasive axial plane cleavage is related to either vertical or east-verging large scale folds developed in the earliest collisional stages (Diez Balda et al., 1990). Other authors, however, attribute the D_1 cleavage to motion along left

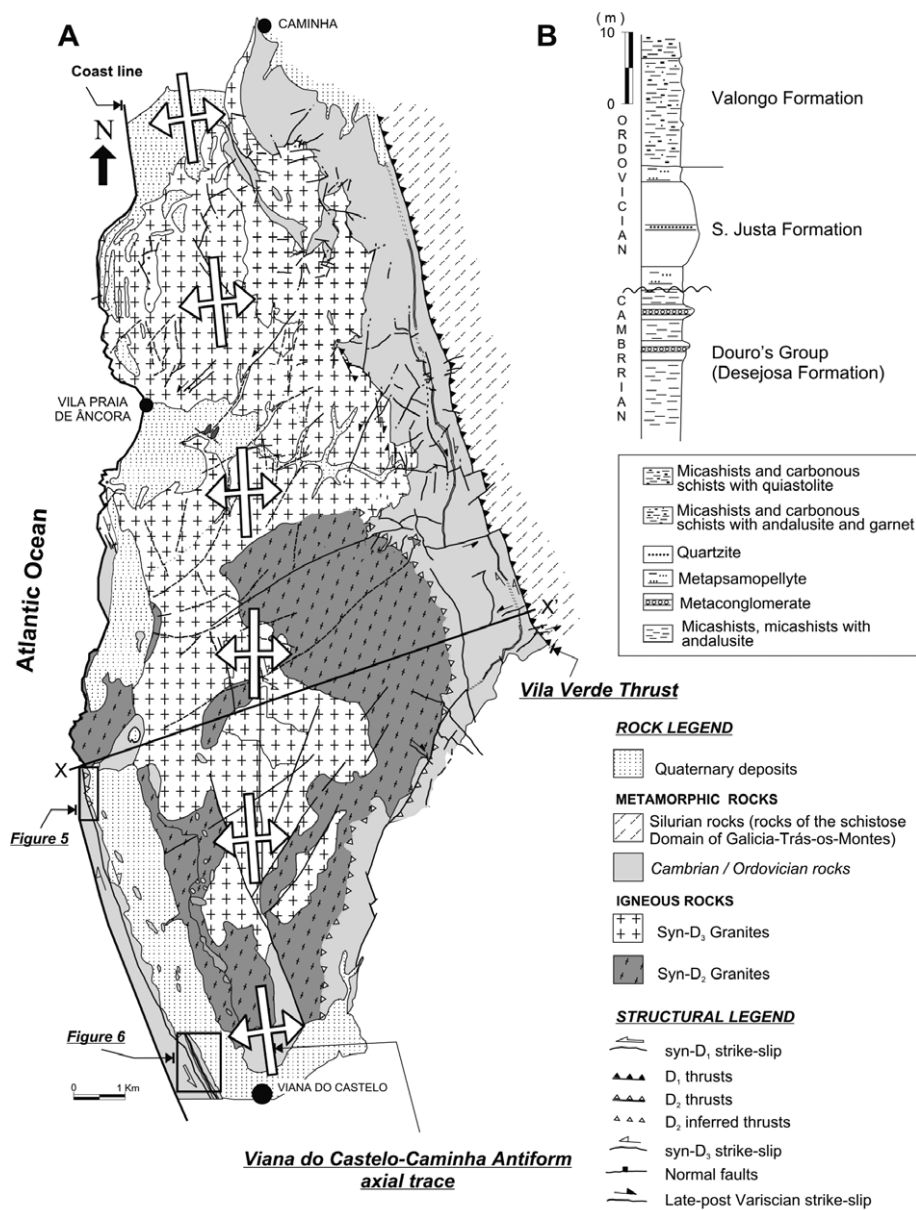


Fig. 2. (A) Geological map of the Viana do Castelo–Caminha antiform showing the axial trace of the studied antiform. (B) Synthetic lithostratigraphic column. X–X'—cross-section in Fig. 3.

lateral shear zones that reflect a reactivation of a postulated Precambrian suture (Ribeiro et al., 1990a,b; Dias and Ribeiro, 1994). D₂ is characterized by the generation of top-to-the-east reverse shear zones related to the emplacement of the peri-Gondwanan allochthonous units (Martinez-Catalán et al., 1999; Gómez Barreiro et al., 2006 and references therein). These shear zones are usually several kilometres thick and occur adjacent to the base of major thrusts that are responsible for the main shortening during the Variscan collision in NW Iberia. D₃ results in the formation of late N–S-trending antiforms and synforms with vertical or east-dipping axial planes. Subsequently, D₄ sub-vertical strike-slip faults and accompanying local shear zones are developed (Dias and Ribeiro, 1994, 1995; Llana-Fúnez and Marcos, 2001), although they are not generally considered to be part of a major

widespread deformation event. These deformational events overlap in time, at least locally, and are clearly diachronous when considered at an orogenic scale (Dallmeyer et al., 1997).

