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Quartz of C-Axis fabric variation at the margins of a shear zone developed in shists from cap de Creus (Spain)

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SUMMARY

By means of geometrical analysis it is established that the studied shear zone, although approaching closely the simple shear model, does not satisfy it completely. Slight departures must be taken into account, i.e. there is an heterogeneity of strain along the shear zone on decimetric to milimetric domains, this caused by the non isotropic character of the original rock. Furthermore, a slight flattening component, besides the dominant simple shearing has to be taken into account when considering the bulk type of strain acting on the outer margins of the shear zone.

In the outer margin of the studied shear zone two incipient sets of extensional crenulations, nearly symmetric about the regional schistosity, appear. In such low strain domains, a weak c-axis preferred orientation is already present consisting in a pseudo-two-girdle pattern. Still at the marginal domains, but approaching the inner part of the shear zone, the regional schistosity progressively rotates into a mylonitic foliation. At the same time one set of the crenulations tends to vanish, while the other becomes better developed but conserves about the same angular relationship with the foliation. This fact coincides with the rotation and strengthening of the preferred orientation c-axis fabric pattern and its progressively more asymmetric character with regard to the foliation. The final fabric is a nearly single girdle which tends to remain perpendicular to the persisting set of extensional crenulations or shear bands if present. The obliquity of the girdle with respect to the mylonitic foliation is by no means related to the amount of strain.

RESUMEN

El análisis geométrico de la zona de la cizalla estudiada permite evidenciar que la deformación global se aproxima sensiblemente al modelo de cizalla simple si bien debe tenerse presente la existencia de un componente menor de aplastamiento no rotacional especialmente significativo en los márgenes externos de la zona de cizalla. Además debe tenerse en consideración la presencia de heterogeneidades en la deformación, en los dominios decimétricos o inferiores, a lo largo de la zona de cizalla y originadas por el carácter no isotrópico de la roca original.

En los márgenes externos de la zona de cizalla existen dos sistemas incipientes de crenulaciones extensivas dispuestas aproximadamente simétricas con respecto a la esquistosidad regional. En estos dominios externos en donde la deformación es débil se aprecia ya la existencia de orientaciones preferentes de los ejes c del cuarzo adoptando disposiciones del tipo: "pseudo-two-girdle". Todavía en las zonas marginales, pero en dirección al interior de la zona de cizalla, la esquistosidad regional gira progresivamente transformándose en una foliación milonítica. Al mismo tiempo un sistema de crenulaciones tiende a desaparecer, mientras que el segundo se acentúa, conservando aproximadamente la misma relación angular con la foliación. Este hecho coincide con la rotación y el refuerzo de la orientación preferente de los ejes "c" del cuarzo y con su asimetrización con respecto a la foliación. La fábrica final se asemeja a una guirnalda sencilla la cual tiende a permanecer en posición ortogonal al sistema de crenulaciones o de bandas de cizalla persistentes, cuando éstas existen. La oblicuidad de la guirnalda con respecto a la foliación milonítica en ningún caso puede ser correlacionada con el valor de la deformación.

INTRODUCTION

In recent years many studies have been carried out on quartz c-axis fabric variations across banded defomation structures assumed to develop under heterogeneous simple shear. Assuming a simple shear defomation model enables the relationship between the c-axis fabric, the kinematic framework and the strain ellipsoid to be made for each located specimen, provided that the overall structural elements in the shear zone are well exposed. Theoretical models on fabric development for quartz and simple shear defomation have also been elaborated (Etchecopar, 1974, 1977; Lister et al., 1978, 1980). However, up to now there is no general agreement on natural and theoretically predicated fabric pattern variation for simple shear deformations.

One of the present points of apparent disagreement concerns whether the c-axis preferred orientation patterns rotate congruently with the foliation plane (Carreras et al., 1977) or the finite strain ellipsoid (Hara et al., 1973) across a shear zone, or mantain a constant angular relationship with the flow or shear plane, i.e. the kinematic axes (Lister et al. 1978, Burg and Laurent, 1978, Roermund et al., 1979, Simpson, 1980).

