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# Shear zones in the Iberian Arc

MOISES IGLESIAS PONCE DE LEON
Laboratorio de Geologia Estructural, Universidad de Salamanca, Spain
and
PIERRE CHOUKROUNE
Laboratoire de Géologie structurale et dynamique de la lithosphere, Université de Rennes, France

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## INTRODUCTION

THE HERCYNIAN arc of Galicia has been the subject of numerous studies which provide us with a good overview of the geometry of its constituent structures, tectonometamorphic and magmatic evolution (Parga-Pondal 1963, 1967, Matte 1968, Capdevila 1969, Ferragne 1972, Tex 1977, Ribeiro 1974, Julivert *et al.* 1977).

The aim of this contribution is to demonstrate that the syntectonic granitic rocks of the North Western Iberian Peninsula furnish evidence diagnostic of a particular strain regime, i.e. they are affected by vertical ductile shear zones which are, at least in part, contemporaneous with folding of the layered country rocks into which they are emplaced. After briefly describing the shear deformation in the granites, the relationship between folding and shearing, and the distribution and geometry of the shear zones, in the general context of this part of the Hercynian chain, are examined.

### *Structural setting*

The mapping scale structures of the Hercynian arc in Galicia result essentially from the superposition of two major fold phases, both associated with cleavage formation (Fig. 1). Recumbent folds of kilometric scale amplitude, overturned towards the interior of the arc, are attributable to the earlier phase. The second phase is represented by upright folds whose axial planes may deep steeply westward. Generally, these folds are associated with axial plane crenulation cleavage (Matte 1968, Ribeiro 1974). The emplacement of two types of syntectonic granitic rocks can be related to this deformation sequence: initially calcalkaline granitic rocks were emplaced prior to the second deformation phase. The later, alkaline leucogranites are generally considered to be syn- to post-phase 2 (Capdevila & Floor 1970), Tex 1977). We shall consider here the deformation affecting the leucogranites which is therefore associated with the second Hercynian fold phase.

## THE DEFORMATION OF LEUCOGRANITES IN GALICIA

### *Description*

The principal observations made at the mapping scale are:

(a) there is a clear correspondence between regions where the leucogranites are deformed and the maximum intensity of the phase 2 deformation;
(b) generally speaking, the deformed granites are located at the borders of the plutons and form bands whose width varies from 3 km down to several metres;
(c) within these bands the leucogranite carried a vertical foliation (S planes) which turns progressively into parallelism with the granite margin, as one passes toward the country rocks. Therefore, the foliation trajectory patterns, within a given band, correspond to half of the ductile shear zone model described by Ramsay & Graham (1970);
(d) the deformed granite is also affected by a second set

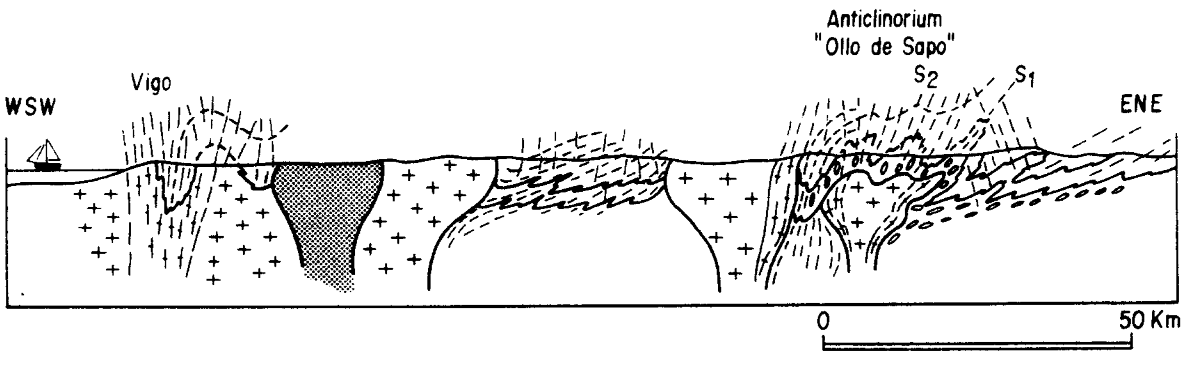


Fig. 1. Generalized cross section of the Hercynian chain in Galicia. Note the correspondence between the zones of deformed granite and those of vertical $S_1$–$S_2$.