The synthetic cross-section depicted in Fig. 3 depicts a large D₃ antiform with a half wavelength of approximately 10 km, which is characterized by many second order and minor folds with east-dipping steep axial planes (Fig. 4D) that commonly show axial plane crenulation cleavage. The minor fold axes predominantly plunge moderately to the south (Fig. 4D). At the western limit of the antiform, a semi-continuous outcrop of metasedimentary rocks is strongly deformed by a NNW–SSE-trending sub-vertical D₃ dextral shear zone and is overprinted by late left-lateral local shear zones with the same orientation. Within this shear zone there are several large elongated, phacoid-shaped volumes of rock that preserve the most

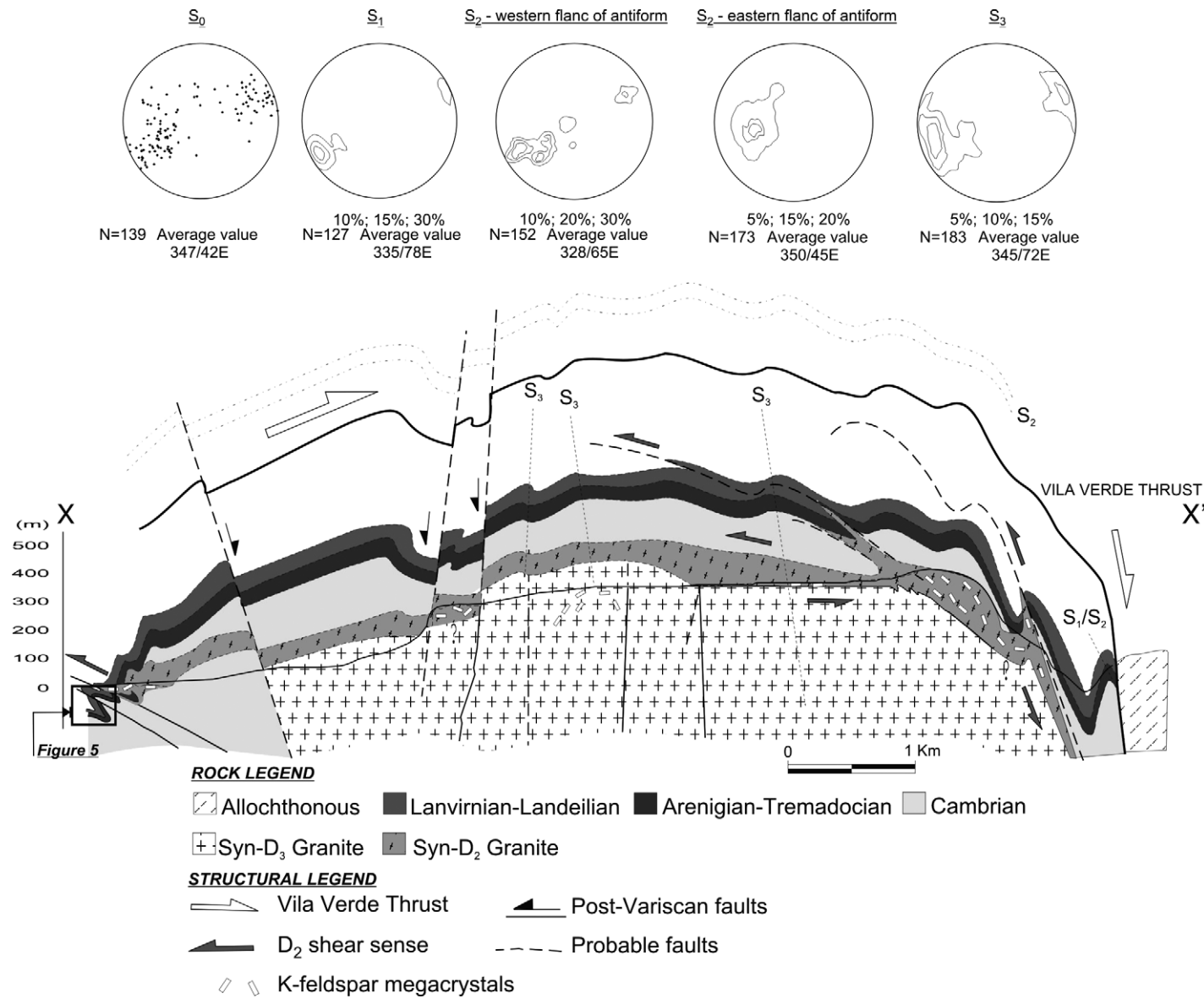


Fig. 3. Contour diagrams (Schmidt net, lower hemisphere) of the orientation of the main structural features in the studied sector and composite cross-section of the Viana do Castelo–Caminha antiform. Because of the general plunge of the structures to the North, most of the structures can be projected above the topographic surface. Location of the cross-section trace is in Fig. 2. Note the vertical exaggeration.

