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Pseudo-two-girdles c-axis fabric patterns in a quartz-feldspar mylonite (Costabona granodiorite, Canigó massif)

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SUMMARY

An example of the relationship that exist between the preferred crystallografic orientation of quartz grains and the attitude of the mylonite foliation of quartz-feldspar mylonites is described. These rocks are the result of the inhomogeneous deformation under low-grade metamorphic conditions of a late Hercynian granodiorite, intruded into the gneisses of the slopes of the Canigó massif (Eastern Pyrenees). The Costabona mylonites have a quartz c-axis fabric in pseudo-two-girdles symmetrical with respect to the mylonite foliation and perpendicular to the shear-band systems which produce an extensional crenulation of the mylonite foliation.

RESUMEN

Se decribe un ejemplo de las relaciones existentes entre la orientación cristalográfica presente del cuarzo y la disposición de la esquistosidad milonítica en unas milonitas cuarzofeldespáticas. Estas rocas son el resultado de una deformación heterogenea, en condiciones de bajo grado metamórfico, de una granodiorita tardiherciana intruida en los gneises de la vertiente sur del macizo del Canigó (Pirineo Oriental). Las milonitas del Costabona presentan una fábrica del cuarzo en dos guirnaldas (pseudo-two-girdles) dispuestas simétricamente respecto a la esquistosidad milonítica, y perpendicularmente a dos sistemas de shear-bands que originan una crenulación extensiva de la esquistosidad milonítica.

INTRODUCTION

The numerous papers dealing with mylonites associated with zones where the deformation is mainly brought about by inhomogeneous simple shear, show that in these rocks (whether built up by one or more different minerals) a marked preferred crystallografic orientation of quartz grains is common.However up til now, there has been a lack of agreement as to what factors control this preferred orientation. Certain authors consider that the kinematic elements of the shear zone (shear strike and sense, shear plane orientation) control the disposition of the c axes (Lister and Price, 1978; Burg and Laurent, 1978; Brunel, 1980; Simson, 1980). For example Burg and Laurent (1978) have established fixed geometrical relationship in a granodiorite mylonite between the shear plane orientation and the disposition of the c axes when the latter are obliquely distibuted (on a single girdle oblique to the mylonite foliation and a right angle to the shear plane). On the other hand other authors (Hara et al., 1973; Carreras et al., 1977; Carreras and García-Celma, in press) observe that at the margins of shear zones the fabric pattern rotates congruently with the mylonite foliation, and thus has a variable orientation with respect to the shear plane

Various interpretations have also been suggested to explain the distribution of the c axes on two girdles symmetrical with respect to the foliation (pseudo-two girdles) According to Etchecopar (1974). Laurent and Etchecopar (1976) Brunel and Geyssant (1978), Burg and Laurent (1978) these distributions would be the result of two distinct intracrystalline slip systems. The predominant one would form the girdle perpendicular to the direction of the shear and thus being oblique to the foliation. The second system less important would only affect those grains favourably orientated beforehand, and only significant in low strained stages, producing a "reverse" slip with respect to the general sense of shear, and creates a second less-developed girdle oblique to the foliation. Other authors (Hara et al., 1973; Shelley 1971; Bouchez and Pecher 1976) consider that these symmetric fabric reflect an irrotational strain with a marked direction of extension.

In the Cap de Creus quartz mylonites, Carreras and García Celma (in press) have reached other different conclusions. Theses authors assert that both the symmetrical fabrics on the edges of the shear zones and the asymmetrical fabrics within the shear zones are controlled by one or two sytems od shear-band planes. García Celma (in press) observe the same thing occurring within the shear zones, where the asymetry of the fabric depends on the disappearance of one of the two extensional crenulation systems present.

We present in this paper new information dealing with the disposition of the c axes on pseudo-two girdles in quartz-feldspar mylonites and relate it to the presence of two shear-band systems which create an extensional crenulation of the mylonite foliation in these rocks.

GEOLOGICAL SETTING OF THE COSTABONA MYLONITES

The crystalline materials (gneisses, medium and high-grade metasedimets and granitoids) outcropping extensively along the axial zone of the eastern Pyrenees are cut across by mylonites belts related to the last phases of folding of the Hercynian orogeny (Carreras, Julivert and Santanach, 1980). Individual bands in these belts trend from NW-SE to E-W and their thickness varies from that of a few centimetres to several hundreds meters.

The mylonite foliation dips steeply and is the result of a group of mineralogical and structural transformations of the original rocks under low-grade metamorphic conditions (greenschist facies).

