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A GEOTRAVERSE THROUGH THE VARISCAN FOLD BELT IN PORTUGAL[1]

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ABSTRACT

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A geotraverse through the Variscan Fold Belt in Portugal is described. The main geometric and chronologic features of the different deformation phases are drawn for each palaeogeographic and tectonic zone (Middle Galician – Trás-os-Montes Subzone; Centro-Iberian, Ossa-Morena and South Portuguese Zones). The problem of the tectonic position of the Bragança and Morais Massifs is referred to. The pattern of vergences and the mechanical origin of the Ibero-Armorican arc are briefly discussed.

INTRODUCTION

One of the most complete profiles through the Variscan fold belt can be seen in the Iberian Peninsula. A major feature of this deformed segment is the zonality of the palaeogeography, structural style, magmatism and metamorphism. This was first recognized by LOTZE (1945) who subdivided the belt into major zones. A modified version has been proposed (JULIVERT ET AL., 1974) considering the following zones, from the NE to the SW: Cantabrian, West-Asturian-Leonese, Centro-Iberian, Ossa-Morena and South Portuguese zones.

A diagrammatic profile of the belt shows that the orogen has a fan-like pattern, with steep structures in the core and outward vergences on the margins. This causes a first-order differentiation between the Internal Zones – where the Precambrian and Lower Palaeozoic are best represented, synorogenic deformation is more intense, and magmatism and metamorphism are widespread – and the two External Zones (Cantabrian and South Portuguese), where the Upper Palaeozoic shows a fuller development, the deformation is less intense and younger, and the magmatism and metamorphism are less extreme.

A symmetrical pattern emerges, but, as we will see, there are major differences between the External Zones on the two sides of the orogen, so that one can only speak of symmetry in a very broad sense.

In the major part of the Iberian Peninsula the structures run in a NW-SE direction, but near the northern coast a very distinctive arc is delineated; it is one of the few structures in the world where the vergences are centripetal. Its genesis remains one of the major tectonic problems in the Variscan Fold Belt.

Before describing the geotraverse through Portugal let us consider, briefly, the tectonic situation in the more north-easterly zones, in order to complete the general picture. (JULIVERT, this issue; SAVAGE, this issue; DEN TEX, this issue).

The Cantabrian Zone is mainly a foreland thrust-belt produced by décollement of the Palaeozoic cover platform facies from Cambrian to Lower Carboniferous. The deformation occurred in the Westphalian and Stephanian, with deposition of thick molasse facies deposits.

The western limit of this zone is a major thrust where the Precambrian basement is exposed. In the West-Asturian Leonese Zone the Lower Palaeozoic thickens: the structural

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style is different from that of the Cantabrian Zone: cleavage appears, being axial planar to the first folds, steep in the E, becoming recumbent, and giving rise to fold nappes to the W and in the domains where the curvature of the arc increases. This general trend in the arc implies that there is a differential crustal shortening across it. This first Variscan phase is of pre-Culm age, definitely older than in the Cantabrian Zone. The corresponding structures are deformed by a later tectonic phase with steep axial-plane crenulation cleavage. Our geotraverse starts in the major antiform where the Precambrian volcano-detrital 'Ollo de Sapo' Formation crops out in the southwest limit of this zone, just near the border between Portugal and Spain.

MIDDLE GALICIAN – TRÁS-OS-MONTES SUBZONE

The northeastern part of the Centro-Iberian zone can be considered as a special domain: the Middle Galician Trás-os-Montes subzone. One of the distinctive features of this subzone is the presence of five massifs consisting of high-grade metamorphic rocks, mainly mafic and ultramafic. These are the massifs of Cabo Ortegal, Santiago de Compostela, Lalin, Bragança and Morais. The eclogite, granulite and almandine-amphibolite facies originated in a very complex tectonic and metamorphic history – the reason why they have been considered polymetamorphic. The external contacts of the massifs are major thrust planes by which they rest on Silurian (and Early Devonian?) monometamorphic successions very rich in acid and mafic volcanics: the 'Transmontan' supergroup; this has a facies distinct from the successions of the same age on the remainder of the less deformed Centro-Iberian zone, from which they are separated by another major thrust plane. This thrust plane rotates through 180° in the Trás-os-Montes region, and can be considered as the limit of the Middle-Galicia–Tràs-os-Montes subzone.