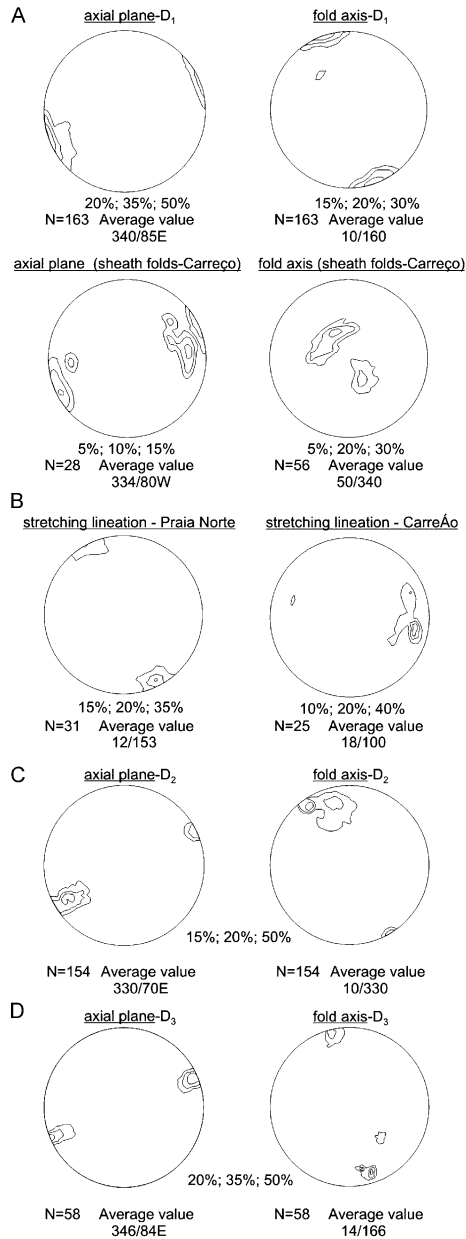


Fig. 4. Contour diagrams (Schmidt net, lower hemisphere) of the main structural elements of the metasedimentary rocks present in the area. (A) Axial plane and fold axis of D₁. (B) Stretching lineation of D₁ in Praia Norte and Carreço. (C) Axial plane and fold axis of D₂. (D) Axial plane and fold axis of D₃. Explanation in the text.

competent quartzites much less deformed than the surrounding, strongly foliated, less competent slates and sandstones. Some of these phacoid-shaped rock bodies in Praia Norte (Fig. 2) show stratigraphic features of the Armorican quartzite, including trace fossils identified as *bilobites*, cross bedding and ripple marks. These phacoids also preserve primary tectonic structures such as the S₁ foliation, which is oblique to bedding and that has been interpreted to correspond to the D₁ (Pamplona, 2001).

Above the Lower Paleozoic sequence, a large thrust, the Vila Verde Thrust (continued to the north as the Valdemíñotes Fault, Toyos, 2003), carried the parautochthonous units above

the Ordovician sediments towards the east (present-day coordinates). A D₂ shear zone several kilometres thick accompanies this east moving thrust. This shear zone progressed into the autochthonous units and imparted a highly penetrative cleavage that is generally parallel to the thrust plane and to bedding obliterating S₁ in most cases. The S₂ cleavage was folded by the D₃ event and thus folded the D₂ thrust plane (Fig. 3).

The widespread granitoid rocks of this area are peraluminous granitoids intruded syn-kinematically with respect to D₂ and D₃ deformation events (ca. 330–300 Ma) and are very abundant in NW Iberia. Some of the granitoid bodies of the studied region are interpreted to be intruded at the end of the D₂ event, but most of them are thought to be related to the D₃ event and some of them even later (Pamplona, 2001). These intrusions are responsible for the several generations of andalusite porphyroblast growth in the intruded sedimentary rocks.

3. Structural features

In order to understand the structural evolution of the studied region, two detail maps were completed in the areas where high quality coastal exposures allowed the structural relationships between the different shear zones to be clearly observed and understood. The two areas studied in detail are Carreço beach (Fig. 5) and Praia Norte beach (Fig. 6). The most prominent structures found in the aforementioned studied areas are folds and several sets of cleavage, which show different characteristics depending on which of the three main Variscan deformation phases they are related to.

3.1. First Variscan deformation phase (D₁)

3.1.1. Structures: folds, cleavage and stretching lineation

The only D₁ folds recognized are isoclinal and are preserved only in the less deformed, lens shaped, quartzite bodies of the Santa Justa Formation. These folds (Fig. 7A) have sub-vertical axial planes (340°/85°E) and sub-horizontal fold axis (Fig. 4A). In addition, there are some small scale sheath folds developed in the Santa Justa Fm. quartzites that are also assigned to D₁. The axial planes of these sheath folds are sub-vertical and sub-parallel to the D₁ isoclinal folds (mean orientation: 344°/80°W) and the fold axis defines a sheath-like girdle along this mean orientation (Fig. 4A).

