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

by J. M. CASAS

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 crystallographic orientation of quartz grains is common. However up till 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 distributed (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 oriented beforehand, and only significant in low strained stages, producing a "reverse" slip with respect to the general sense of shear, and creating a second less-developed girdle oblique to the foliation. Other authors (Hara et al., 1973; Shelley, 1971; Bouchez and Pecher 1976) consider that these symmetrical 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. These 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 systems of shear-band planes. García Celma (in press) observe the same thing occurring within the shear zones, where the asymmetry of the fabric de-
The crystalline materials (gneisses, medium and high-grade metasediments and granitoids) outcropping extensively along the axial zone of the eastern Pyrenees are cut across by mylonite 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 centimeters 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 irregular 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, Fontielles 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).
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-clinozoisite, 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-clinozoisite association) are associated to the development of a penetrative mylonite foliation. Two apparently conjugated shear-band systems symmetrically arranged with respect to the foliation (Fig. 3C) are also recognizable. 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 microscopically. These shear-band planes, along which the grain refinement process are especially well developed, are arranged at 30-40° to the foliation 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 phyllosilicates, and by elongates ribbons of small quartz crystals (Fig. 3A).

The quartz

During the formation of the mylonite, the quartz suffered a drastic grain refinement, related to a very restricted recrystallization, and a fragile behaviour of the crystals coexisting with mechanisms of intracrystalline deformation. The old grains which are strongly lengthened parallel 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 localized and the polygonization 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. 3B) Quartz enriched ultramylonite. The foliation is defined by the lengthwise alignment of the lens-shaped quartz crystals surrounded by ribbons of smaller grain size and a dark fine-grained 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.
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 ultramylonite (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).

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 ultramylonite (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).

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.
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 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 obliquely arranged with respect to the foliation, at an angle of about 30 and 45°. These extensional crenulation systems are often associated with narrow zones of ductile deformation on rocks with a marked planar anisotropy. Such shear-bands have been described both in relatively underformed margins of shear zones affecting previously anisotropic 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 anisotropy.

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 80°) 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).

ACKNOWLEDGEMENTS

I thank Jordi Carreras, Amparo García and Pere Santanach for their helpfullness and fot their critical review of the text, also I thank Juan Lorenzo for the translation.

This work was supported by the program AUJT A LA INVESTIGACIÓ 1980 - Universitat de Barcelona.

REFERENCES


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.


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.


LAURENT, P & ETCHECOPAR, A., 1976: “Mise en ´evidence a
l’aide de la fabrique du quartz d’un cisaillage simple a de-
versement Ouest dans le massif de Dora Maira (Alpes Occi-
quartz feldspar mylonite”. Tectonophysics, 49: 37-78.
SIMSON, C., 1980: “Oblique girdle orientation patterns of quartz
c-axes from a shear zone in the basement core of the Maggia
Nappe, 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: “Micro-
structures and preferred orientations of experimental defor-
WHITE S., 1979: “Large strain deformation: report on a Tecto-
nic Studies Group discussion meeting held at Imperial Colle-
333-339.
WILSON, C.J.L., 1975: “Preferred orientation in quartz ribbon

Received, March 1982