The Canigó massif is a gneiss/schist dome shaped anti form intruded locally by granitoid bodies (mainly granodiorites). In this massif the mylonite bands have a very irregual distribution and are mainly located on the northern slopes of the massif, forming a E-W trending belt (Fig. 1B). These bands are related essentially to shear zones with a reverse dip-slip movement, and within them the associated mylonite foliation dips strongly towards the north, and forms a large angle to the regional foliation of the gneisses and micaschists. On the southern slope of the massif, the gneisses are intruded by a large body of biotite granodiorite (10 x 9 km) (The Costabona granodiorite), emplaced after the main tectonic and metamorphic Hercynian events (development of regional schistosity and metamorphic climax). (Autran, Fonteilles and Guitard, 1970). This granodiorite has a rather homogeneous facies and a very sharp contact with the country rock and clearly cuts the regional deformational structures in the gneisses. The Costabona granodiorite is locally cut by aplite dykes, and some associated small leucocratic bodies are located close to the contact with the country rock.

Within the granodiorite and close to the eastern contact with the gneisses (Fig. 1C) there are a group of mylonite bands associated with reverse shear zones, of variable thickness (between one and about ten meters wide) where it is possible to observe the transition from a poorly deformed or underformed rock to its mylonite equivalent (quartz-feldspar protomylonites, mylonites and ultramylonites). Within these bands the granodiorite has a penetrative mylonite foliation with an approximately E-W strike and 45-50° dip towards the north (Fig. 2). The associated mylonite lineation which is especially well recognizable in the quartz-rich ultramylonites, has quite a regular orientation dipping 40-50° towards the N-NE (Fig. 2).

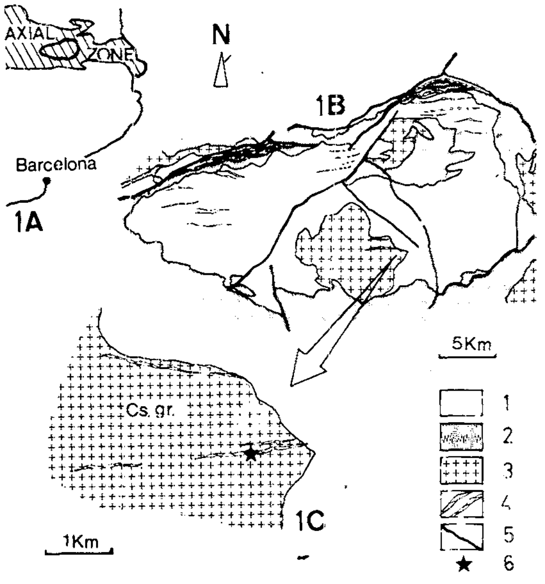


Fig. 1 - 1.A) Location of the Canigó Massif within the Axial Pyrenean Zone. 1.B) Geological Map of the Canigó Massif (after Guitard, 1970, slightly modified). 1C) Location of the Costabona mylonites. - Key: 1) gneisses, 2) metasediments, 3) intrusive granitoids, 4) mylonite bands, 5) faults, 6) location of the studied samples. Cs. Gr. = Costabona granodiorite.

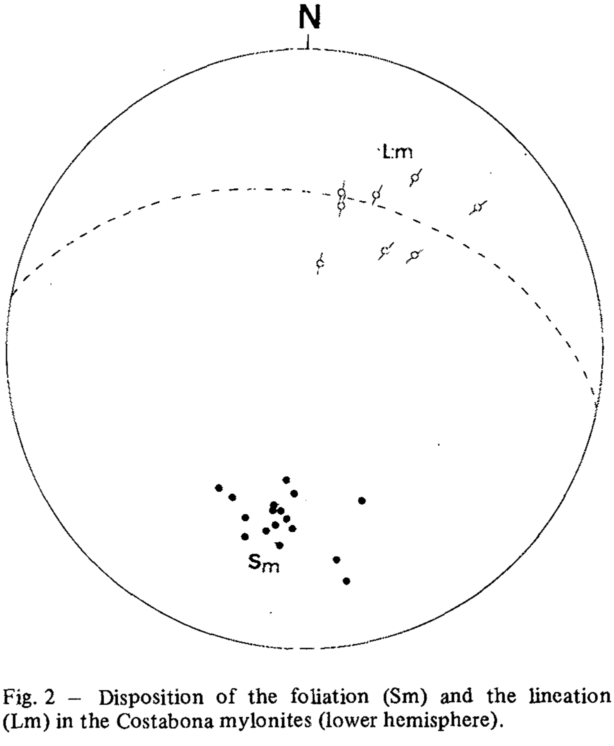


Fig. 2 – Disposition of the foliation (Sm) and the lineation (Lm) in the Costabona mylonites (lower hemisphere).

