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HAVE NNE-SSW TRANSCURRENT SHEAR ZONES ALWAYS BEEN SINISTRAL IN THE VARISCAN BASEMENT ?

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Abstract

Traditionally, the NNE-SSW shear zones have been considered mainly sinistral transcurrent faults troughout their entire evolution, from late Variscan times to Alpine, in the Variscan basement. This is not in agreement with their PT evolution, nor with the expected orientation of the maximum compressive stresses (between ENE and NE) by the end of Variscan Orogeny. The PT record suggests evolution during crustal uplift, most probably the isostatic recover of the Variscan Chain. If this relaxation is not accompanied by break up of the Variscan Pangea, compression is induced by the rising roots of the mountain belt. The variation in the orientation of the stress field, together with post-collisional flattening and folding, would be responsible for the observed geometry and kinematics of the Variscan transcurrent shear zones that were not further reactivated with opposite kinematics: dextral NNE-SSW and NW-SE systems, and conjugate sinistral ENE-WSW to ESE-WNW families.

Resumo

Os acidentes tectónicos NNE-SSW que afectam o soco Varisco, têm sido globalmente considerados como falhas transcurrentes esquerdas no decurso de toda a sua evolução, desde os tempos tardi-variscos. Tal não se afigura, contudo, consistente com a sua evolução PT, nem com a orientação esperada para as trajectórias de compressão máxima (entre ENE e NE) estabelecidas durante as derradeiras etapas da Orogenia Varisca. O registo PT sugere um percurso evolutivo síncrono do levantamento crustal, muito provavelmente associado à recuperação isostática da Cadeia Varisca. Se este relaxe não for acompanhado pela partição da *Pangea* Varisca, criam-se condições para o desenvolvimento de esforços compressivos induzidos pela ascensão gradual do domínio de raízes da cordilheira montanhosa. A variação de orientação do campo de tensões regional, em conjunto com o achatamento e dobramento pós-colisional, deverá determinar a geometria e cinemática preservada em zonas de cisalhamento variscas não reactivadas posteriormente com cinemática oposta: sistemas direitos NNE-SSW e NW-SE, e famílias conjugadas esquerdas ENE-WSW a ESE-WNW.

Introduction

In NW Iberia, the variscan terranes are cut by a prominent, statistically self-affine, fracture network that comprise distinct families of accidents with a dominant transcurrent movement, whose geodynamic meaning can only be accurately evaluated when both geological mapping in appropriate scales are produced and a multidisciplinary approach is considered in their characterization. A complete evaluation of the geodynamic conditions that favoured the genesis and earlier propagation of this fracture network (usually designated as late-variscan network) must take into account all the late Variscan record in NW Iberia (fig. 1), *i.e.*: (1) post-collisional intrusion of granitoids (295 to 270 Ma; Dallmeyer *et al.*, 1998, and references therein); (2) NW-SE open folding, upwright or facing outwards symmetrically relative to the granitic core of the orogen; (3) late orogenic thrusts verging outwards symmetrically relative to the core of the orogen; and, finally, (4) the ductile (earlier) to brittle (later) subvertical shear zones that form the referred network and that can be grouped into distinct families striking close to NW-SE, NNE-SSW, ENE-WSW to E-W, and ESE-WNW.

Recent evaluation of the geometry and kinematics of the above mentioned shear zones in several domains of NE Portugal, allowed a comprehensive characterization of the late Variscan deformation events, which includes also the available data concerning the PT deformation conditions of the earlier post-collisional granitoid intrusives and the PT evolution of some major transcurrent shear zones (*e.g.* Mateus, 1995, 1996; Mateus *et al.*, 1995). Because Variscan Pangaea break up was at a high angle to the NW-SE striking of the mountain belt, and will take place sometime prior to c. 200 Ma (the age of evaporites that lie on top of Triassic red beds), it is clear that isostatic recover of the orogenic chain occurred in laterally confined space. This will induce a particular stress field that enables the uplift of the granitic core and, simultaneously, the development late folds and shear zones, as shown by the analogical modelling recently produced in laboratory (Marques & Mateus, *submitted*) This will favour also a more or less complex evolution of the latter structures: early ductile to semi-ductile shear zones (first stages of the isostatic recover), grading gradually into brittle, as the crust is exhumed and cooled by uplift. The major goal of the present extended abstract concerns therefore this general geodynamic scenario, focusing in particular the evolution of the most prominent and best studied system of shear zones, *i.e.*, the one of average NNE-SSW direction.

