Journal of Structural Geology, Vol. 7, No. 5, pp. 555 to 562, 1985
Printed in Great Britain

0191-8141/85 $03.00 + 0.00

Quartz microstructures and fabrics in the Island of Groix (Brittany, France)

M. CANNAT*

Laboratoire de Tectonophysique, 2, rue de la Houssinière, 44072 Nantes Cedex, France

(*Received* 5 *December* 1983; *accepted in revised form* 10 *October* 1984)

Abstract—Quartz microstructures and fabrics in the southeastern part of the island of Groix developed during the last stages of the Palaeozoic synmetamorphic deformation. The zonation of the quartz microstructures in map view suggests an upward positive gradient of strain. The plastic flow plane in quartz found in folds with axes aligned parallel to the stretching lineation, is parallel to the axial planes of the folds. The dominant regional sense of shear, as deduced from quartz fabrics, corresponds to the northward displacement of the upper block. This sense of displacement supports the hypothesis made by previous workers that the synmetamorphic deformation in Groix occurred in a N-directed intra-lithospheric thrust rather than in a N-dipping subduction zone. Quartz *c*-axis patterns argue for the distinction of two synmetamorphic phases with different transport directions. The transition between these two phases is thought to have occurred progressively during the course of the thrusting.

Résumé—Les microstructures et les fabriques du quartz dans le Sud-Est de l'île se Groix se sont développées lors des derniers stades de la déformation Paléozoïque. La distribution en carte des types microstructuraux suggère une diminution de l'intensité de la déformation vers le bas de la série. Dans les plis à axes parallèles à la linéation d'étirement échantillonnés, le plan d'écoulement plastique du quartz est parallèle du plan axial. Le sens de cisaillement régional, indiqué par la fabrique du quartz, correspond au déplacement vers le NNW du compartiment supérieur. Ce sens de cisaillement confirme l'hypothèse émise dans des travaux antérieurs selon laquelle la déformation et le métamorphisme de Groix témoignent d'un charriage intra-lithosphérique à vergence Nord et non d'une subduction à pendage Nord. L'analyse des fabriques d'axes *c* du quartz amène en outre de nouveaux arguments en faveur d'un changement de la direction de transport au cours de ce charriage. Ce changement de direction, de NW-SE à NNW-SSE, est probablement progressif.

INTRODUCTION

THE ISLAND of Groix, situated south of Lorient in Brittany (Fig. 1), consists of horizontally foliated metapelitic rocks intercalated with metabasic ones. High-pressure and low- to medium-temperature metamorphism (Cogné *et al.* 1966, Makanjuola & Howie 1972, Triboulet 1974) produced mineral associations such as glaucophane + lawsonite and omphacite + garnet in the basic rocks. All rocks were subsequently slightly to completely retrograded under greenschist-facies metamorphic conditions (Félix 1972, Triboulet 1974, Boudier & Nicolas 1976). Radiometric ages of 335 ± 20 Ma (Carpenter & Civetta 1976), 320 ± 8 Ma (Maluski 1976), 375 to 340 Ma (Peucat & Cogné 1977) have been determined for the blueschist-facies prograde metamorphism. The greenschist-facies retrograde metamorphism is dated at 294 Ma by Carpenter & Civetta (1976) and at 320 Ma by Peucat & Cogné (1977).

The rocks of the island present a variety of deformation-related structures. This study concerns the synmetamorphic ones; later postmetamorphic phases (Boudier & Nicolas 1976, Quinquis 1980) will not be considered. Quinquis *et al.* (1978) established that synmetamorphic progressive deformation was dominantly simple shear along a N-S to NNW-SSE direction. However, the glaucophane, garnet and lawsonite lineations throughout the island are observed to trend mainly N 120° E to N 140° E. Boudier & Nicolas (1976) proposed that the high-pressure minerals crystallized during an early episode of transport along a NW-SE direction, followed by an episode of N-S to NNW-SSE flow produced in greenschist-facies conditions. Quinquis (1980) opposed this hypothesis and suggested that the geometry of the flow lines along the limbs of N-S to NNW-SSE trending sheath folds could account for the NW-SE orientation of the high-pressure lineations. The study of quartz microstructures presented in this paper brings new insights to this discussion.