MICROSTRUCTURES AND PREFERRED ORIENTATIONS IN THE MYLONITES

The formation of the granodiorite mylonite is accompanied by a drastic process of grain refinement, by the formation of a fine groundmass basically composed of K-feldspar and plagioclase fragments and small crystals of relict or neoformed phyllosilicates, and a group of mineralogical changes (neoformation of chlorite and muscovite from biotite and feldspars, neoformation of epidote-clinozoisi, increase in the proportion of phyllosilicates with respect to the feldspars, etc.). As well as this the rocks exhibit a noticeable enrichment in their quartz contents (Casas, 1982) in the ultramylonite stages. This group of transformations, given under low-grade metamorphic conditions (biotite instability, chlorite/epidote-clincoisite association) are associated to the development of a penetrative mylonite foliation. Two apparently conjugated shear-band systems symetrically arranged with respect to the folitation (Fig. 3C) are also reconizable. These systems of "extensional crenulations" (Platt and Vissers, 1980) coupled with the presence of more resistant bodies (feldspar prophyroclasts) make the foliation take on sigmoidal shapes as observed microcopically. These shear-band planes, along which the grain refinement process are especially well developed, are arranged at 30-40° to the folitation and have been identified in samples with different microstructures.

The mylonite foliation is basically defined by elongated bands of angular feldspar prophyroclasts and/or large quartz crystals markedly elongated and with a strong undulose extinction, which in some cases can alternate with layers richer in phyllosillicates, and by elongates ribbons of small quartz cristals (Fig. 3A).

The quartz

During the formation of the mylonite, the quartz suffered a drastic grain refinement, related to a very restricted recristallization, and a fragile behaviour of the cristals coexisting with mechanisms of intracrystalline deformation. The old grains which are strongly lengthened paralel to the mylonite foliation have a marked undulose extinction and clearly sutured grain boundaries. They have a tendency to make on elongated shaped adapting themselves to the more resistant bodies. In low strained samples the quartz crystal grains have well developed fracture planes systems and tension gashes, that coexist with signs of intracrystalline deformation (undulose extinction). The processes of recrystallization are very localised and the poligonization is restricted. The new grains are small sized (several microns) and form small ribbons parallel to the old elongated grains. They are found either on the edges of the old grains or inside them, along the planes of discontinuity. The quartz has a mar-