The NNE-SSW transcurrent shear zones

There is usually a clear conformity between the earlier emplaced post-collisional granite batholiths and the late variscan deformation events typified by: 1) periodically generated and emplaced batches of anatectic melts, recording distinct mineral fabrics (and sometimes distinguishing late-magmatic metasomatism); and 2) the development of transcurrent shear zones whose trace often controls the geometry of the igneous bodies that comprise the highly deformed granite facies (*e.g.* Reavy, 1989; Mateus, 1996). Regional, heterogeneous, near E-W ductile left-lateral shear zones are frequently located at the margin of the earlier emplaced batholiths, denoting the mechanical instabilities caused by the polyphasic granite emplacement. Further deformation appears to be concentrated within thermally (frequently narrow, < 3m thick) softened bands that regularly establish the contact with the strongly deformed metasedimentary rocks. Strain variations across these tectonic contacts consist often on: 1) cleavage development, whose intensity and dip increase with strain; 2) gradual change from regional to local, polyphasic, structures; 3) sporadic occurrence of asymetric folds which are sheared parallel to the cleavage plane; and 4) development of NNE-SSW (locally NE-SW), right-handed, semi-ductile shear zones which form narrow corridors of intense non-coaxial deformation, typically conjugate of the ubiquitous left-lateral E-W (on average) shear zones.

When NNE-SSW (NE-SW) shears are not object of late reactivation in brittle regime, the original C-S fabrics are preserved, and microscopic examination of oriented samples reveals the presence of several microstructures ascribable to cyclic, continuous-discontinuous yielding mechanisms at the grain scale acting in presence of late-magmatic fluids under the most probable average P-T conditions of 3-5 kbar and 450-500°C (Burg & Laurent, 1978; Berthé *et al.*, 1979; Iglesias & Choukroune, 1980; Mateus *et al.*, 1995). The subsequent evolution of these structures records the progressive transition from aseismic to seismic conditions of deformation, being thus consistent with the continental uplift that occurred immediately after the earlier post-collisional granite emplacement. According to the available data, the earlier seismic events (responsible for the generation of (proto-)mylonite rocks occurred in crustal levels of moderate depth ($\approx$ 8-10 km) under temperatures ranging from 300 to 350°C and global pressures lower than 3 kbar. Induced by crustal uplift, most probably isostatic recover, anomalously hot regions and consequent surface anomalies will develop, favouring significant fluid pumping into the NNE-SSW structures in the course of their late propagation towards outer domains of synorogenic granites and, therefore, enabling the polyphasic precipitation of hydrothermal siliceous aggregates. Strain concentration at fractures tips should thus promote the development of local stress fields that may lead to fracture interaction, assuring their coalescence before the emplacement period of latest granite bodies (270 Ma); during this general evolution, the geothermal gradient should decrease from an average value of 55°Ckm^{-1} to 40°Ckm^{-1} (Godinho, 1974; Mateus, 1995).

At this point, it should be emphasized that kinematical criteria of earlier dextral movement of NNE-SSW (to NE-SW) shear zones exist at all scales: notable cartographic examples can be found at NE Trás-os-Montes (*e.g.* shear zone labelled 1 in fig.1). Note also that the most common cataclasites and fault-gouges observed along these tectonic accidents are typically related to the fault segments reactivated in the course of the Alpine Orogeny, namely during the seismic events that took place in Plio-Quaternary times (*e.g.* Mateus & Barriga, 1995).