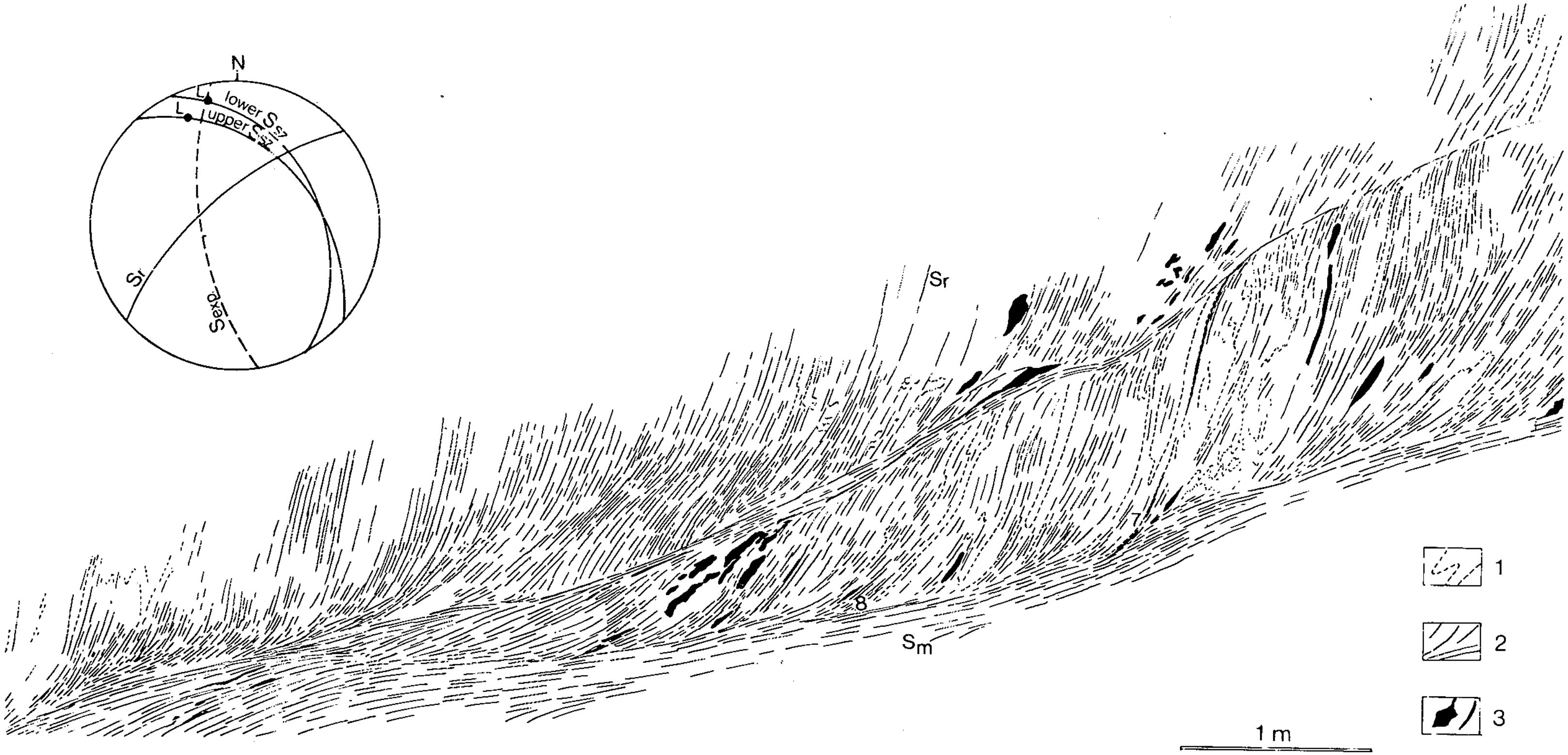

Fig. 1 – *The Cala Prona shear zone*. (Cap de Creus mylonite belt). Legend: 1, traces of litological boundaries; 2, traces of foliations; 3, segregation quartz. The lower hemisphere stereoplot shows the mean orientation of the regional schistosity (Sr), the lower and upper shear zone planes (Ssz) and the associated stretching lineations (L). S_{exp} indicates the mean orientation of the cliff exposure. Numbers 7 and 8 refer to the location of the fabric seuqences shown in figures 7 and 8 respectively.

A second point not satisfactorily solved concerns the very common asymmetry of the c-axis patterns with regard to mylonite foliation planes reported by Strand (1945) Eisbacher (1970) and Carreras et al. (1977), which has been subsequently used to elucidate sense of shearing in shear, thrust or nappe structures (Bouchez and Pécher, 1976; Bouillier and Quernadel, 1979; Brunel, 1980; Lagarde, 1978; Simpson and Schmid in press) and correlated with the amount of shear strain (Burg and Laurent, 1978).

The aim of this paper is to provide new data on c-axis fabric variations under increasing strain in naturally deformed anisotropic rocks. A detailed geometrical and c-axis fabric analysis is presented for a selected shear zone boundary in the Cap de Creus area, which was previously described by Carreras et al. (1977) and recently discussed by Lister and Williams (1979) from a theoretical point of view.

As the Cap de Creus shear zones develop across foliated rocks, the effect of the preexisting anisotropy will be taken into account in order to first, characterize the strain and second, consider the relation between the anisotropy induced minor structures and the observed c-axis fabric pattern variations.

Geological setting of the studied example

The shear zone studied (fig. 1) belongs to the late Hercynian mylonite belt cutting through the medium grade schists outcropping on the northern part of the Cap de Creus peninsula, in the eastern end of the Pyrenees (Carreras, 1975; Carreras et al., 1980).

The schists have a marked schistosity (Sr), commonly parallel to the transposed layering, and exhibit at least two phases of tight folding prior to mylonitization. A new mylonitic foliation develops in the shear zone under greenschist facies conditions, which obliterates the earlier deformation structures. A generally gently plunging, marked stretching lineation is visible in quartz rich mylonites derived from quartz segregation veins and lenses. Quartz-mylonites have granoblastic microstructure consisting of rather equant grains of about 50 to 150 μm diameter formed under dynamic recrystallitzation (Carreras, 1974, White, 1976).

I GEOMETRY

Banded deformation structures cutting obliquely across preexisting planar or linear elements in rocks produce an offset of these earlier structural elements. In ductile deformation bands this offset is usually achieved through a progressive change in orientation of the preexisting planes or lines which tend, with increasing strain, towards parallelism with the trend of the band (Ramsay and Graham, 1970). The offset of prexisting planar and/or linear features occurs either if the relative displacements of the undeformed or less deformed walls, are parallel to the boundaries of the banded structure (S bands), perpendicular (P bands) or oblique (P-S bands), (Cobbold, 1977 a and b).

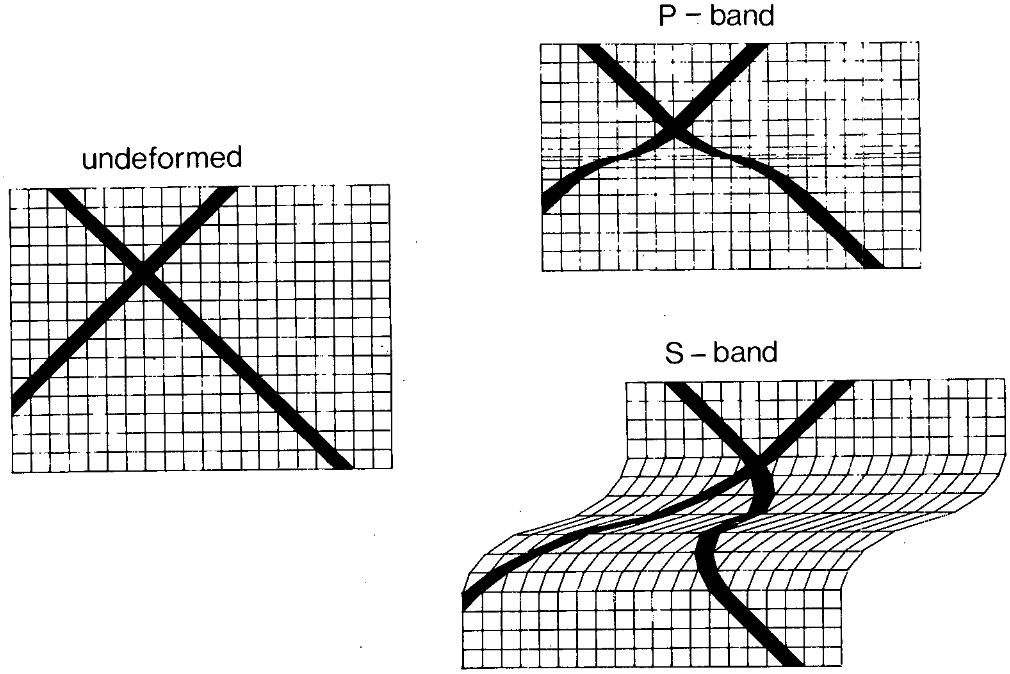

Fig. 2 – The effect of heterogeneous irrotational flattening (P bands) and heterogeneous simple shear (S bands) on grids containing differently oriented marker bands. (Based on Cobbold 1979 a and b, and Ramsay 1980).