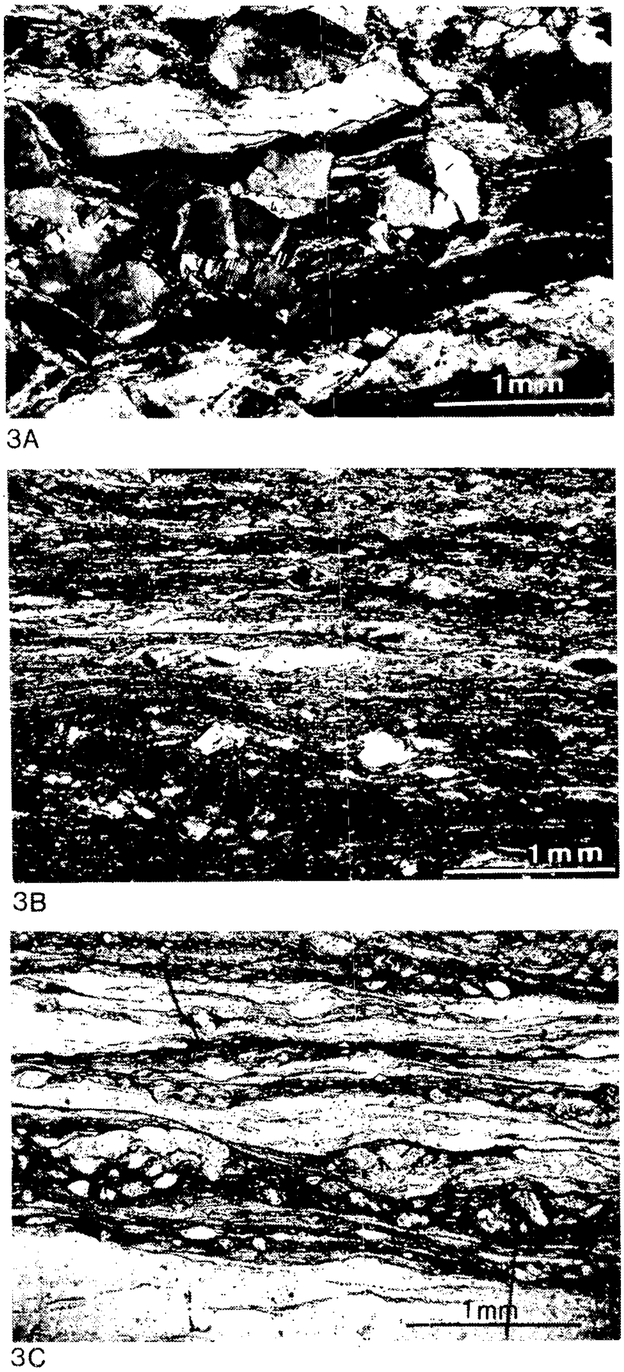


Fig. 3 – 3A) Protomylonite. The foliation is defined by bands of fractured feldspar porphyroclasts, surrounded by strongly elongated quartz grains with a marked undulose extinction. NX. 3.B) Quartz enriched ultramylonite. The foliation is defined by the lengthwise alignement of the lenseshaped quartz crystals surrounded by ribbons of smaller grain size and a dark fine-grined groundmass with occasional prominent feldspar porphyroclast. NX. 3.C) Sigmoidal foliation in an ultramylonite. Two shear bands systems oblique to the foliation can be seen. PPL.