Late Variscan shear zones; kinematical analysis

Considering only the late Variscan record, a logical kinematic solution is possible for all the families of shear zones present in the Variscan basement of Northern Portugal: NE to NW systems would be dextral conjugates to the sinistral ENE to ESE families, denoting an orientation for σ_1 between ENE and NE (fig.2). The variety of angles among the conjugates may have a simple explanation that takes into account the early development of the vertical transcurrent shear zones was correlative of the latest Variscan folding: since rocks experienced flattening, the earliest structures should rotate, and the initial acute angle between the conjugates should grade into obtuse values. This is clear for the ESE-WNW (older, dutile to semi-ductile, and rotated sinistral conjugate) and ENE-WSW (younger and non-rotated sinistral conjugate) systems. Unfortunately, the relative chronological relationships between the NNE-

SSW and NW-SE families are not so obvious, regardless the common ductile corridors related to the latter shear zones. If the NW-SE system predates the development of the NNE-SSW shears, then they could all result from the same stress field (ENE to NE σ_1). Otherwise, a more elaborate solution is needed, *i.e.*, that some rotation of σ_1 orientation took place during the deformation regime change from transpressional (oblique E-W collision – Dias & Ribeiro, 1991) to pure shear (confined isostatic recover) by the end of the Variscan Orogeny. In this perspective, σ_1 should lie near ENE during the initial stages of late variscan evolution, rotating subsequently towards NE (fig.2). During this gradual rotation, the relative chronology inferred for the ESE-WNW and ENE-WSW systems remains valid and an elegant explanation for the development of thicker and longer quartz infillings along NNE and NE shears is achieved. Therefore, the reactivation of NNE-SSW structures as left-lateral strike-slip faults should have occurred mainly in Mesozoic (post-Cretaceous) times, under a regional stress field characterized by regional compressive trajectories near N-S.

Conclusions

The laterally confined isostatic recover of the Variscan chain enables the uplift of the granitic Variscan core and, simultaneously, the development of late folds and shear zones, favouring also a more or less complex evolution of the latter structures: early ductile to semi-ductile shear zones (first stages of the isostatic recover), grading gradually into brittle, as the crust is exhumed and cooled by uplift. The age, geometry and early kinematics of folds and of all the shear zones are compatible with a stress field with σ_1 striking between ENE and NE. A possible rotation of σ_1 from ENE, typical of the final stages of the Variscan oblique collision, towards near NE, in the latest stages of the isostatic recover, should be considered in order to explain some of the characteristic features exhibited by the most common shear zones that form the typical late variscan network and that were not subsequently reactivated: dextral NNE-SSW and NW-SE systems, and conjugate sinistral ENE-WSW to ESE-WNW families.

The fracture network in NW Iberia is clearly asymmetric and the prevailing system, displaying an average NNE-SSW direction, records a long and complex evolution, being polyphasically reactivated since the end of Hercynian Orogeny until present day (*e.g.* Ribeiro, 1984). According to the available results, the whole geometry and notable extension exhibited by these structures are mainly due to their late reactivation as left-lateral strike-slip faults in Alpine times, under a regional stress field characterized by regional compressive trajectories near N-S.