P bands differ geometrically from S bands in the relative sense of deflection of differently oriented earlier planar structures deformed within the band (fig. 2). While in S bands the deflection sense is controlled by the dextral or sinistral character of the relative movement, in P bands the apparent sense of displacement depends on the angular relationship of the planes with respect to the P band. In addition, in pure P bands the amount of offset across the deformation band is small, provided that only negative dilatation is responsible for such deformation structures (see Ramsay and Graham, 1970; Ramsay, 1980). The smallest displacements occur where the earlier structural elements are aligned at highest angles to the P band. Thus the sense of rotation and amount of displacements of preexisting structural elements should enable S band to be distinguished from P bands in the field.

Most of the microstructural and quartz fabric studies across banded structures have been performed in S-type bands considered to develop predominantly by simple shear without significant volume change. The contradictions arising from the comparison of fabric variations across the Cap de Creus shear zone studied here (described by Carreras et al., 1977) with those encountered in other areas (Burg and Laurent, 1978; van Roermund et al., 1979; Simpson, 1980) makes it necessary to examine in more depth the type of deformation associated with this shear zone. The approach will be based on the comparison of measured geometrical relationships with those expected for strictly simple shear zones that contain a component of negative dilatation as well as simple shear deformation.

In shear zones resulting from simple shear only, with or without a heterogeneous negative volume change, the variation in thickness of passive marker layers bounded by parallel planes, measured on a section perpendicular to the shear zone boundary but parallel to the movement direction is given by (Ramsay, 1980):

$$t_i = t_o \frac{\sin \alpha_i}{\sin \alpha_o} \quad (1\ a)$$

where t_o and α_o are original thickness of the marker layer and its original angle with the shear zone respectively, while t_i and α_i refer to the same parameters of the deformed marker layer.

The relative contribution of shear strain and negative dilatation to the overall deformation do not affect the relationship in (1a) expressing change in thickness versus change in angle. In the above ideal shear zones the thickness of a sheared marker layer measured parallel to the shear zone boundary remains constant. Thus this type of shear zone boundary is geometrically analogous to class 2 - similar folds (Ramsay, 1967).

If the relationship:

$$\frac{t_i}{t_o} = \frac{\sin \alpha_i}{\sin \alpha_o} \quad (1b)$$

is not satisfied, deformation must deviate from a model that involves only simple shear strain (γ) and negative dilatation (Δ) as strain components.

A set of t_i/t_o versus α_i measurements, correcting the slight cut effect produced by the obliquity of the exposure, has been made across a wide section of the well exposed Cala Prona shear zone (fig. 3). Although this shear zone closely approaches the simple shear (with $\pm \Delta$) conditions, the introduction of a further strain component is necessary to explain the slight departure from ideal simple shear zone geometry. Thus the use of this kind of graph, developed by Ramsay (1967) for fold classification is also relevant for the characterization of the type of deformation at shear zone margins.

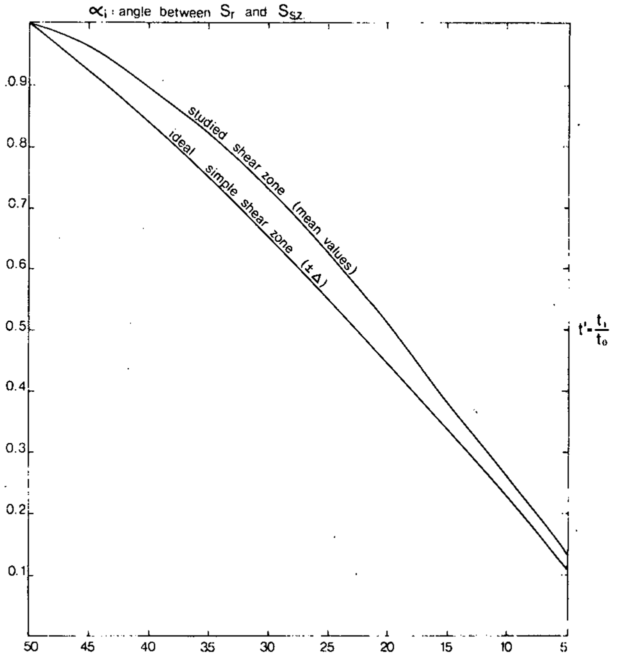

Fig. 3 – t'/α_i plot showing the bulk departure of the studied shear zone from an ideal simple shear zone.

It has been sometimes suggested (eg. Christie, 1963) that in shear zones where deformation is achieved predominantly by simple shear, a non-rotational flattening perpendicular to the band might also have played a role during or after shearing. Such S-P type bands with a component of displacement normal to the band imply either a negative dilatation in the band or a superimposed homogeneous flattening on both the wall rock and deformation band (Ramsay and Graham, 1970; Ramsay, 1980). This restriction arises provided that the following two conditions are maintained: i) the banded structure is parallel sided, and ii) the strain profile across the band remains identical at all positions except at the termination zones of the band (Ramsay and Graham, 1970; Ramsay, 1980).

A more general model for a homogeneous point domain including non-rotational flattening perpendicular to the band can be expressed by a coordinate transformation matrix of the type:

$$\begin{matrix} a & b & 0 \\ 0 & \frac{1+\Delta}{a} & 0 \\ 0 & 0 & 1 \end{matrix} \qquad (2)$$

It can easily be shown for this model that if (a) varies across the band, i.e. there is a heterogeneous irrotational strain component of shortening normal to the band, a displacement and strain gradient along the band are required. Thus Ramsay and Graham's condition (ii) is not mantained. This implies that any heterogeneous irrotational flattening across the band, related to displacement component normal to it, must also contain rotational components. Even in a bulk homogeneous shortening as postulated by Bell (1981) pure shear condition can only be mantained when in (2) b = o, in single point domains, at sites where the sign of rotation changes. Thus banded structures produced by plane strain bulk shortening involving large components of inhomogeneous shortening will induce deformation bands with large rotational components and deformation within the band will approach simple shear conditions in most domains.