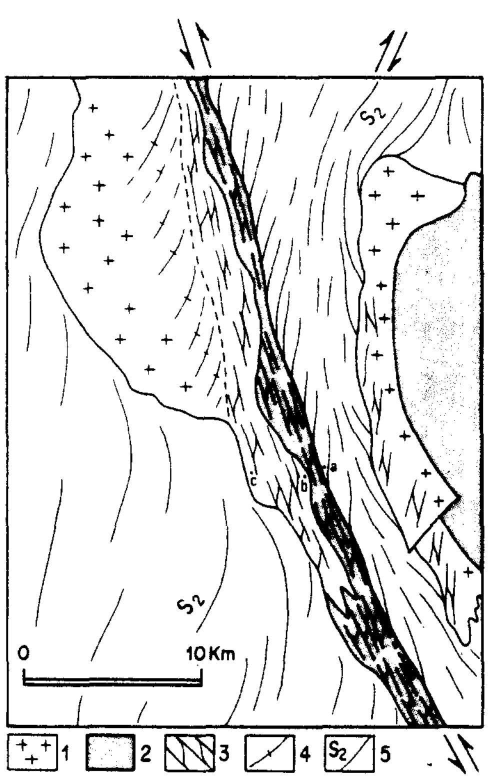


Fig. 2. Sketch map of a sinistral shear zone near Gutiriz. a, b, c: location of plates in Fig. 3. 1 = undeformed alkaline granite. 2 = calcalkaline granite. 3 = deformed granite with *S/C* planes. 4 = trace of $S_2$ in granite. 5 = $S_2$ trajectories in metasediments.

of vertical planes (C planes) whose orientation is nearly constant at the scale of a given band (Fig. 2).

At the mesoscopic scale, the angle between the two sets of planes (*C* and *S* planes) diminishes progressively toward the margin of the granite; concomittantly the size of the constituent grains diminishes and the frequency of the *C* planes increases. At a given stage of this evolution, a third set of vertical planes (*C'* planes) appears, making an angle of 30° to the *C* planes (Fig. 3). Stretching lineations seen on *S* and *C* planes are always close to the horizontal. Ultramylonites are found locally in certain bands where *C* and *S* planes are parallel. This type of deformation is comparable to that recently described from leucogranites associated with the South Armorican shear zone (Berthé *et al.* 1979).

At the microscopic scale, the constituent grains of the granite are reoriented into the *S* planes, the micas are recrystallized and the feldspars cataclastically deformed. Pressure shadows lying in the *S* planes, and the *S* planes themselves are sigmoid between any two adjacent *C* planes.

### *Interpretation*

These deformation bands constitute shear zones in which strain increases toward the pluton margin. The sense of displacement is given by the general foliation trajectory patterns. The movement along *C* planes within the band is always compatible with the general sense of the shear zone. Locally, minor conjugate shear zones are present, spatially associated with the major one. The progressive strain across an example of a sinistral major shear zone is illustrated (Figs. 2 and 3).

## SHEAR DEFORMATION AND FOLDING

The nature of the relationship between shearing deformation affecting the granites and the phase 2 folding affecting the metasedimentary envelope rocks can be illustrated by three field situations.

(a) Where the contact between the deformed granite and the metasediment is vertical, sleepily plunging asymmetric microfolds are present, which deform the $S_1$ schistosity and whose axes are curved within their axial planes (Figs. 2 and 3 c). The mechanism of formation and development of such folds in a shearing regime is now well known (Quinquis *et al.* 1978, Bell 1978, Quinquis & Cobbold 1980, Berthé & Brun 1980). Away from the contact zone, the axes of phase 2 folds within the envelope rocks are horizontal.