D₁ folds are characterized by a sub-vertical cleavage (S₁), parallel (or almost parallel) to their axial plane (mean orientation of 335°/78°E; Fig. 3). This cleavage is well developed in the Santa Justa quartzites, but has been obliterated in the less competent lithologies. Locally, however, this cleavage has transecting relationships with respect to D₁ axial planes, especially in the Praia do Norte outcrop where the axial planes of folds (335°/90°) are transected more than 10° by the S₁ cleavage (345°/80°NE).

A pervasive stretching lineation, attributed to D₁ shows two different orientations (Fig. 4B): in the Praia do Norte sector the

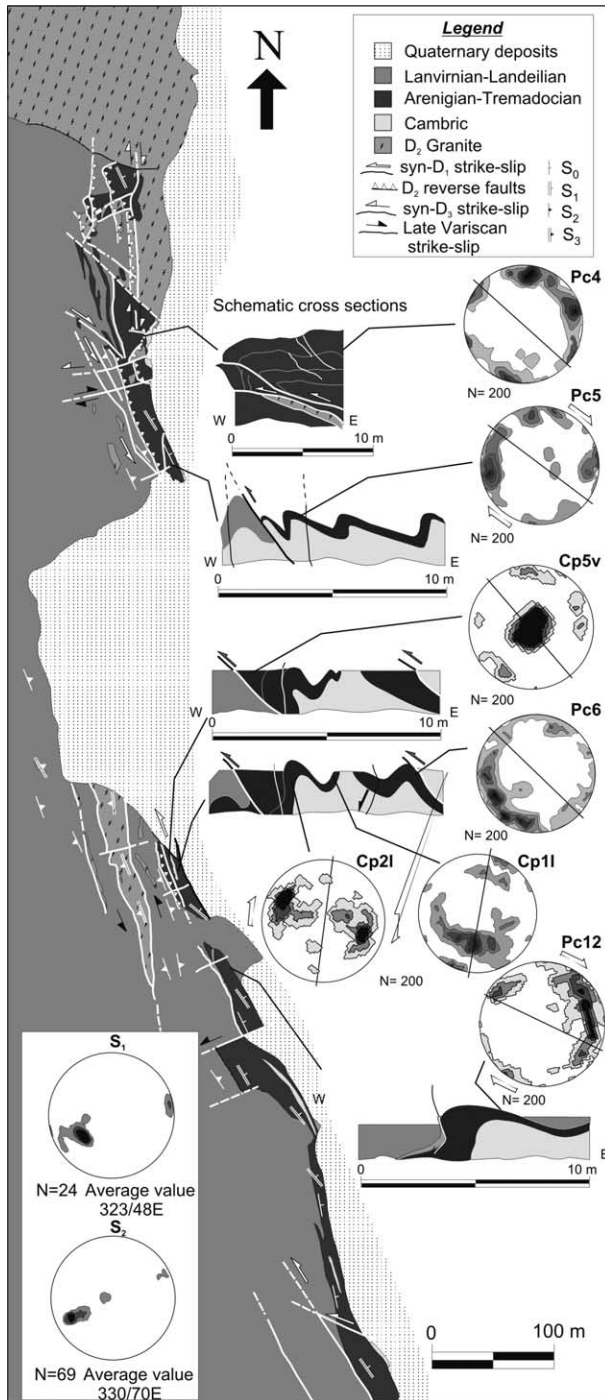


Fig. 5. Detailed geologic map of Carreço area with CPOs (density intervals 1%), schematic cross-sections and stereographic projections, Schmidt net, lower hemisphere. Location in Fig. 2.

mean orientation is $12^{\circ}/153^{\circ}$ and in the Carreço sector is $18^{\circ}/100^{\circ}$.

3.1.2. Interpretation of D_1 in the studied sector

D_1 isoclinal and sheath folds, and the others preserved in the quartzite phacoids, are interpreted to be related mainly to shear zone development during the emplacement of the allochthonous units to the east above the Vila Verde thrust (Ribeiro et al., 1990a). Unfortunately, the sheath folds do not

show a marked asymmetry and do not indicate clearly the top-to-the-east sense of movement of the Vila Verde thrust, presumably due to the subsequent deformation, mostly the steepening of the D_1 folds during the D_2 and D_3 deformations (see below). Transection of some of the D_1 folds can be explained by the dextral transpressive nature of the D_1 deformation in this sector of the Variscan Belt of NW Iberia (Ribeiro et al., 1990a).

Following the same reasoning, both orientations of the stretching lineation are interpreted to reflect the dextral transpressive and progressive nature of the D_1 deformation. The E–W-trending lineation can be explained in relation to the early stages of the Vila Verde thrust emplacement, while the N–S one is related to the left lateral strike-slip component (Ribeiro et al., 1990a).

3.2. Second Variscan deformation phase (D_2)

3.2.1. Structures: folds and cleavage

D_2 is characterized by the presence of abundant folds that are tight to isoclinal that can be recognized only in the Carreço sector affecting the previous S_1 . The density contour diagrams of the D_2 axial planes and fold axis (Fig. 4C) show mean values of $330^{\circ}/70^{\circ}$ E and $10^{\circ}/330^{\circ}$, respectively, but some folds have more shallowly dipping ($<30^{\circ}$) axial planes.