In order to characterize the type of deformation in the zone under consideration, in which a slight increase in the thickness parallel to the zone margins of deformed bands has been observed, a displacement matrix including flattening will now be considered. As the result of such deformation any planar surface (S_r: regional schistosity) sheared passively, will deform and rotate around the intersection line of S_r and the shear plane (S_{sz}). On a two dimensional section perpendicular to the shear zone boundary and parallel to the movement direction, the change in angles will be given by the following expression:

$$\mathrm{cotg}\alpha_i = a \cdot b + a^2 \cdot (1 \pm \Delta)\ \mathrm{cotg}\alpha_o \qquad (3)$$

The change in thickness will be now also dependent on the value of the irrotational flattening component

$$t_i = t_o \cdot a \cdot \frac{\sin\alpha_i}{\sin\alpha_o} \qquad (4)$$

In this approach a further a priori assumption is made: the value of Δ is neglected. In other words, if there is any heterogeneous volume change across the zone, its contribution to the overall deformation will be negligible with respect to the γ value. This assumption is justified by the fact that a pegmatite dyke, oriented at a high angle to the approximately 0.5 m thick shear zone, presents an offset of more than 25 m. Furthermore there is no microstructural evidence of pressure solution processes which might contribute to a volume loss. In any case, volume changes would not affect the t_α/t_i versus α_i relationship.

By means of expression (3) with $\Delta = 0$, and (4), it is possible to evaluate the amount of irrotational flattening component (a) for different values of shear strain component (b); (fig. 4). This graph reveals that the studied shear zone configuration can not be explained in terms of simple shear plus a superimposed homogeneous strain, as values of (a), vary across the zone. The highests a/γ ratios are obtained closest to the shear zone boundary, while towards the inner part of the shear zone the deformation gradually approaches the simple shear model. The existence of this small heterogeneous flattening component indicates that a series of profiles taken across the zone can not remain absolutely identical.

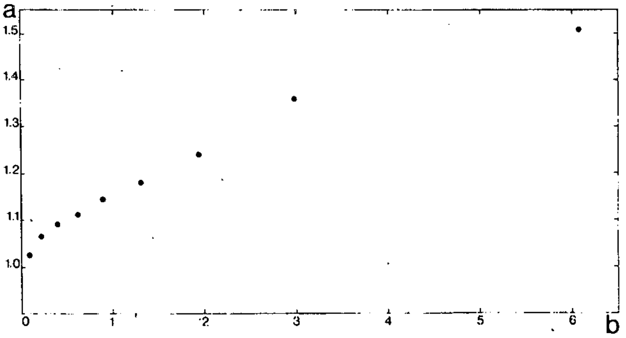

Fig. 4 – Graph showing the relative values of the shear strain component (b) versus the irrotational flattening component (a). The bulk shear strain is given bay $a \cdot b = \gamma$

The role of pre-existing foliation planes

Up to this point is has been assumed that the earlier foliation was behaving passively during shearing. Now the role of the preexisting foliation in the geometrical development of the shear zone must be introduced. It is well known that ductility contrasts between layers and/or mechanical anisotropies will originate instabilities which will lead to the formation of new structures i.e. folds, boudinage, crenulations and extensional crenulations.

In the shear zone under consideration the effect of both ductility contrasts and mechanical anisotropy induced by the penetrative schistosity subparallel to the layering should be taken into account. Each causes different sized minor structures; and both are responsible for departures from the simple shear model.

The layering effect is difficult to estimate accurately because primary lithology was rather monotonous. Furthermore considerable recrystallization occured during the peak of metamorphism. Later downfall of temperature caused the overall ductility of the rock to decrease along with any initial ductility contrast. Repeated folding, during the prograde metamorphic event, strongly

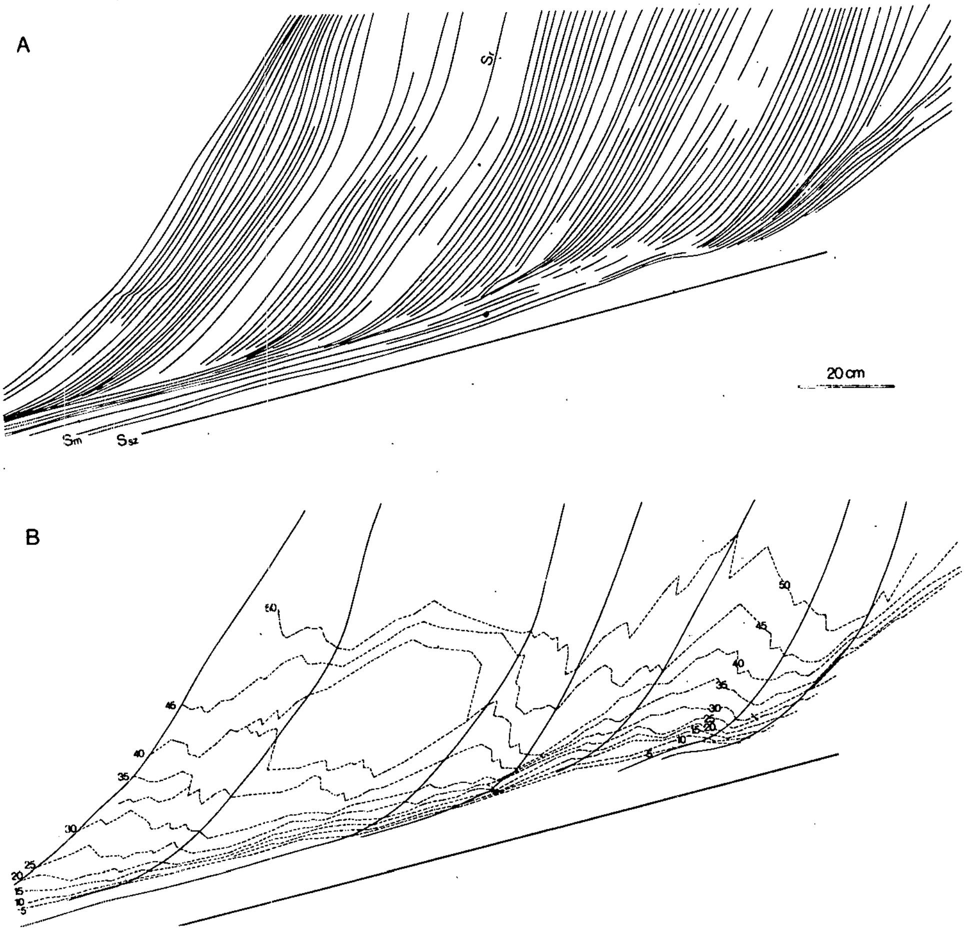

Fig. 5 – (A) Geometrical configuration of the lower shear zone shown in fig. 1 and (B) the trace of the dip isogons (dotted lines). The zig-zag patterns of the dip isogons indicates heterogeneities in strain along the shear zone.

transposed the original parallel layering. The trace of dip isogons of the foliation planes, these being closely parallel to the layers except in the hinge domains, reveals the existence of ductility contrast effects during shearing (fig. 5). The isogons zig-zag, converging and diverging. This indicates again that the required t_i/t_o relationship for simple shear (eq. Ib) is not mantained and where smaller domains are under consideration the observed departures are even greater than those encountered for a bulk section. While in some domains the t_i/t_o relationship (eq. 1b) is exceeded (divergent isogons) in other the required relation is not reached. This pattern is more accentuated on the outher boundaries of the deformation band margins, while isogons become more parallel towards the inner part of the band.