(b) Where the deformed granite margin is horizontal, the axes of phase 2 folds are subhorizontal. In the example presented in Fig. 4, the shear deformation in the granite is relatively advanced; the fold axial planes in the sediments, making a small angle with the *C* planes in the granite. At the outcrop scale, the $S_2$ axial crenulation is continuous with the *S* planes in the granite. These three observations suggest that this situation represents a relatively advanced stage of the model of interaction between shearing and folding presented in Fig. 5.

(c) Locally in the contact zones, veins of leucogranite are intruded and deformed with the folded metasediments. Within the veins, *C* and *S* planes can be distinguished. This case, illustrated in Fig. 6, is well exposed in the Punta Langustera region, where a dextral shear zone occurs. The phase 2 fold axes are horizontal and parallel to the stretching lineation in the deformed granite. The $S_2$ axial planes are the *S* surfaces in the granite veins. The direct correspondence of these linear and planar structures in folded metasediments and sheared granite demonstrates very clearly the common origin by shearing of all these structures.

## REGIONAL PATTERN OF HERCYNIAN SHEAR ZONES IN GALICIA

Systematic mapping of deformation bands in the Hercynian leucogranites of Galicia and determination of the sense of shearing within these bands shows the existence of three main shear zones; from east to west these are (Fig. 7):

(i) the "Vivero – Puebla de Sanabria" shear zone which is dextral and more or less corresponds to the Ollo de Sapo anticline. Within the metasediments in the vicinity of this zone, the principal axes of the finite strain ellipsoid show a marked change of orientation related to the presence of the shear zone; outside the zone, the stretching lineation and boudinage are generally