The D_2 shear cleavage (Fig. 7D and E) dips mostly to the NE showing a different attitude (dip values) in both flanks of the Viana do Castelo–Caminha antiform (Fig. 3). The D_2 cleavage appears concentrated within bands parallel to the D_2 thrusts, crenulates the previous S_1 and shows kinematic criteria, both indicating top-to-the-west and top-to-the-east movements.

3.2.2. Interpretation of D_2 in the studied sector

The origin of the D_2 structures is interpreted to be related to the emplacement of the Vila Verde thrust. Conjugate, top-to-the-west, minor thrusts developed in the footwall of the main thrust, as can be seen in Fig. 3. Several laminar granitoid bodies were emplaced in orientations that are parallel with D_2 thrusts and are thought to be early syn- D_2 , having been rotated to their present attitude by the progressive D_2 shear zones.

In addition, the studied sector is the only domain of the West Iberian Variscan Belt described so far where it is possible to document the rapid passage of the D_1 strike-slip structures to late D_1 or early D_2 east vergent flat-lying structures.

3.3. Third Variscan deformation phase (D_3)

3.3.1. Structures: folds and cleavage

Ubiquitous D_3 structures were formed during the last main Variscan deformational event. D_3 cylindrical folds are predominantly steep, shallowly plunging, open structures with mean axial plane and fold axis orientations of $346^{\circ}/84^{\circ}$ E and $14^{\circ}/166^{\circ}$, respectively (Fig. 4D), and produce type 3 interference patterns (Fig. 7C) with both D_1 and D_2 isoclinal folds. In the region between Carreço and Praia Norte, the D_3 have interlimb angles of about 135° .

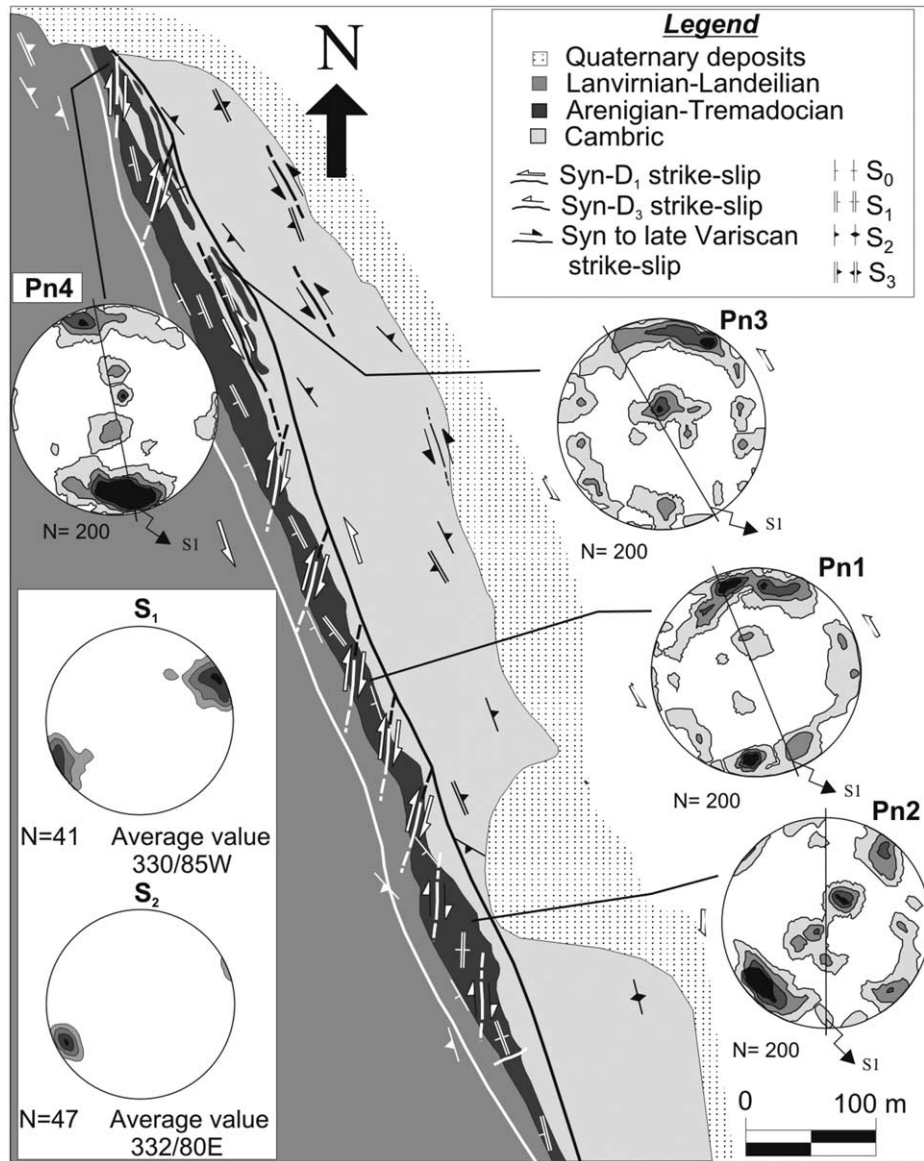


Fig. 6. Detailed geologic map of Praia Norte area with CPOs (density intervals 1%) stereographic projections, Schmidt net, low hemisphere. Location in Fig. 2.