The anisotropy effect induced by the earlier foliation is responsible for the formation of discontinuous spaced extensional crenulations which are preferentially developed in the mica rich layers. These crenulations occur as centimetre to milimetre sized S - bands (Platt and Vissers, 1980). Two sets are common in the slightly deformed domains. Towards the inner parts of the shear zone one set prevails over the other. Although the development of crenulations in anisotropic rocks undergoing a bulk rotational strain is not yet well understood, one should expect that such structures should form in a similar manner to those obtained by Cobbold et al. (1971) for pure shear. Where the maximum shortening direction of the incremental strain ellipsoid lies closely perpendicular to the preexisting or reworked anisotropy two sets of crenulations should form. Oblique extension of the preexisting anisotropy due to the rotation of the foliation with respect to the incremental strain ellipsoid will cause the development of a single set of extensional crenulations. The two sets of extensional crenulations that are present in low strain domains probably formed at initial stages of the shear zone development, and thus must be distinguished from geometrically analogous extensional crenulations or shear bands inside the mylonite band developed probably in a later stage and after high strain values have been reached (White, 1979; Platt and Vissers, 1980). However both pertain to a progressive deformation event and both form as result of instabilities created by the effect of preexisting or newly formed planar anisotropies in the deforming rock.

II QUARTZ C-AXIS VARIATION ACROSS THE SHEAR ZONE BOUNDARY

The general pattern of the Cap de Creus quartz c-axis fabrics for quartz mylonites has been described in García-Celma (a, in press) as consisting of three fabric elements **A**, **B** and **C** (see fig. 6) of which **B** can be absent. Patterns constituted by the three fabric elements seem to correspond to the so called pseudo-two-girdle pattern (Sander, 1948, 1950, 1970).

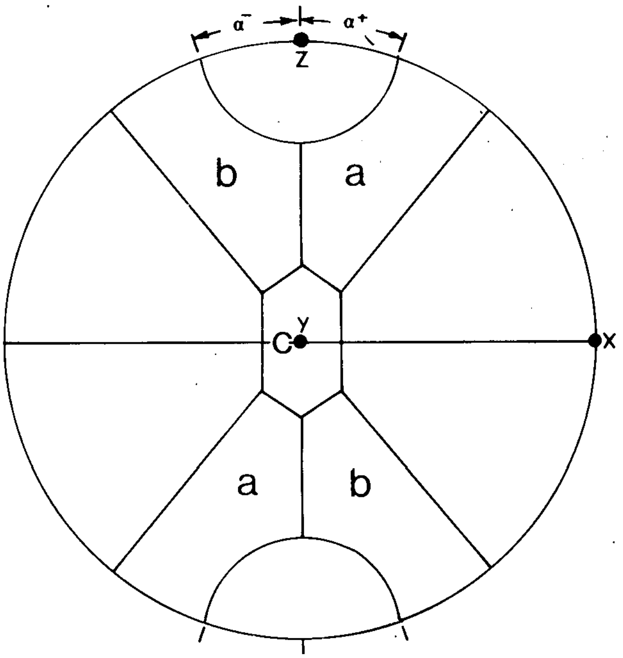

Fig. 6 - c-axis fabric pattern elements (after García-Celma, in press).

The symmetry of the c-axis fabric with respect to mylonite foliation

Figure 7 corresponds to a sequence of quartz c-axis fabric measurements performed in a centimetre to milimetre thick lens of segregation quartz that is pre shear zone formation in age and is located in a domain of converging isogons. In this sequence it can be seen that the fabric patterns for low strain domains (1, 2 and 3 on fig. 7) consist of crossed girdles in which the three fabrics elements **A**, **B** and **C** are symmetric with respect to the foliation (S). Following that lens towards the inner part of the shear zone, the fabric element **B** progressively disappears. The fabric patterns thus become single girdle distributions asymmetric with respect to S. Note that the progressive asymmetry of the c-axis pattern is exclusively produced by the loss of the fabric element b. No significant change in the angular relationships between the a fabric element of the c-axis fabric pattern and S is observed.

The departure of the remaining single quartz c-axis fabric from orthogonality to the foliation (S) is in a clockwise direction for this dextral shear zone. The same relationship between the sense of shear and the sense of asymmetry of the quartz c-axis fabric was first reported by Eisbacher and for Cap de Creus mylonites by Carreras (1974), Carreras et al. (1977 p. 16-17) and García-Celma (a, in press). Similar relationships have also been reported by Etchecopar (1974, 1977), Burg and Laurent (1978), Brunel (1980), Simpson (1980) and Bouchez and Pecher (1981).

Geometrical relationships between quartz c-axis fabric patterns, foliation and extensional crenulations.

As reported by Carreras et al. (1977), quartz c-axis fabrics in the Cala Prona shear zone under consideration track the orientation of the regional foliation as it curves progressively into near parallelism with the trend of the shear zone boundary. Other investigated c-axis fabric sequences across shear zones (eg. Burg and Laurent, 1978) did not show such a fabric rotation and an apparently contradictory situation has arised. The general angular relationships between c-axis fabric and shear zone kinematics have been recently discussed by Lister and Williams (1979) who compare theoretical predictions and field structures studied by different authors.

The perpendicularity of fabric elements to foliation and extensional crenulations have been studied for the reported shear zone, in the seuqence represented in fig. 8. In low strain domains of the schistose shear zone boundary two sets (S' and S") of spaced and discontinuous crenulations are developed. Their traces are approximately symmetrically disposed about the foliation plane (S), forming angles to it of around 25 to 35 degrees. Towards the inner part of the shear zone, one set of crenulations (S') becomes better developed, while the other (S") is rare. In the whole sequence, the **A** element of the c-axis fabric remains perpendicular to S' set of crenulations, while the **B** elements id perpendicular to S". The gradual disappearance of the S" set coincides with the fading out of the **B** fabric element and consequently fabric pattern becomes asymmetric with respect to S.

The two sets of extensional crenulations traces conserve their angular relationship with the schistosity S, and thus, the fabric element **A** being constantly perpendicular to the crenulation traces (S') are bound to the S surface with a constant angular relationship and rotate congruently with respect to the shear plane.