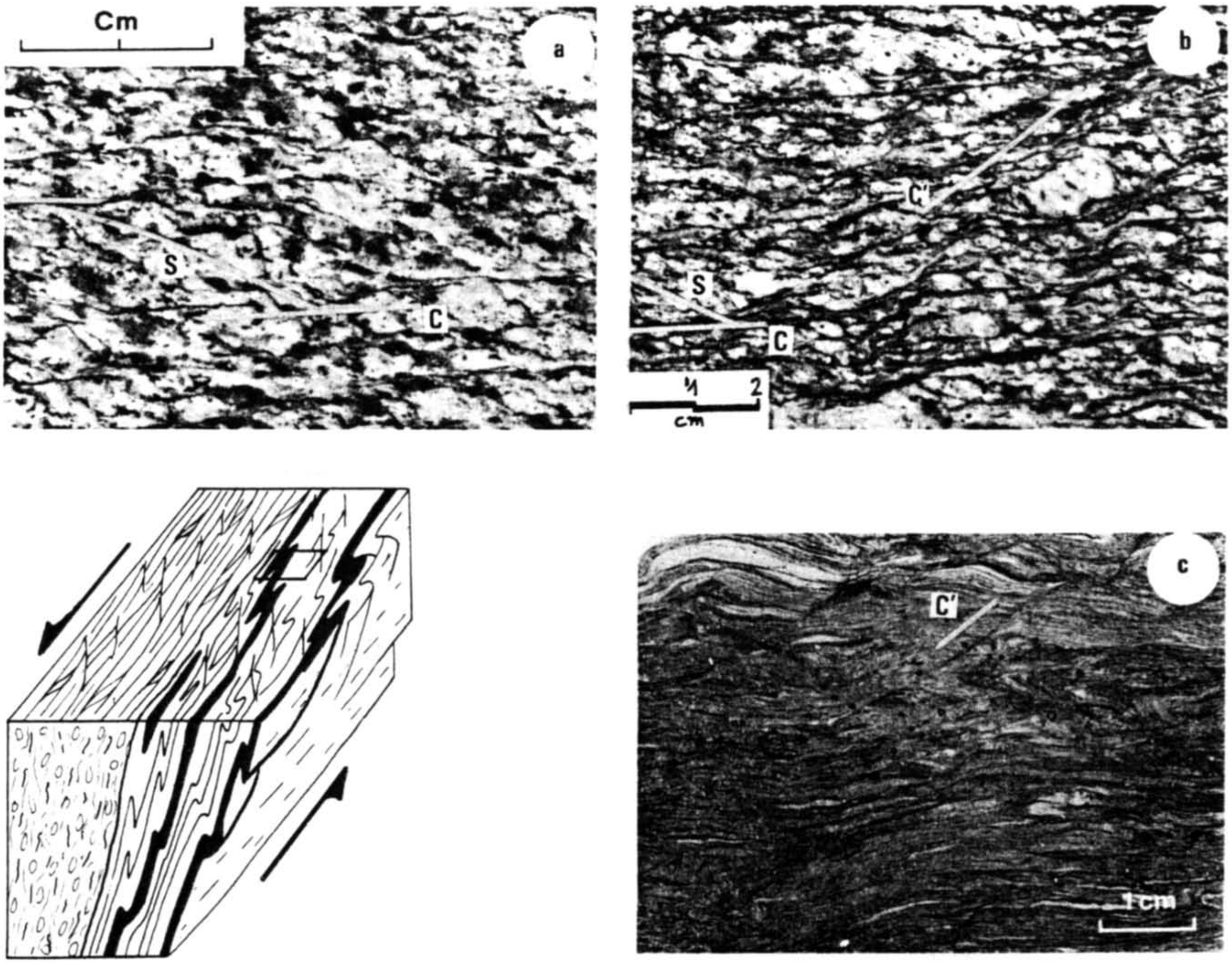


Fig. 3. Block diagram to illustrate the details of deformation in granite and sedimentary rocks in a sinistral shear zone near Gutiriz. (a) Two planes (*S* and *C*) making an angle of ~ 30° at an early stage of the shearing deformation. (b) A more advanced deformation stage with the appearance of *C′* planes. (c) Asymmetric folds (with curved axes) cut by *C′* planes in the sedimentary material. All photographs in the horizontal plane.