D₃ folds deform pre-existing (D₁ and D₂) cleavages. S₃ has a mean orientation oriented 345°/72°E (Fig. 3), parallel to the axial planes of the D₃ folds. This cleavage is not prevalent across the whole region and is most commonly observed in the fine grained metasediments. According to the field data, S₃ surfaces contain local sub-horizontal stretching lineation parallel to the fold axis. Parallel to the stretching lineation there is microscopic evidence of dextral kinematic criteria (Fig. 7F). Pre- or syn-D₃ granitoid bodies are also affected by this deformation, developing S–C fabrics with mostly dextral asymmetry.

Rare late D₃ structures have been recognized in the study area: NE–SW open folds that produce type 1 interference patterns with previous folds and also non-pervasive, little penetrative cleavage, kink bands and N10°E–N40°W left-lateral deformational corridors affecting the latest aplitic and pegmatitic dykes not deformed by the D₃ in the region.

3.3.2. Interpretation of D₃ in the studied sector

We can interpret D₃ to reflect either a switch from dextral to a left lateral transpressive regime or to the presence of a conjugate set of transcurrent shear zones coeval with the E–W shortening that gave rise to the open folds. This event took place under ductile to brittle conditions producing abundant en échelon vein arrays. It is probable also that the abundance of previous already cooled granitoid bodies surrounding the studied region caused a deformation shadow in this area during the D₃ event, which may explain its low intensity compared with the same event in surrounding areas.

4. Quartz CPOs

Quartz crystallographic preferred orientation (CPO) studies (Wenk and Christie, 1991) of deformed polycrystalline aggregates can provide constraints on the kinematics and

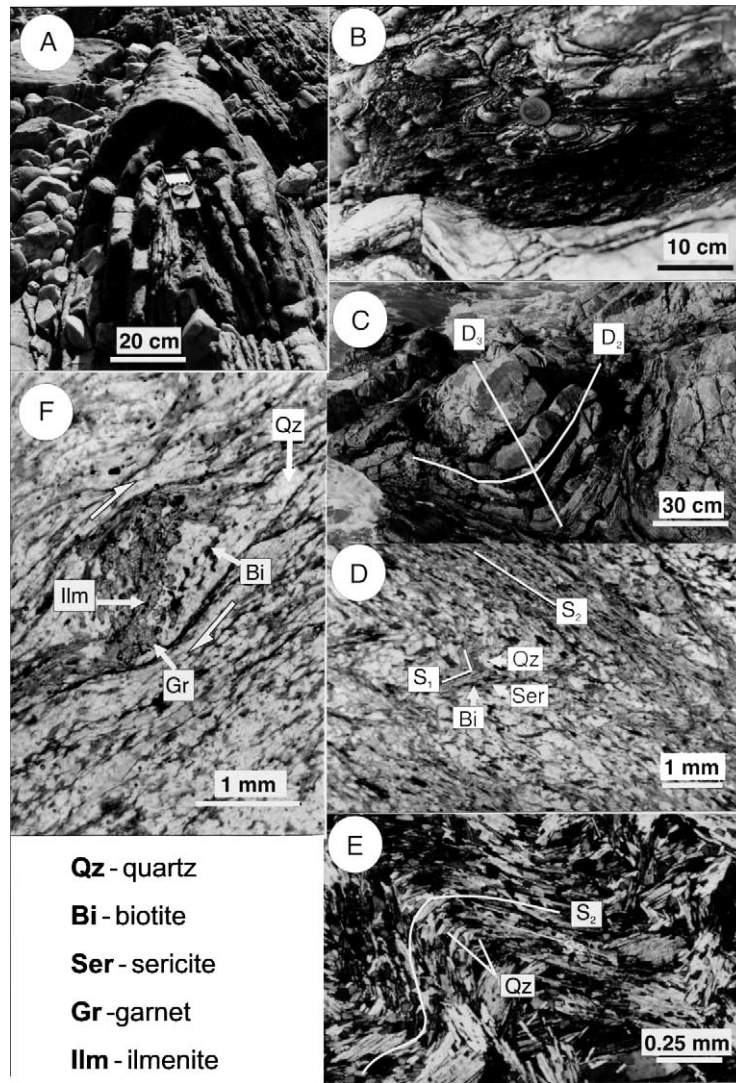


Fig. 7. Field ((A)–(C)) and microscope photos ((D)–(F)). (A) D_1 fold in the Armorican Quartzite; (B) D_1 sheath folds in the Armorican Quartzite; (C) D_3 fold folding a D_2 fold in the Armorican Quartzite; (D) crenulated S_1 and S_2 in the Cambrian micashists; (E) D_3 crenulation in the Cambrian micashists; (F) D_3 dextral cinematic criteria in the Cambrian garnet bearing micashists.