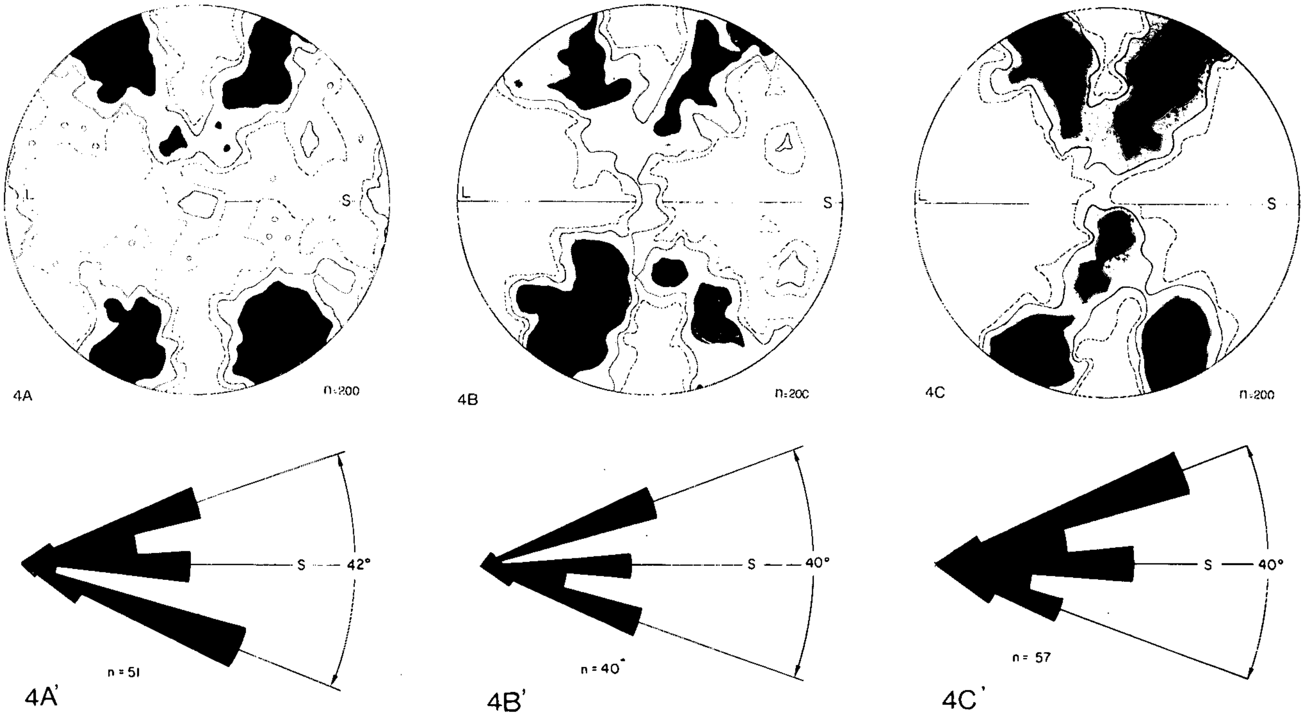
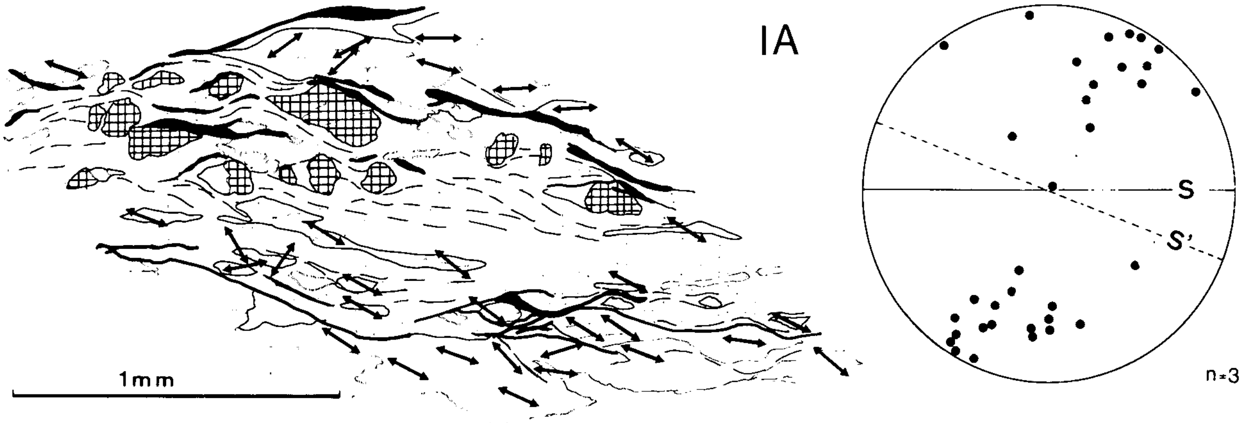
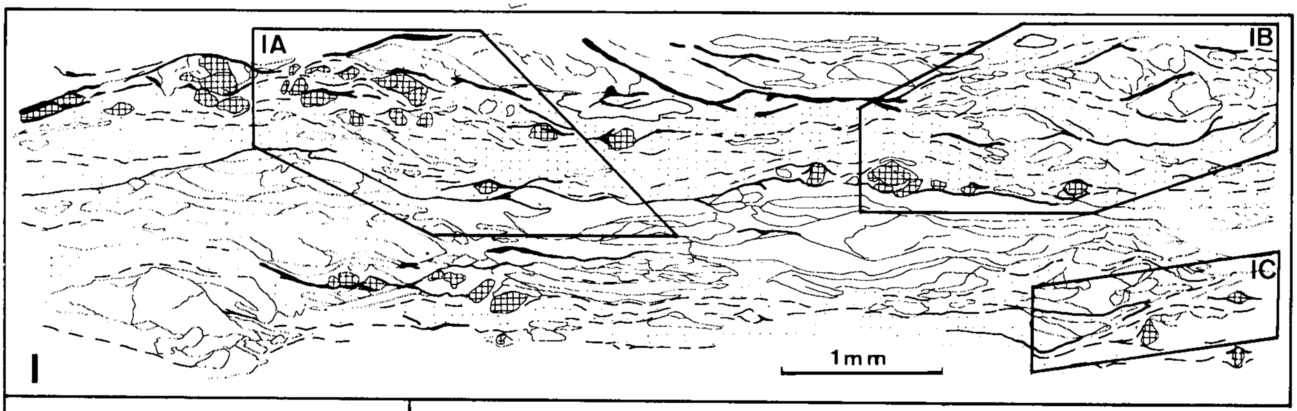


Fig. 4 - Diagram of the quartz c axes orientations (4A, 4B and 4C) and of the disposition of the trace of the shear-band planes (4A', 4B' and 4C') in the Costabona mylonites. 4A and 4A' quartz-feldspar mylonite (same sample), 4B and 4B' quartz-feldspar mylonite/ultramylonite (same sample), 4C and 4C' quartz enriched ultramylonit (same sample). *S* is the average plane of the mylonite foliation and *n* indicates the number of measurements made. Outlines 4A and 4B: 0,5 (dashed), 1, 2 and 4%, 4C: 0,5 (dashed), 1, 2, 4, and 8%. (Lower hemisphere).