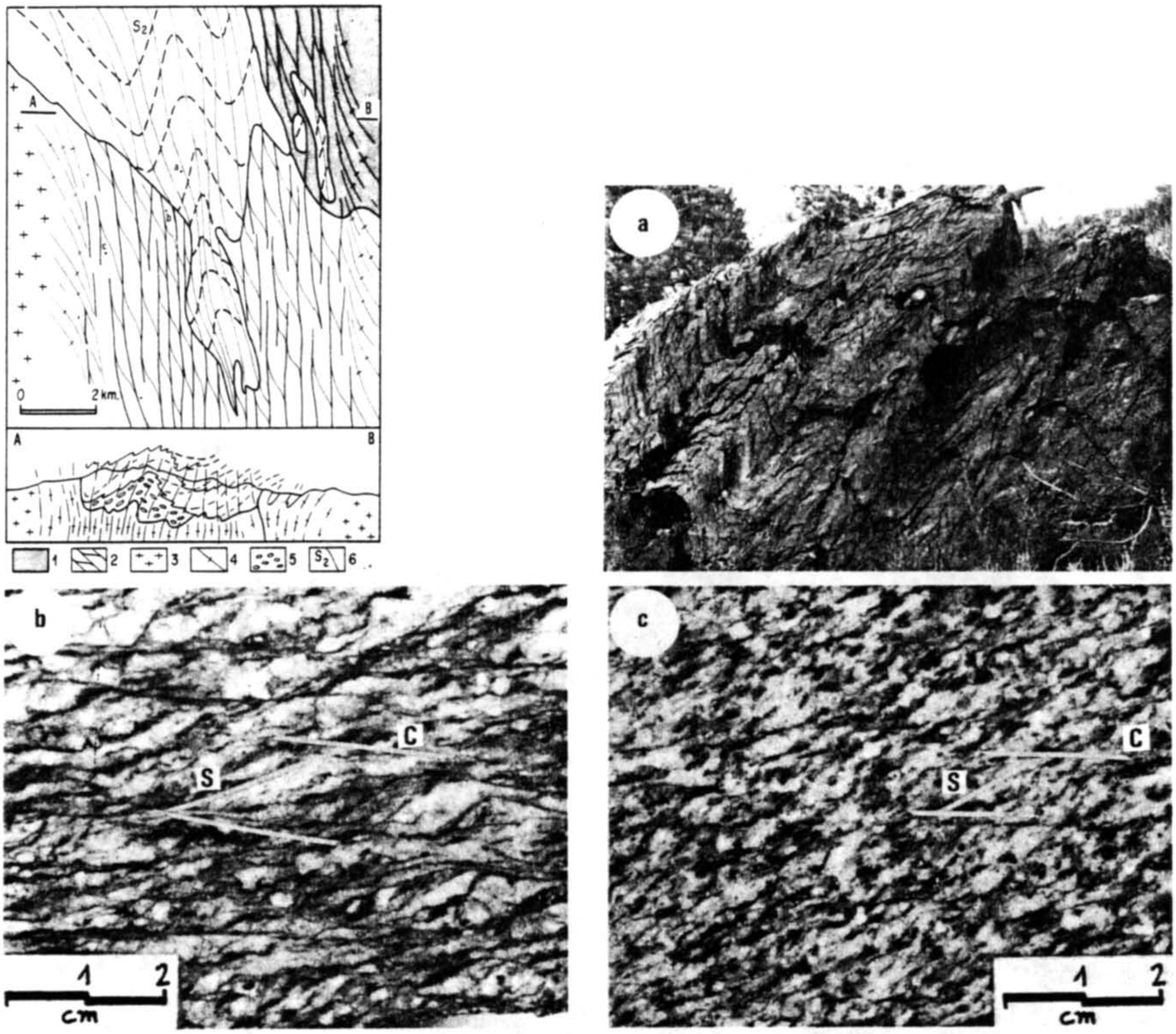


Fig. 4. Sketch map located in Fig. 7 and cross section of folded metasediments within a dextral shear zone affecting leucogranite near San Esteban. a, b, c: plate localities: 1 = calcalkaline granite. 2 = deformed granite (with *S/C* planes). 3 = undeformed alkaline granite. 4 = trace of $S_2$ plane in deformed granite. 5 = Ollo de Sapo formation. 6 = $S_2$ trajectories. (a) Phase 2 folds in metasediments. (b and c) Two stages of dextral shear deformation in granite. All photographs in the horizontal plane.