The c-axis patterns from the centres of shear zones from the Cap de Creus area (García-Celma a, in press), when asymmetric with respect to the mylonite foliation

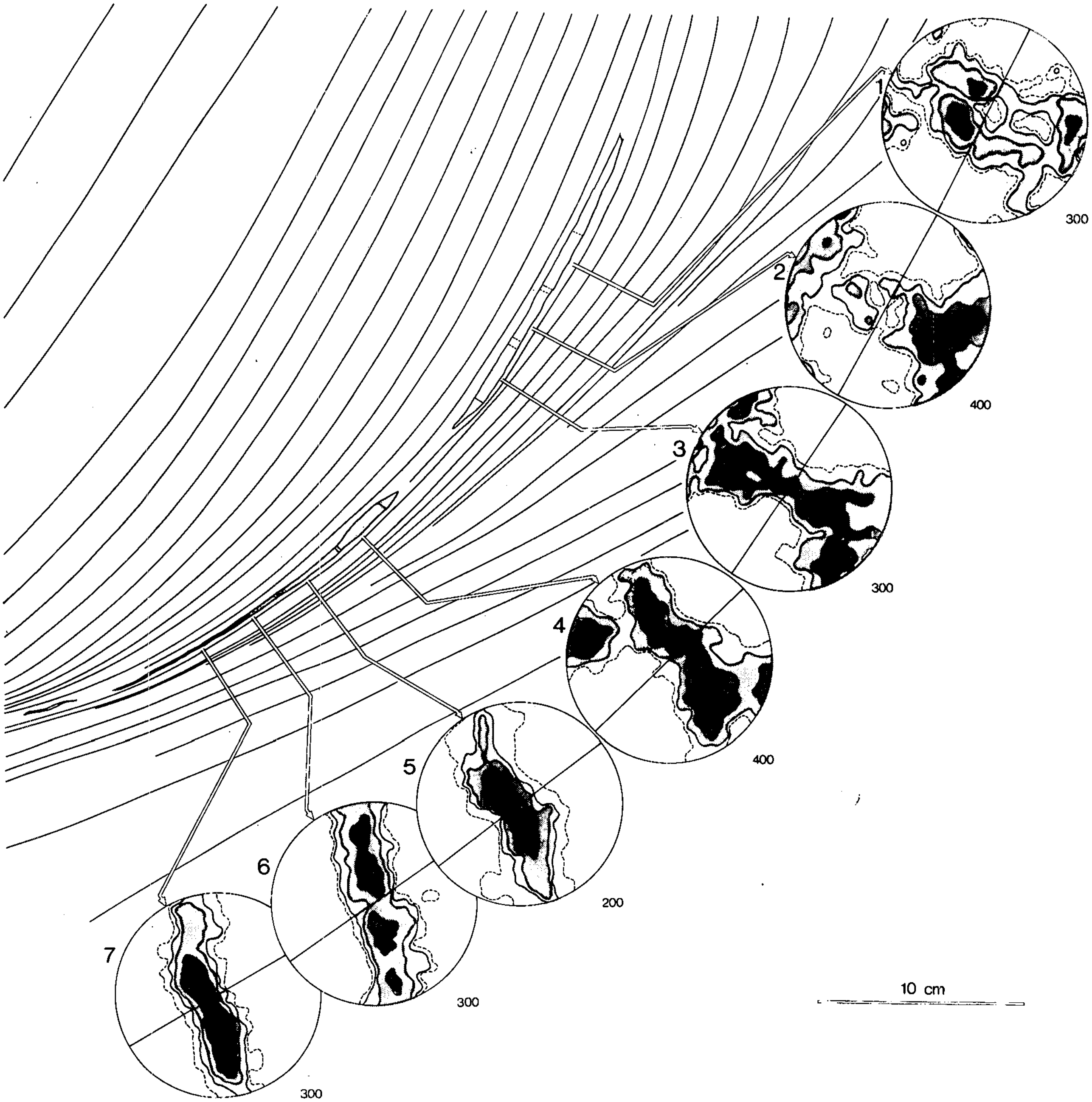

Fig. 7 – *Progresive development (1-7) of the quartz c-axis fabric in a quartz segregation vein parallel to the regional schistosity at the margins of the studied shear zone.* For location see fig. 1. The number on the lower right side each stereoplot indicate the number of c-axes measured. Contours in all plots are: 0,5 (dashed) - 1 - 2 - 4 - 8%.

were observed to be "approximately" perpendicular to the traces of one set of extensional crenulations or shear bands. When symmetric with respect to mylonite foliation either none or two sets of extensional crenulations could be found.

The behaviour of the c-axis fabrics in microscale

An axial distribution analysis (A.V.A.) has been performed in a thin quartz band enwrapped by small micas (fig. 9) that occurs between two crenulations of the dominant set S', in order to establish the penetrativeness of the orientation characteristics of c-axis fabrics in this shear zone. Fig. 9 illustrates the traces of the basal planes within each quartz grain. The measured quartz c-axis fabric patterns, also represented in figure 9, are mainly composed of the A and C elements A few grains contributing to the weakly developed **B** element are located in domains of incipient S" crenulations. The c-axis fabrics are not fixed in orientation with respect to the microshear plane, but turn congruently with the micas position, in the same way that the c-axis fabrics turn together with the schistosity for the mesosopic structure. Furthermore, the traces of the basal planes in the band represented in the A.V A. (fig. 9) turn with respect to the microshear plane mantaining their angular relationships with the schistosity (S) at every point, in much the same way as the crenulation set S' does in the mesoscale structure (fig. 8).