ked preferred crystallografic orientation. Figure 4 shows three diagrams (4A, B and C) made with tha aid of universal stage, showing the orientation of the c axis in the old grains from thre quartz-feldspar mylonite samples. The measurements shown on the diagrams have been made on sections perpendicular to the foliation and parallel to the lineation (XZ Plane). The three samples have been collected from the inner zone of single mylonite band (Fig. 1C) and belong to three rocks with diferent microstructures: 4A quartz-feldspar mylonite, 4B quartz-feldspar mylonite-ultramylonite, 4C quartz-feldspar ultramylonite with a quartz enrichment. The c axes in these diagrams sweep out girdles symmetrically arranged with respect to the prevailing mylonite foliation (S in the diagrams). The angle between these two gridles varies between 45 and 60° and the angle between them and the normal to the average of the foliation planes is about half this value (22 and 30°). These three samples reflect different amounts of deformation and the girdles are best defined in the most evolved stages (ultramylonites). The maxima inside any one girdle has a more symmetrical distribution and at the same time the weak maxima defined by the c axes parallel to the lineation disappear (Fig 4A). In all of the samples studied the two planes of penetrative crenulation already described, are recognizables. Comparing the diagrams of figure 4 (4A with, 4A' 4B with 4B', 4C with 4C') it can be seing that the girdles in the three samples are arranged nearly perpendiculary to the average trace of each of these two plane system. So as to verify this relationship we have made an A.V.A. of a reduced area in the ultramylonite represented in figure 3C and 4C. Figure 5.1 shows a diagram of the microscopic chosen area of study in which is possible to see the sigmoidal arrangement of the foliation at this scale of observation. In figure 5.2 the orientation of 300 axes measured in this sector are represented. A two-girdle arrangement similar to that ontained by marking measurements all over the thin section (Fig. 4C) is recognizable. Three sectors have been considered in which the mylonite foliation has slighly different orientation caused by the

Fig. 5 – C axes fabric in a quartz-feldspar mylonite with two shear-band systems. 1) Microscopic view of the sector studied, in which the foliation and the shear-bands are penetrative (crosshatching: feldspar, dots: groundmass, hatching: phyllosilicates, white: quartz). 2) C axes orientation in the whole of the sector. Outlines; 0,5 (dashed), 1, 2 and 4%. (lower hemisphere). 1.A), 1.B) and 1.C) Positions of the trace of the basal plane (arrows) and the c axes (points in the diagrams) of quartz crystals in three sectors where the foliation and the shear-bands (S' and S") are not penetrative and present different orientations (see text for explanation) *S* is the average plane of the mylonite foliation and *n* indicates the number of measurements.


IA
S
S'
n=34
1mm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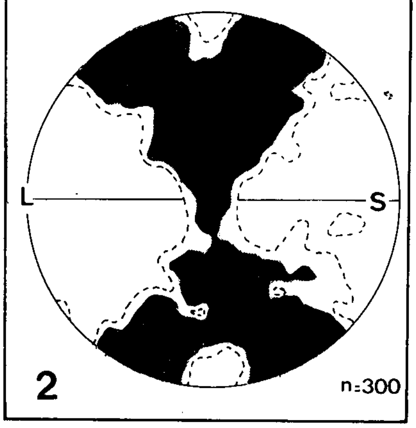
L
S
2
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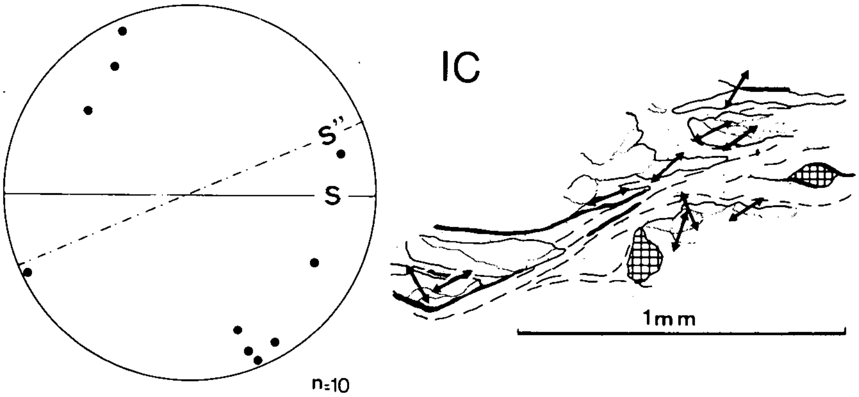
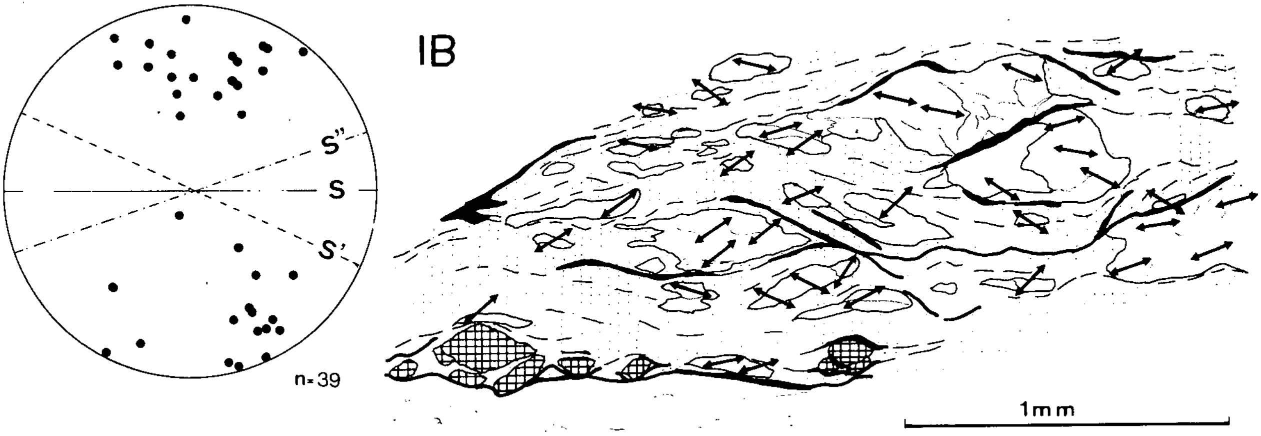