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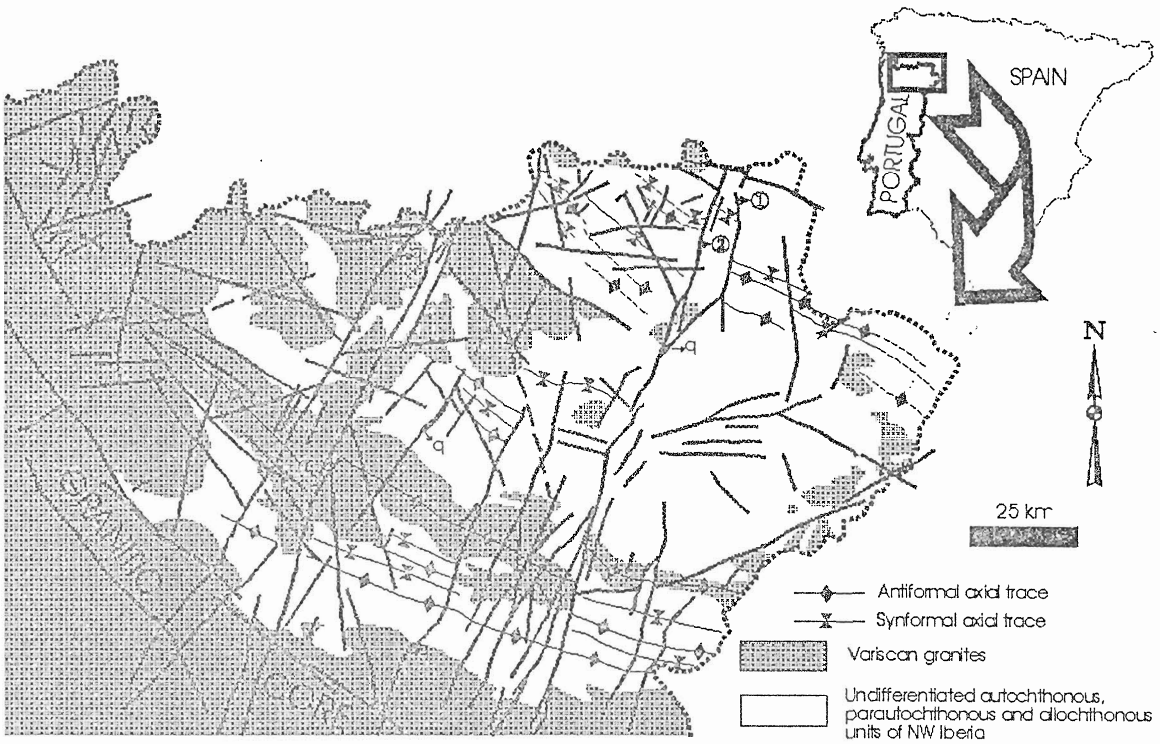

Fig. 1 - Sketch map with late Variscan folds, main faults and exhumed (uplifted) granitic core of the mountain belt in NE Portugal. Quartz infillings: q. Shear zones marked with 1 and 2 have the same geometry but opposite kinematics; shear zone 2 has taken up all the Alpine sinistral movement, while shear zone 1 preserves the late Variscan dextral kinematics.

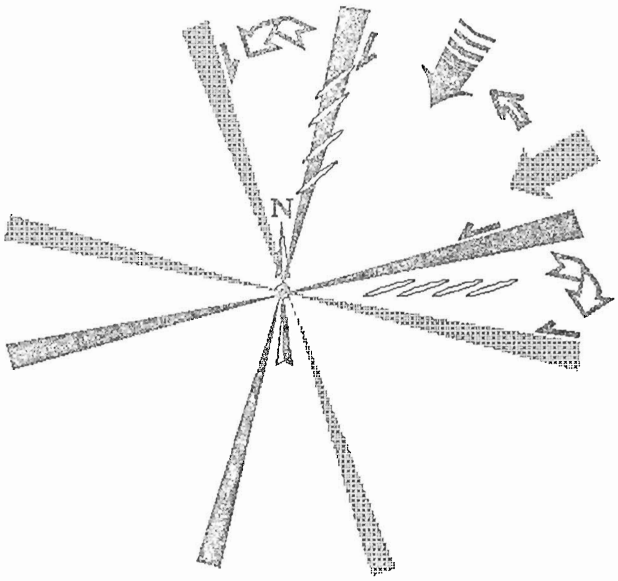

Fig. 2 - Schematic representation of the mean azimuth of shear zone families, and rotation of both shear zones and maximum compressive stress during Variscan late- to post-collisional stages.