The relationships between the high-pressure, low-temperature rocks of Groix and the low-pressure, high-temperature ones cropping out on the mainland north of Groix (Peucat & Cogné 1977) have been explained by the existence of a Siluro-Devonian paired metamorphic belt (Cogné 1977, Peucat *et al.* 1978) formed as a result of N-dipping subduction (Fig. 2a). From the study of sigmoidal inclusion trails in garnets, Quinquis (1980) concluded that the sense of shear during prograde high-pressure metamorphism corresponded to the northward displacement of the upper block. This sense of shear does not fit a N-dipping subduction model (Fig. 2a). The emplacement of the South Armorican granites and the southward vergence of the main thrust-nappes in the Massif Central (Mattauer 1974, Burg & Matte 1979, Bard *et al.* 1980) argue against the existence of a S-dipping subduction zone in pre-Hercynian times. Quinquis (1980) and Quinquis & Choukroune (1981) therefore relate the syntectonic high-pressure metamorphism

---

* Present address: Department of Earth Sciences, University of Durham, South Road, Durham DH1 3LE, U. K.

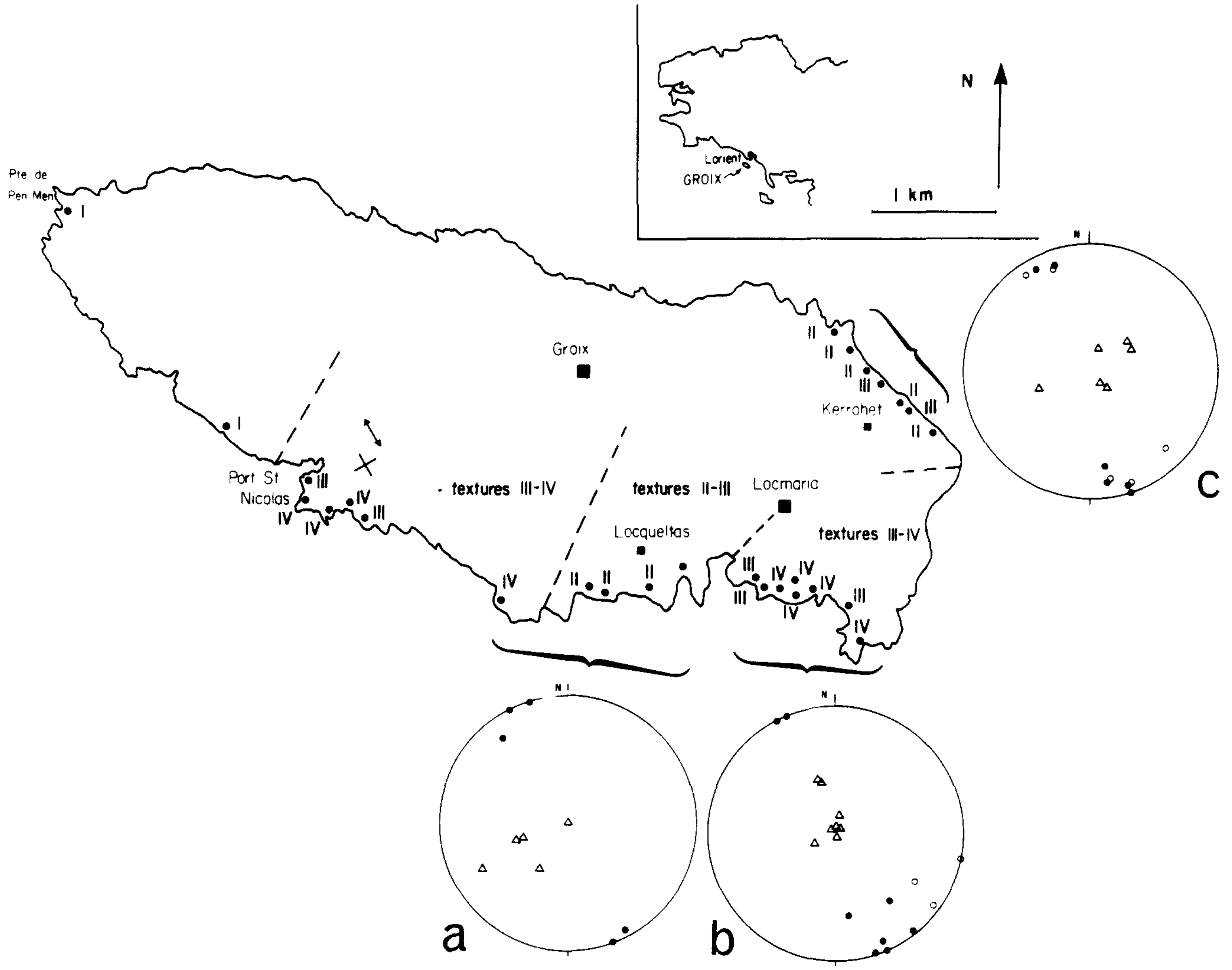


Fig. 1. Map of sample locations and microstructural types. Stereonets a, b and c: foliation (open triangle), *L*1 lineation (open circle) and *L*2 lineation (closed circle) in samples from the Locqueltas, Locmaria and Kerrohet areas. Lower hemisphere projection.

in Groix to continental collision rather than to subduction (Fig. 2b).