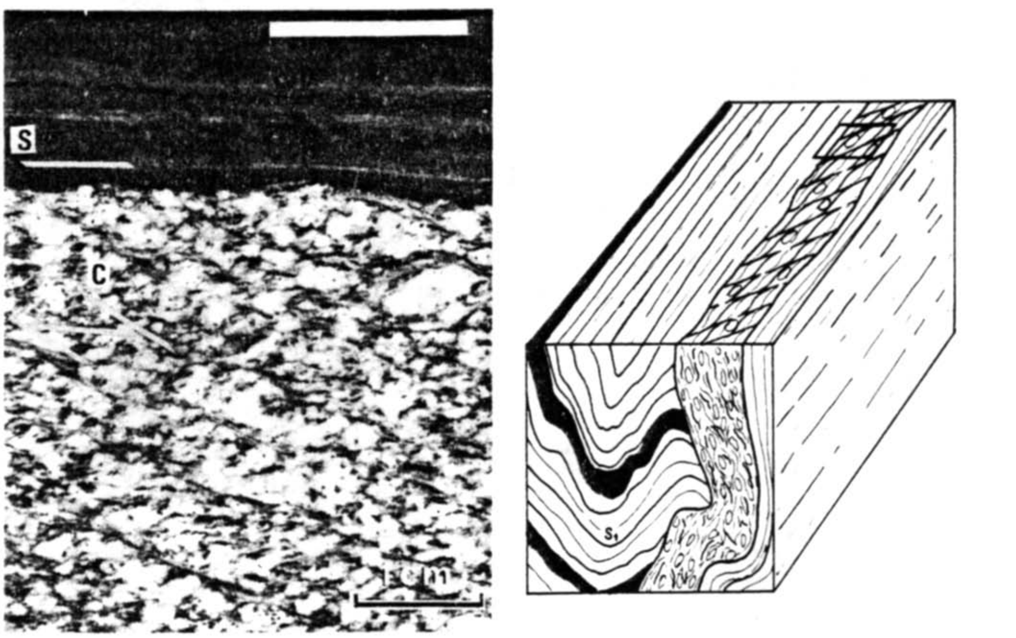


Fig. 6. Block diagram of folding in sediments cut by a granite vein. The vein is affected by shear deformation. The photograph (located by square) shows the metasediment granite contact. Note that *S* planes are parallel on either side of the contact and that *C* planes are only present in the granite (photograph in the horizontal plane) (scale bar = 2 cm).

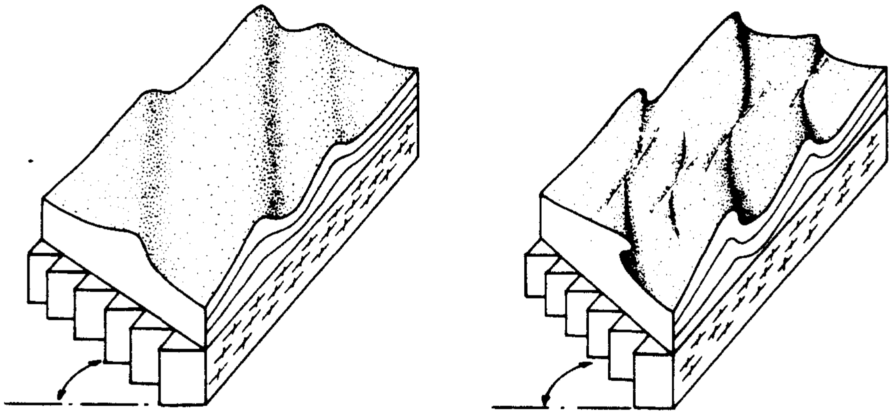

Fig. 5. Schematic illustration of the proposed mechanism to account for the relationship between folding in the metasediments and shearing deformation in the granite (see also Graham 1978).