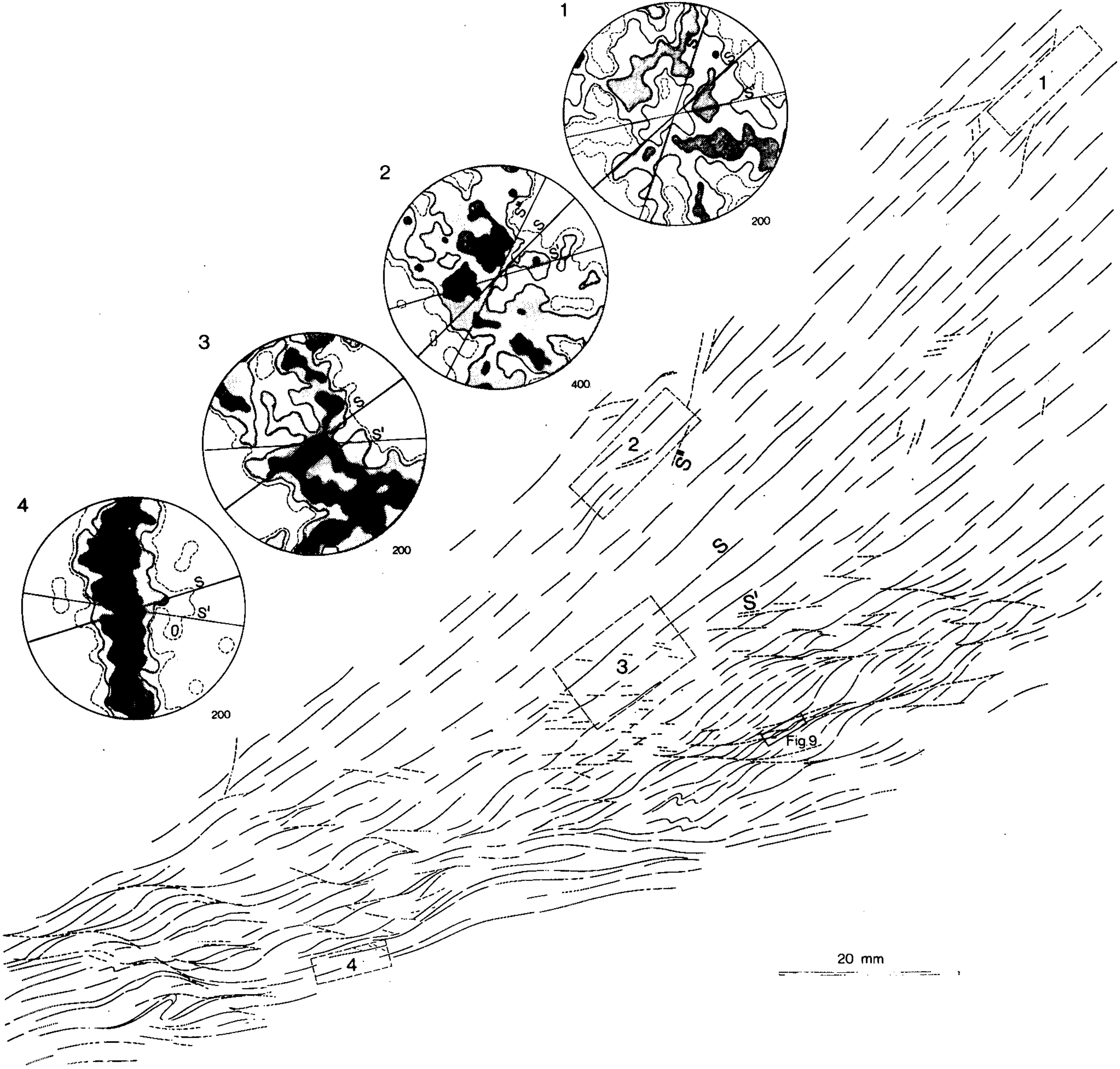

Fig. 8 – *Quartz c-axis fabrics from different microdomains on a mylonitized schist sample from the shear zone boudary*. Per location see fig. 1. S: schisto-mylonitic foliation, S' and S": sets of extensional crenulations. Number of measurements are indicated close to each plot and measured microdomains are enclosed in dashedline rectangles. Contours as in fig. 8.

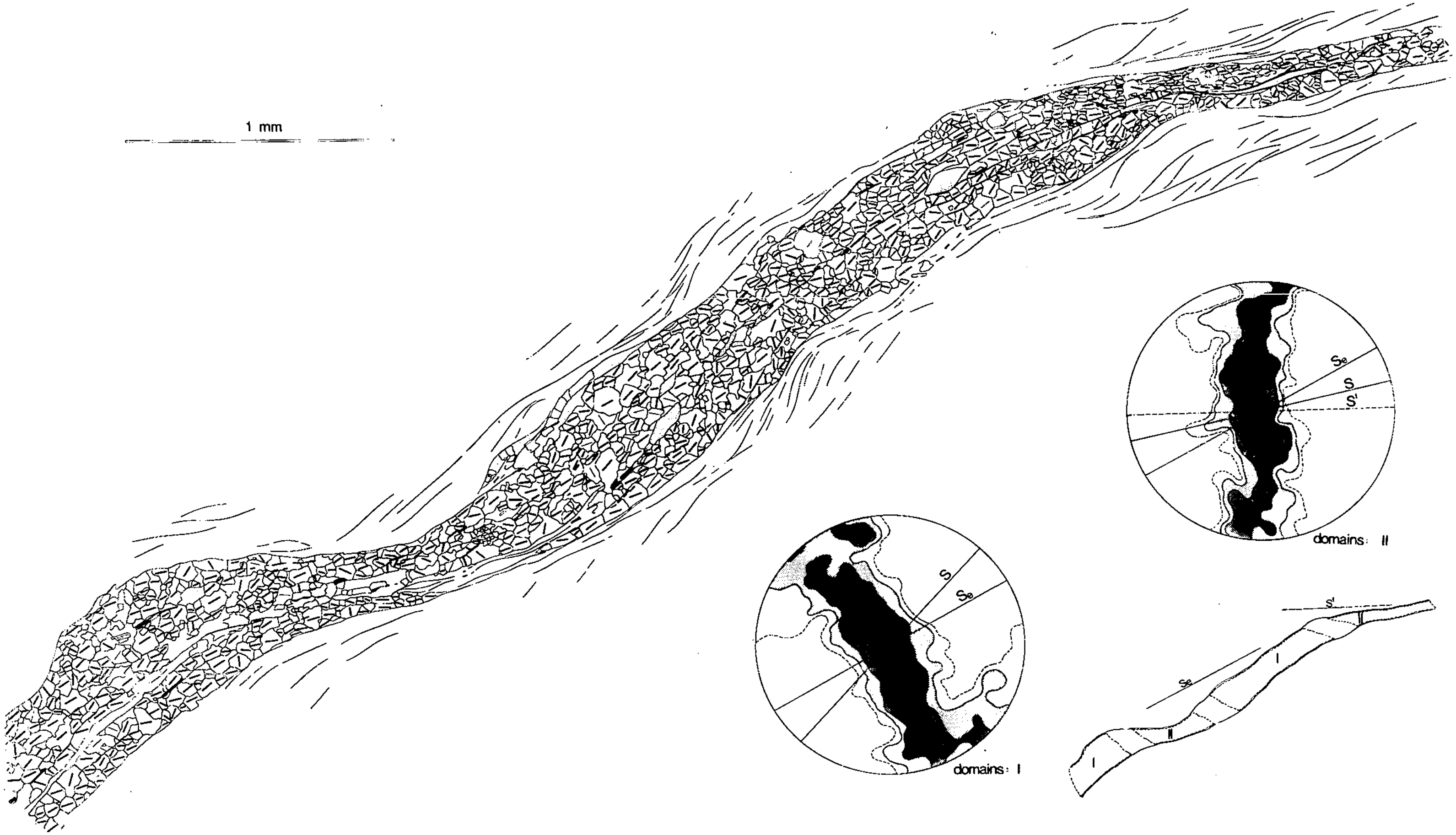

Fig. 9 – *Fabric variation in a quartz ribbon affected by shear bands.* The location of the domain is shown in fig. 8, and corresponds to the inner boundary of the shear zone margin, where S' is almost the unique crenulation set. The broad line inside each grain indicate the trace of the quartz basal plane (In grains with basal planes at low angle to the section the intersection trace is marked by means of a finers line). Domain I: 404 grains; domain II: 220 grains. Contours in both plots start with 0,5 (dashed) and then 1 - 2 - 4 - 8%. S_e: trace of the enveloping surface, S: trace of the dominant foliation in the domain, S': trace of extensional crenulation cleavage.