deformation conditions in rocks deformed under ductile conditions and the relationship between simple shear and the interference of flow geometries (Llana-Fúnez, 2002). However, in many cases, an important component of pure shear and coaxial overprints is needed to unambiguously interpret some texture elements (Lister and Dornsiepen, 1982; Hobbs, 1985). Because of the complex structure and strain superposition within the studied region, CPO studies can provide useful constraints on the nature of the different deformation phases (especially the earlier phases where they are not modified subsequently), the conditions in which they developed and the deformation mechanisms involved in the generation of the ductile shear zones.

4.1. Objective and sampling strategy

We used the quartz CPOs in order to try to deduce the structural relationships and kinematics of the D_1 structures developed in the shear zones and the relationships among them.

Oriented samples from the Santa Justa Fm. (the Armorican Quartzite) in the two areas studied in detail were collected in order to compare and understand the two different deformation patterns observed in them. These areas have different orientation to the D_1 structures and show different recrystallization histories. Samples were collected along both limbs of the post- D_1 folds in order to explore the effect of re-folding and to understand the kinematics of the D_1 deformation.

All oriented samples were studied in thin sections cut on the XZ plane, in sections normal to the D_1 cleavage (S_1) and parallel to the observed L_1 stretching lineation. Because of its complex deformation and metamorphic history, samples with evidence of intense late-Variscan static recrystallization or with strong crenulations affecting the S_1 were rejected.

4.2. Description of the CPOs

The Santa Justa quartzite studied samples are composed originally of 99% quartz xenomorphic grains that, when

deformed, range from slightly elongated to irregular. The grain boundaries are commonly sutured although rare rectilinear contacts are also observed.

CPOs analyses were performed using a manually operated U-Stage and the orientation of quartz c-axes are plotted on stereonet (Fig. 5: Carreço outcrop; Fig. 6: Praia Norte). The kinematic vectors are oriented in relation to the orientation of the structures (cleavage and lineation) present in the studied sections.

In the Carreço and Praia Norte outcrops, the quartz c-axis distribution patterns are different in all studied samples. For example, the patterns of samples Pc4 and Pc6 (Fig. 5) are highly symmetric and indicate predominantly coaxial deformation. Cp11 (Fig. 5) and Pn4 (Fig. 6) depict an orthorhombic pattern that may reflect symmetric coaxial extension (Twiss and Moores, 1992). Sample Cp5v also depicts a CPO coaxial deformation type, although its high temperature nature precludes a thorough kinematic interpretation.

CPO patterns in the more deformed samples are asymmetric (type II crossed girdle pattern; Twiss and Moores, 1992) with respect to both the foliation plane and the stretching lineation, features that are interpreted to provide shear sense indicators in non-coaxial deformation (Lister and Williams, 1979). Samples Pc5, Cp21 and Pc12 from the Carreço outcrop (Fig. 5) and samples Pn1, Pn2 and Pn3 from Praia Norte (Fig. 6) all show a low temperature non-coaxial deformation pattern with asymmetrical type II girdles. The Carreço samples indicate a top-to-the-east thrust component, whereas the Praia Norte samples imply left-lateral movements.

4.3. Interpretation of the CPOs

The appearance of different morphologies of quartz CPOs and quartz grains is attributed to the sequential and progressive deformation from ribbon to irregular to polygonal grains (Llana-Fúnez, 2002) and to an increasing role of grain boundary migration as the recrystallization mechanism during regional deformation. The studied samples can be interpreted in the light of an overall non-coaxial deformation that produced a concentration of the quartz c-axis orientations by the slip of the [a] basal planes. The type II maxima present in the girdles are related to the slip in the rhombohedral planes (r)[a] and (z)[a] as illustrated in the sample Cp21 as well as the type III maxima present in samples Pc5, Pc12, Pn1, Pn2 and Pn3, all of them related to the (0001)[a] slip system.

The presence of coaxial quartz c-axis patterns may reflect strain partitioning within narrow (decametric to kilometric) shear corridors according to the 2D and 3D finite strain patterns obtained in the Viana do Castelo–Caminha antiform (Pamplona et al., 1997; Pamplona, 2001) and adjacent areas (Coke et al., 2003) where the bedding surfaces acted as the main anisotropy controlling the style of deformation.

The fabric in the sample depicting a high temperature deformation (Cp5v; Fig. 5) is interpreted to be synchronous with respect to the D₁ deformation (at least the late stages) and with early D₂ magmatism.

Furthermore, the shear senses obtained in the CPOs are congruent with the regional and field evidence and support the different style of D₁ deformation in the Carreço and Praia Norte outcrops. The results obtained in Carreço are in general agreement with the overall interpretation of the late D₁ or early D₂ deformation in this sector of the Variscan Iberian belt, which includes the earlier stages of the east-directed thrusting of the allochthonous units above the autochthonous ones (Fig. 8A).