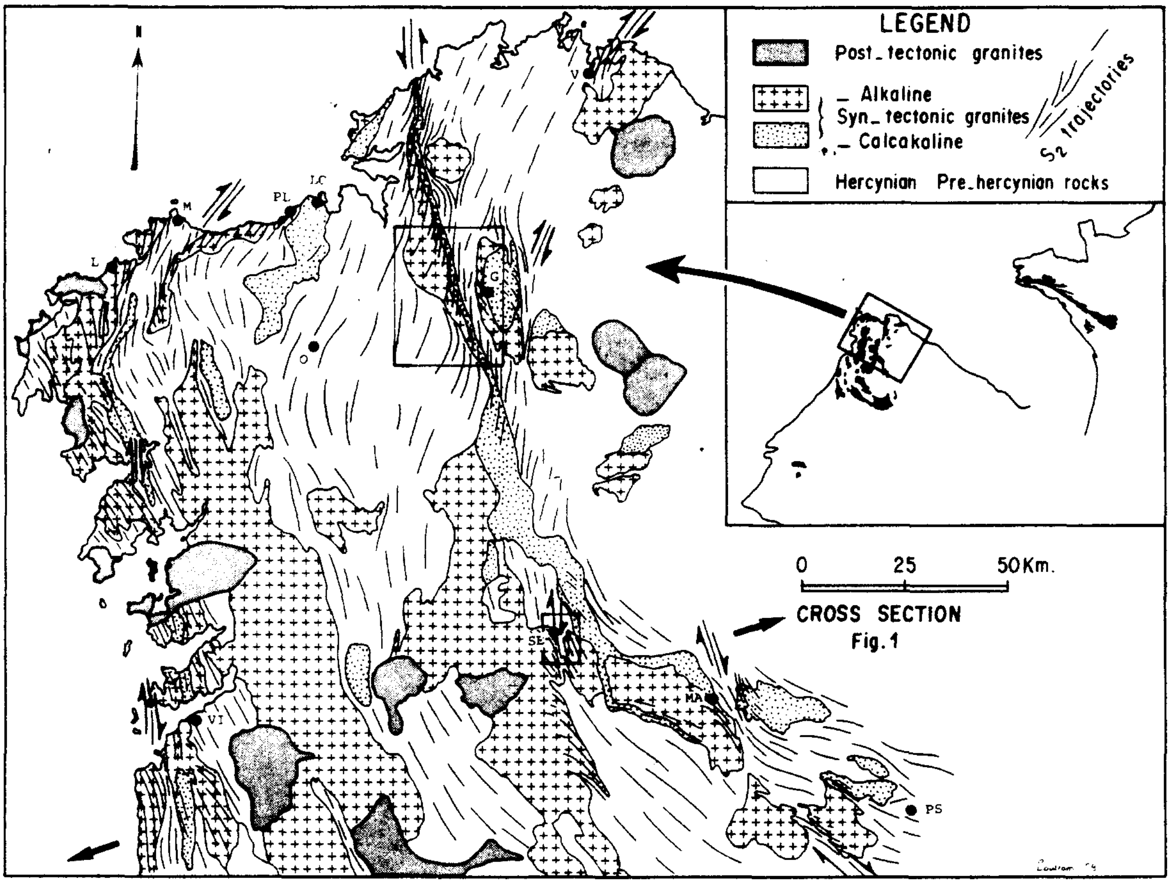


Fig. 7. Structural map of Galicia showing $S_2$ trajectories, and the three main shear zones discussed in the text. The squares represent the location of Figs. 2 (large square) and 4. (L : Lage, M : Malpica, PL : Punta Langustera, LC : La Coruna, G : Guitiz Vi : Vigo, SE : San Esteban, MA : Manzaneda, PS : Puebla de Sanabria, O : Ordenez).

perpendicular to the overall regional grain. Within the zone, these structures become abruptly concordant to the general trend of the arc. The orientation of the dextral shear zone varies from N 30° in the north to N 160° in the south.

(ii) The "Punta Galeira – Palas de Rey" shear zone is sinistral and generally oriented N 170° (Figs. 3 and 7).

(iii) The "Malpica – Vigo" shear zone is dextral; its orientation varies from N 30° in the north to N 170° in the south.

Each of these shear zones corresponds to a deformation band within which a given sense of shear is dominant. Locally, minor conjugate shear zones are associated with the major ones. Small scale bends of metric to kilometric scale which complicate the simple model of progressive curvature of structures within the Iberian Arc are attributable to this association of major and minor shear zones. The geometry of certain deformed leucogranite bodies may be influenced by a similar mechanism, e.g. the granite of Manzaneda

(Fig. 7). It is emphasized that the shear zones here described are curved within the arc, but with a greater radius of curvature than that of the arc itself.

## CONCLUSIONS

In Galicia, the Hercynian folding is, at least in part, related to the presence and operation of major transcurrent ductile shear zones which affect the syntectonic leucogranites in this part of the Hercynian chain.

As for the Hercynian in Armorica (Gapais *et al.* 1980) (Hanmer pers. comm.), three factors play a major role in the deformation: crustal shortening, the ascent of granitic rocks through the crust and the operation of major transcurrent ductile shear zones. It seems clear that the finite strain at all points in the arc represents the result of the sum of these three phenomena and that the symmetry and the orientation of the principal axes of the finite strain ellipsoid related to this deformation are locally controlled by the predominance of one of these factors over the others. This must be taken into account in any strain model (Matte & Ribeiro 1975, Ries & Shackleton 1976) which attempts to explain the Ibero-Armorican Arc.