DISCUSION: QUARTZ C-AXIS FABRIC ROTATION AND SYMMETRY

Sequence studies in shear zones are performed in order to determine the geometric relationships between c-axis fabrics and foliation planes, shear planes, sense of shear etc. The perpendicular to the strongest developed girdle in quartz c-axis fabrics has been reported to represent the flow plane (Lister et al. 1978) and/or to lay near the bulk shear plane (Burg and Laurent, 1978; Bouchez, 1978; van Roermund et al., 1978). However, the c-axis fabrics sequences reported here are different from previously reported sequences in many respects.

Hara et al. (1973) reported a sequence in a shear zone developed in granites for which the symmetry planes of the c-axis fabrics are the planes of the finite strain ellipsoid, the XY plane corresponding to the foliation plane. These fabrics do not lose any fabric element with increasing strain. The opening angle ($\alpha^+ + \alpha^-$, fig. 6) remains approximately constant with increasing simple shear strain.

Burg and Laurent (1978) in their study of a sheared granodiorite reported a c-axis fabric sequence with an orientation that remained fixed with respect to the shear plane in a mesosopic domain. The oblique angle (α) between the quartz c-axis girdle and, foliation normal diminishes with increasing strain and this process is accompanied by the disappearance of a part of the c-axis fabric. The most deformed samples of their sequence show a single great circle girdle c-axis pattern, perpendicular to the shear plane. This girdle remains perpendicular to the shear plane right across the shear zone boundary. As a consequence, for high simple shear strains the c-axis fabric ought to approach perpendicularity to the foliation plane due to the decrease of the angle θ between the shear plane and the foliation plane.

V. Roermund et al. (1979) published a sequence from a shear zone also developed in granites with an interpretation that does not agree with either of the above two examples, but which is reported to agree with Taylor-Bishop-Hill analysis. Although their less deformed samples appear to have an almost random c-axis fabric, their c-axis fabrics are reported to remain fixed with respect to the shear plane. The best developed girdle of their fabric diagrams is reported to be perpendicular to the shear plane. No change in the opening angle was observed, and no fabric element disappears with increasing simple shear strain.

Simpson (1980) presented another sequence of c-axis fabric development in a shear zone in granites. However, this sequence is difficult to interprete because of the existence of a previous fabric in the non-sheared granites. For this sequence the angle of orientation of the c-axis fabric with respect to foliation varies, and the initial simple shear fabric appears to be constituted by a single great circle girdle. The α angle does not reflect the amount of simple shear deformation undergone by the samples.

The shear zone discussed in the present paper developed in schists, and therefore the schistosity planes cannot be considered to be XY planes of the finite strain ellipsoid. Consequently no exact comparison in terms of foliation significance can be made with the published fabric patterns discussed above. However, some evident contradictions and similarities exist:

– The c-axis fabric orientation turns with respect to the main shear zone plane. This result agrees with the findings of Hara et al. (1973) and contradicts those of Burg and Laurent (1978) as well as the theoretical considerations of v. Roermund et al. (1979).

– The α angle remains constant across the shear zone boundary and thus is not related to the amount of simple shear deformation. This result agrees with the findings of Simpson (1980) and contradicts those of Burg and Laurent (1978).

– The opening angle (taken as the anlge between the two pseudo-girdles) does not change with increasing strain; in this point there is a coincidence with Hara et al. (1973) and v. Roermund et al. (1979) for all the samples of the present study in which the B fabric element is still present.

– An element of the c-axis fabric disappears with increasing dominant bulk simple shear strain. This agrees with Burg and Laurent's (1978) results and Etchecopar's (1974, 1977) two dimensional model. Our most deformed samples have fabric patterns similar to those of Simpson (1980) but different from those of Hara et al. (1973) or v. Roermund et al. (1979). However, some of the reported pseudo-two-girdle fabrics for supposed highly deformed samples located in the inner part of shear zones could really correspond to lower simple shear strain values than expected, as it is well known than strain inside mylonite bands is often highly heterogeneous. Other possibilities regarding this fabric characteristic are related to curved shear zones (García-Celma b, in prep.) or to the presence of two sets of shear bands roughly symmetrical to the mylonitic foliation (Casas, in press).

Attention should be paid to the fact that in natural sequences in shear zones, for those domains in which the c-axis fabrics are already well developed, the angle between the shear plane and the foliation of the samples is very small and conclusions about the c-axis fabric orientation with respect to these planes are therefore hampered. In addition, the spread of the girdle distribution and the maxima contained therin allows the possibility of drawing great circles whose positions may have a variation of the same order of mangitude as the angular relationship between foliation and shear plane.

Lister ans Williams (1979) discuss some of these apparent contradictions and propose a model for shear zone development in Cap de Creus whereby the c-axis fabrics could rotate with respect to the shear plane while still remaining fixed with respect to the kinematic axes. Their model is based on decomposing strain in a coaxial stretching parallel to the foliation plus slip along discrete planes parallel to it, mantaining the geometrical requeriments for bulk simple shear. Their model would justify Taylor-Bishop-Hill analysis in the sense of asymmetry of the fabric (taking in acocount only sp. VI. in fig. 2 in Carreras et al., 1977, which comes from the highly heterogeneously deformed and anastomosed marginal domain, but disregarding the general agreement between asymmetry and sense of displacement statet in p. 16), and the orientation of the fabric diagrams with respect to the kinematic axes. From geometrical point of view this model assumes bulk simple shear, while in the studied zone departures from the simple shear model have been reported above, especially in the outer boundary of the shear zone. Furthermore, the model of Lister and Williams (1979) requires the existence of discrete planes along which shear strains are expected to be very large, separating thin domains where all the deformation is expected to occur by coaxial stretching. Such alternating and differentiated domains do not exist in the studied rocks at any scale as the foliation does not consist of a set discrete discontinuities.

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