The palaeogeographic and tectonic situation is quite similar to that of the 'Münchberger Gneiss Masse' and other massifs of the Saxothuringian zone; the Centro-Iberian facies is comparable to the Thuringian facies, and the 'Transmontan' to the Bavarian facies. This palaeogeographical differentiation is also imprinted both in the structural style (the folds are recumbent and isoclinal above the thrust plane and, mainly, with steep axial planes and more open below) and in the metamorphic grade (when we approach the massifs biotite and almandine isogrades are successively crossed; the thrust planes are underlined by jumps in the metamorphic grade).

As in the case of 'Münchberger Gneiss Masse', allochthonist and autochthonist hypotheses have been put forward by different authors at different times. At first sight, the allochthonist interpretation seems obvious, because the higher-grade rocks occupy the core of late synforms separated by antiforms. But a more detailed survey shows some intriguing facts: the first Variscan fold axes curve around the massifs, with opposed vergences; this suggests that the strain in the Palaeozoic tends to mould against the boundaries of the less ductile, high-grade rocks of the massifs.

The age of emplacement of the massifs can be established by the presence of detrital fragments of the high-grade rocks in a Late Devonian flysch in the Bragança region. Some important problems of this domain remain unsolved, such as the mechanism of emplacement and the age of the metamorphism of the high-grade complexes. In fact, in the Morais Massif monometamorphic augen gneisses and micaschists rest on the high-grade rocks, but the nature of the contact is disputed (thrust or unconformity?). On the other hand, one cannot exlude the possibility of overthrusting of the high-grade complexes from the west during the first Variscan phase of penetrative deformation in order to explain the observed geometric relationship of these complexes and the 'Transmontan' supergroup. In that case the root zone must lie in the contact between the Ossa-Morena and Centro-Iberian zones, which is a fundamental fault bringing polymetamorphic Precambrian in contact with much less deformed Palaeozoic sediments, with movement to the E, the minimum displacement of the nappe being 170 km (RIBEIRO, 1974).

CENTRO-IBERIAN ZONE

The main palaeogeographic difference between the Centro-Iberian Zone and the West-Asturian-Leonese Zone is the unconformity of the Arenig quartzite over the (late Precambrian? and) Cambrian flysch sequence. This implies the presence of a 'Sardic' deformation phase, which is of epeirogenic nature.

The structure is characterized by the presence of a steep axial zone with opposed vergences of first Variscan folds in both sides. This axial zone is in the continuation of the so-called 'Blastomylonitic Graben' of Western Galicia (DEN TEX, this issue) with polymetamorphic rocks of probably Precambrian age and peralkaline and calc-alkaline Late Ordovician and Silurian granites. This unit narrows to the south and the axial zone is obscured by posttectonic Variscan granites 280 Ma old. Towards the east and west of this axial zone the first Variscan folds are recumbent near the hinge of the arc; further southeast they become steep, exhibiting axial-plane slaty cleavage and schistosity.

These structures were refolded by a second Variscan folding phase with axial-plane crenulation cleavage grading into schistosity. In the core of the antiforms of this phase a succession of more or less deformed alkaline and calc-alkaline granites 320-300 Ma old was emplaced, synchronous with that F_2 folding phase. The rocks are affected by an intermediate, low-pressure regional metamorphism with a peak between the two Variscan folding phases.

Westphalian D and Stephanian B-C molasse deposits are preserved in the Douro-Beira trough which is a steep shear zone with a sinistral component of movement.

The contact between the Centro-Iberian and the Ossa-Morena zones is a major fault: a thrust to the Northeast with an imbricate structure in Central Portugal, passing to a steep N-S fault with upthrusting over the Autunian in W Portugal.

OSSA-MORENA ZONE

In the Ossa-Morena zone the sequence starts with a poly-metamorphic Precambrian, followed by an Upper Precambrian of Brioverian affinities overlain by a Cambrian basal conglomerate: the Lower Cambrian starts in a platform facies followed by a thick slate-quartzite sequence with interbedded spilites.

The Ordovician shales indicate a facies, deeper than the Armorican quartzite and the Silurian is rich in basic and acid volcanics. The Lower and Middle Devonian in platform facies are separated from the Late Devonian flysch by a major unconformity that corresponds with the first Variscan deformation phase. In fact, this flysch carries fragments of deformed and metamorphosed Palaeozoic rocks. We notice the presence of a Blastomylonite Belt, limited by steep faults, quite similar to the Galician one, also with peralkaline and calc-alkaline Late Ordovician granites and syenites separating domains with opposed vergences.

A second deformation phase shows an axial-plane crenulation cleavage. In the upper structural level, between the Juromenha overthrust and the Terena syncline, this F_2 structure dips steeply to the SW. A slaty cleavage occurs because the rocks were folded but not cleaved during the first deformation episode.