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## REFERENCES

Bell, T. H. 1978. Progressive deformation and reorientation of fold axes in a ductile mylonite zone: the Woodroff thrust. *Tectonophysics* **44**, 285–320.

Berthé, D. & Brun, J. P. 1980. Evolution of folds during progressive shear in the South Armorican shear zone. *J. Struct. Geol.* **2**, 127–133.

Berthé, D., Choukroune, P. & Jegouzo, P. 1979. Orthogneiss, mylonite and non-coaxial deformation of granites: the example of the South Amorican shear zone. *J. Struct. Geol.* **1**, 31–42.

Capdevila, R. 1969. Le métamorphisme régional progressif et les granites dans le segment hercynien de Galice Nord-Orientale (NW de l'Espagne). Thèse University of Montpellier.

Capdevila, R. & Floor, P. 1970. Les différents types de granites hercyniens et leur distribution dans le Nord-Ouest de l'Espagne. *Bol. Geol. Min.* **81**, 215–225.

Ferragne, 1972. Le Précambrien et la Paléozoique de la Province d'Orense (Nord-Ouest de l'Espagne). Thèse University of Bordeaux.

Gapais, D., Le Corre, C. & Pivette, B. 1980. The role of regional transcurrent shear component in orogenic belts with particular reference to the Hercynian belt of Brittany. To be published.

Graham, R. H. 1978. Wrench faults, arcuate fold patterns and deformation in the Southern French Alps. *Proc. Geol. Ass.* **89**, 125–142.

Julivert, M., Marlos, A. & Perez-Estaun, A. 1977. La structure de la chaîne hercynienne dans le secteur ibérique et l'Arc ibéroarmoricain. La chaîne varisque d'Europe moyenne et occidentale. *Coll. Intern. CNRS, Rennes* **243**, 429–440.

Matte, Ph. 1968. La structure de la virgation hercynienne de Galice (Espagne). *Trav. Lab. Géol. Univ. Grenoble* **44**, 1–128.

Matte, Ph. & Ribeiro, A. 1975. Forme et orientation de l'ellipsoide de déformation dans la virgation hercynienne de Galice. Relations avec le plissement et hypothèses sur la genèse de l'Arc ibéro-armoricain. *C. r.hebd. Séanc Acad. Sci., Paris* **280 D**, 2825–2828.

Parga-Pondal, I. 1963. Mapa petrologico estructural de Galicia. E. 1/400 000. I.G.M.E., Inst. Geol. Min. de Espana.

Parga-Pondal, I. 1967. Carte géologique du Nord-Ouest de la Péninsule ibérique. E. 1/500 000. Direçao Geral. Min. Serv. Geol. Lisboa.

Quinquis, H., Audren, C., Brun, J. P. & Cobbold P. R. 1978. Intense progressive shear in Ile de Groix blueschists and compatibility with subduction or obduction. *Nature, Lond.* **273**, 43–45.

Ramsey, J. G. & Graham, R. H. 1970. Strain variation in shear belts. *Can. J. Earth Sci.* **7**, 786–813.

Ribeiro, A. 1974. Contribution à l'étude tectonique de Trés-os-Montes Oriental. *Mems. Servs. Geol. Portugal* **24**.

Ries, A. & Shackleton, R. 1976. Patterns of strain variation in arcuate fold belts. *Phil. Trans. R. Soc.* **A283**, 281–288.

Tex, den E. 1977. Le socle poly-cyclique et son rôle dans l'évolution de la chaîne varisque en Galice (Espagne du N W). La chaîne varisque d'Europe moyenne et occidentale. *Coll. Intern. CNRS, Rennes* **243**, 441–451.