S"
S
n=10
IC
1mm


IB
S"
S
S'
n=39
1mm

predominance of either one or both systems of extensional crenulation (S' and S") so as to discover whether this disposition is maintained on an even smaller domains. In these sectors the basal planes (arrows) of the measured grains have been also traced. The orientation of the c axes, represented in the diagrams that accompany figures 5.1.A, 5.1.B. and 5.1.C. is clearly different. In the sectors 1A and 1C the axes tend to draw out only one girdle symmetrical with respect to S and inclined in opposite senses. Differently, the axes of figure 1.B tend to reproduce the disposition obtained from the study of the overall A.V.A and of all the thin section (compare figures 4.C, 5.2 and 5.1.B.).

This differences in the patterns are interpreted as the results of the existence of a single shear-band system in the first case (1.A and 1.C) and of two systems in the second (1.B).

CONCLUSIONS

In the quartz-feldspar mylonites of the Costabona, the planes of discontinuity identifiable mesoscopically (mylonite foliations) have a sigmoidal microscopic disposition as a result of the interference of the mylonite foliation with two systems of shear-bands. These planes are symmetrically and obliquelly arranged with respect to the foliation, at an angle of about 30 and 45º. These extensional crenulation systems are often associated with narrow zones of ductil deformation on rocks with a marked planar anistropy. Such shear-bands have been described both in relatively underformed margins of shear zones affecting previously anitsotropic rocks (Carreras and García-Celma, in press), and in zones of high strain (inner part of shear zones, thrust planes, etc.) In this case (White, 1979; Platt and Vissers, 1980) the formation of these planes would reflect a situation of strain softening in advances stages of deformation, and would produce one or two shear-bands systems depending on the orientation of the shortening direction of the finite strain ellipsoid with respect to the pre-existing planes of anistropy.

At the domain of analysis where the foliation and the shear-bands become penetrative, the c axes define two crossed girdles, equally developed and symmetrically arranged with respect to the foliation. At the scale of analysis where the foliation and the shear-bands are not penetrative, we obtain simple girdles, oblique to the foliation when only one system of shear bands is present and symmetrical fabrics formed by two girdles if two sets or shear bands are present. It both cases the girdles are perpendicular to the average shear band system or systems planes. The type of pattern thus depends on the scale of observation that is chosen, given that the later controls how penetrative the recognised deformation structures are.

The dip of the maxima with respect to the average plane of foliation (between 55 and 80º) suggests that in these mylonites the preferred orientation is basically formed by a process of basal slip. The observed metamorphic transformations and the microstructures of the quartz imply low-grade metamorphic conditions (lower part of greenschist facies) in which this mechanism of intracrystalline slip seem to be the most effective (Tullis et al., 1973; Wilson, 1975).

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REFERENCES

AUTRAN, A.; FONTEILLES, M. & GUITARD, G., 1970: "Rélations entre les instrucions de granitoïdes, l'anatexie et le méthamorphisme régional considerées principalment du point de vue du rôle de l'eau: cas de la chaîne hercynienne des Pyrénées Orientales". *Bull. Soc. Géol. Fr.*, s. 7, XII: 673-731.