The metamorphism is restricted to two belts: one of Barrovian type (probably polymetamorphic) following the Blastomylonite Belt, and the other one of low-pressure type in the Evora-Beja-Aracena massif.

The synorogenic magmatism is quite different from the Centro-Iberian zone, quartz diorites and gabbros being largely dominant over granites.

The contact between the Ossa-Morena and South-Portuguese zones is a major reverse fault dipping steeply to the NE.

SOUTH PORTUGUESE ZONE

In the South Portuguese zone the oldest exposed beds are of Late Devonian age; acid and mafic vulcanism of Tournaisian and early Visean age is widespread in the NE part (the Pyrite Belt) followed by Culm deposits. Further to the SW the series is thinner, in platform facies from Famennian to Namurian, followed by a flysch of Westphalian A age. From the tectonic point of view, the Pyrite Belt shows an imbricate structure facing SW. The relationships between folding and thrusting are variable. One can recognize pre-cleavage thrust planes, as the Biguina thrust plane, which rest on a very continuous olistostrome on top of the turbidites of the local Culm sequence. This is probably a synsedimentary thrust. For the major part the imbricate structure is due to high-angle reverse faults postdating the main cleavage. That cleavage dips steeply to the NE and in some places is axial planar to the folds but in other places is slightly oblique to axial planes of folds, with a more northerly trend.

Further SW the cleavage becomes more gently dipping as we approach the major thrust planes (Odemira and Carrapateira). The last one dies out in the frontal part passing to an asymmetric fold facing SW. All these characteristics can be explained by a model invoking an almost continuous process from sedimentation to hard-rock deformation through slumping and soft-rock synsedimentary deformation. The oldest beds exposed on major anticlines are always of Late Devonian age; this may suggest the presence of a major décollement at the base of the imbricate complex, leaving an almost underformed basement below.

The metamorphism is of lower greenschist facies near the Ossa-Morena zone, passing to prehnite-pumpellyite facies in the Pyrite Belt, and to almost non-metamorphic or anchimetamorphic rocks further SW.

Comparing the palaeogeography and the tectonics of the Ossa-Morena and South-Portuguese Zones, polarity is evident, the flysch is younger towards the SW (Upper Devonian in the Ossa-Morena Zone, upper Visean in the Pyrite Belt, upper Namurian further SW) and the age of the main deformation decreases towards the SW (somewhere in the Middle Devonian in the Ossa-Morena zone, affecting the Westphalian A on the extreme SW corner of the South Portuguese zone). This migration of the orogeny to the SW is symmetrical to the migration to the NE that we have noticed in the NE branch of the fold belt.

CONCLUSIONS

The first problem that arises concerning the structural distribution is the explanation for the vergence pattern. Two fan-like axial zones separating areas with opposed vergences can be seen, disposed 'en échelon'. They are asymmetric, with one branch better developed than the other (the NE one in the NE side of the orogen, the SW one in the SW side). These axial zones were the site of emplacement of the peralkaline magmatism of Late Ordovician age, recorded by gaps in the sedimentary column of the Palaeozoic of these areas. This suggests that the crust was thinned in a continental rift setting affording a more intense and penetrative deformation during the Variscan orogeny, giving rise to the Blastomylonite Belts.

The other problem concerns the mechanical origin of the arc. Considering the relationship between stretching direction and fold axes in the NW part of Iberia we can see that on the inner side of the arc the stretching is in (a) and on the outer side is in (b). The two domains are separated by a flattening domain. This can be explained by bending the entire crust around a vertical axis by a process of tangential longitudinal strain: the homogeneous components of the deformation imply an extension on the outer side (stretching in b), a compression on the inner side (stretching in a) separated by a neutral surface with pure flattening. So the arc has been gradually bent during the Palaeozoic, probably with the highest strain rates during the Variscan orogeny. (RIBEIRO, 1974; RIES & SCHACKLETON, 1976). As the curvature of the arc increases, a component of simple shear is added in its limbs, with a sense of movement towards the hinge zone. This process (MATTE & RIBEIRO, 1975) can explain the sense of movement of the ductile shear zones associated with the main Variscan deformation in SW Portugal and Brittany. We must remember that in SW Portugal the cleavage is not axial-planar to the folds, and the more northerly direction of cleavage implies that a sinistral wrench-shear component must be added to the compression perpendicular to the structural core of the orogen.

The Ibero-Armorican arc must be explained by some kind of lateral movement, but a problem remains: was the arc formed (1) by continental collision, (2) in an active margin setting, or (3) by a conbination of both processes?

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