The kinematic results obtained from the CPOs in Praia Norte are attributed to left lateral transposition that is widely recognized in the autochthonous units of CIZ and Galicia-Tras-os-Montes (Fig. 8B).

5. Kinematic history of the Viana do Castelo antiform

Fig. 8 illustrates and summarizes the Variscan deformational history of the studied region and adjacent areas. It starts with the D₁ deformation event, which is responsible for the corval left lateral transposition and the early thrust emplacement of the allochthonous terranes (Fig. 8A and B).

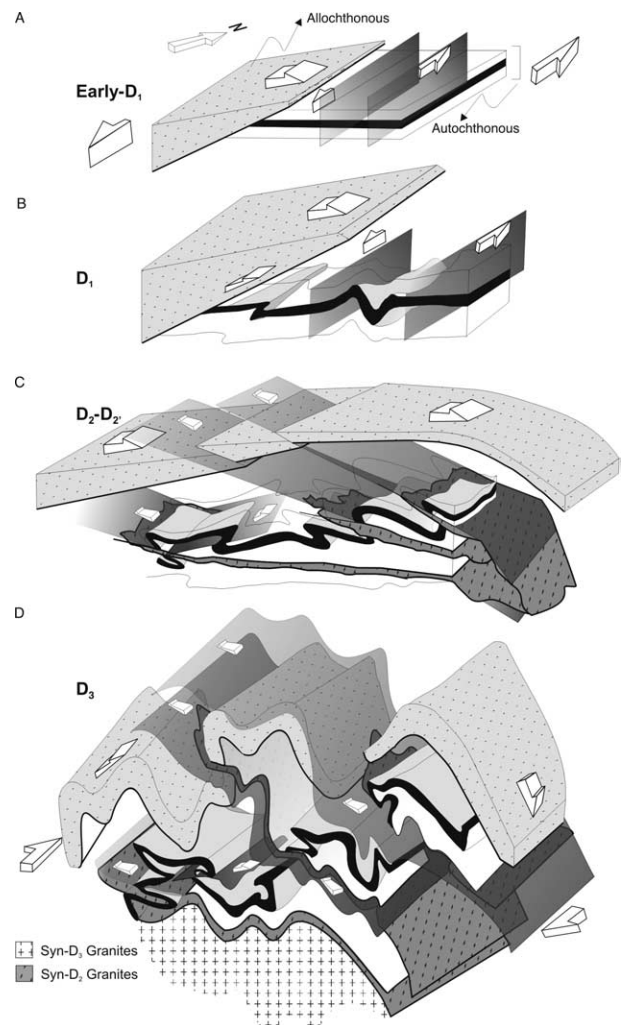


Fig. 8. Sequential diagrams ((A)–(D)) summarizing and depicting the evolution of the different Variscan deformation phases as recognized in the studied area (antiform of Viana do Castelo–Caminha).

Further deformation events did not affect the D_1 CPOs of the studied samples and the succession of events can be reconstructed from the analysis of the meso- and micro-structures already mentioned. From this point of view the structural history, after the D_1 event, of the studied region can be summarized as follows:

1. The continental collision during the D_2 event was responsible for the development of E and W dipping reverse shear zones. The intrusion of syn-kinematic laminar granitoid bodies along the shear zones is the dominant D_2 feature in this area (Fig. 8C).
2. D_3 is characterized by shear corridors, 0.5 km wide, related to dextral transpression that resulted in open folds, conjugate shears and refolding the previous folds, cleavages, thrusts, shear zones (D_1 and D_2) and the early granites sheets. In addition, the voluminous late-Variscan syn- D_3 granitoids were emplaced in the core of the D_3 Viana do Castelo–Caminha antiform (Fig. 8D).
3. Late D_3 left-lateral transpressive deformation is characterized by the reactivation of earlier shear zone corridors and the development of a weak folding and cleavage.

6. Conclusions

The Viana do Castelo–Caminha antiform is a region where the main deformation events in the autochthonous units of the Variscan Iberian Belt are well represented and its relations can be well understood. Field data and CPO studies in quartzitic rocks of the Santa Justa Fm. allow the reconstruction of the earlier episodes of the Variscan deformation despite the complex evolution and the strong thermal imprint along the subsequent Variscan deformation and magmatic events.

The two areas studied in detail provide evidence for the different components of D_1 deformation, pure shear and transpression that occurred in the autochthonous units below the Vila Verde thrust.

A complete geological history of the studied region, regarding the Variscan deformation, can be reconstructed, showing the complex evolution along the main tectonic events (Fig. 8). The colliding process between Laurentia and Gondwana in the studied sector involved large scale strain partition in time and space between transpressional and orogenic-normal deformations in the most internal parts of the Variscan Belt.

This study proves the need to produce alternative, non-cylindrical, deformation models to develop new ideas in the Variscan orogen in order to fully understand the evolution of its complex kinematic history, especially the transpressional events that are often overlooked and understated.

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