BOUCHEZ, J.L. & PECHER. A., 1976: "Plasticité du quartz et sens de cisallement dans les quartzites du Grand Chevauchement Central himalayen". *Bull. Soc. Geól, Fr.*, s 7, XVIII: 1377-1385.

BRUNEL, M. 1980: "Quartz fabrics in shear zones mylonites: evidence of a major imprint due to late strain increments". *Tectonophysics*, 64: T 33-T 44.

BRUNEL, M. & GEYSSANT, J., 1978: "Mise en évidence d'une déformation rotationelle Est-Ouest par l'orientation optique du quartz dans la fenêtre des Tauern (Alpes orientales). Implications géodynamiques". *Rev. Geogr. Phys. et Geol. Dyn.*, s. 2, XX: 335-346.

BURG, J.P. & LAURENT, P., 1978: "Strain analysis in a shear zone in a granodiotine". *Tectonophysics*, 47: 15-42.

CARRERAS, J. & GARCIA-CELMA, A., in press: "Quartz c axis fabric variation at the margins of a shear zone developed in schists from Cap de Creus (Spain)". *Acta Geol. Hisp.*

CARRERAS, J., ESTRADA, A., & WHITE, S., 1977: "The effects of folding on the c axis fabrics of quartz mylonite". *Tectonophysics*, 39: 3-25.

CARRERAS, J., JULIVERT, M. & SANTANACH, P., 1980: "Hercynian mylonite belts in the eastern Pyrenees: and example of shear zones associated with late folding". *J. Struct. Geol.*, 2, (1/2): 5-9.

CASAS, J M., 1982: *Les roques milonítiques del massís del Canigó-Carançà.* Unpublish. rep., Univ. Barcelona, 76 p.

ETCHECOPAR, A., 1974: *Simulation par ordinateur de la déformation progressive d'un agrégat polycristalin.* Thèse 3 e cycle, Univ. de Nantes, 135 p.

GARCIA-CELMA, A, in press: "Domainal and fabrics hetereogeneities in Cap de Creus quartz mylonites. *J. Struct. Geol.*

GEYSSANT, J., GUITARD, G. & LAUMONIER, B., 1980: "Analyse structurale des gneiss oeillés blastomylonitiques du versant nord du Canigou (P.O.)". *C.R. Acad. Ss.*, 209, s. D, 1103-1106.

GUITARD, G., 1970: "Le métamorphisme hercynien mésozonal et les gneiss oeillés du massif du Canigou (Pyrénées Orientales). *Mém. Bur. Rech. Géol. Min.*, 63, 353 p.

HARA, I., TAKEDA, K. & KIMURA, T., 1973: "Preferred lattice orientation of quartz in shear deformation". *J. Sci. Hiroshima Univ.*, s. C, 7: 1-10.

LAURENT, P & ETCHECOPAR, A., 1976: "Mise en évidence à l'aide de la fabrique du quartz d'un cisaillement simple à déversement Ouest dans le massif de Dora Maira (Alpes Occidentales)". *Bull. Soc. Géol. Fr.*, s. 7, XVIII: 1387-1393.

LISTER, G.S. & RICE, G.D., 1978: "Fabric development in a quartz feldspar mylonite". *Tectonophysics*, 49: 37-78.

PLATT, J.P. & VISSERS, R.L.M., 1980: "Extensional structures in anisotropic rocks". *J. Struct. Geol.*, 2 (4): 397-410.

SIMSON, C., 1980: "Oblique girdle orientation patterns of quatz c-axes from a shear zone in the basement core of the Maggia Nappe Tizino, Switzerland". *J. Struct. Geol.*, 2 (1/2): 243-247.

SHELLEY. D., 1971: "The origin of cross-girdle fabrics of quartz". *Tectonophysics*, 11: 61-68.

TULLIS, J., CHRISTIE, J.M. & GRIGGS, D.T., 1973: "Microstructures and preferred orientations of experimental deformed quartzite". *Bull. Geol. Soc. Am.*, 84: 297-314.

WHITE S., 1979: "Large strain deformation: report on a Tectonic Studies Group discussion meeting held at Imperial College, London on 14 Novembre 1979". *J. Struct. Geol.*, 1 (4): 333-339.

WILSON, C.J.L., 1975: "Preferred orientation in quartz ribbon mylonites". *Geol. Soc. Am. Bull.*, 86: 968-974.

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