Because of its bearing on the subduction–collision discussion, as the two models presented in Fig. 2 correspond to opposite senses of shear, the main purpose of this work is the determination of the dominant regional sense of shear as indicated by quartz fabrics. In the southeastern part of the island, the crystalline fabric in quartz, due to its plastic deformation, is contemporaneous with the development of chlorite-filled pressure-shadows around garnets, characteristic of retrograde metamorphism. It gives information on the sense of shear prevailing during the final stages of the deformation. The quartz microstructures and the effects on the *c*-axis fabric development of isoclinal folding around N–S to NNW–SSE trending axes are also analysed. The sampling area is restricted to the southeastern part of the island (Fig. 1) where the influence of postmetamorphic deformation is limited. The sampled quartz-rich layers are exudation lenses of metamorphic origin.

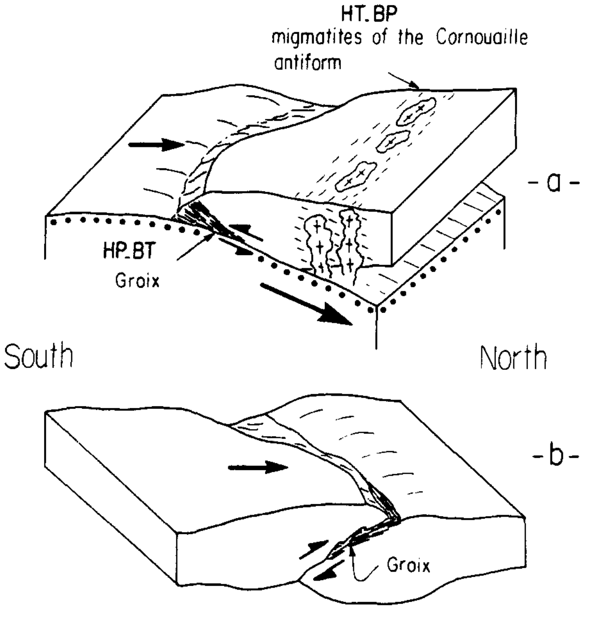


Fig. 2. Schematic illustration of the subduction (Fig. 2a after Cogné 1977) and collision (Fig. 2b after Quinquis 1980) hypotheses.

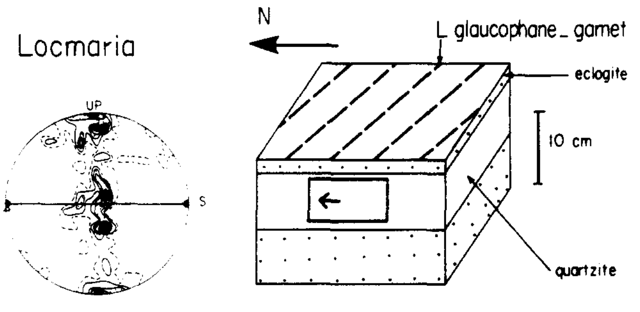


Fig. 3. Quartz *c*-axis fabric and NW–SE high-pressure lineation. Sample from the Locmaria area. 100 measurements, contours: 1, 2, 3, 4, 5% per 0.4% area. Lower hemisphere projection. Heavy line, trace of foliation; closed circle, stretching direction in quartz; open triangle, flow line in quartz.

THE GLAUCOPHANE–LAWSONITE–GARNET LINEATION

The microstructural study of quartz exudation lenses in the eclogitic sequence (Locmaria and Kerrohet areas, Fig. 1) shows that the quartz lattice preferred orientation (L.P.O.) is consistently related to a N–S to NNW–SSE stretching direction even when the high-pressure mineral lineation markedly differs from this NNW trend. For example, in a sample taken near Locmaria (Fig. 3), the glaucophane–garnet lineation trends N 110° E while the intracrystalline slip direction in quartz, indicated by the normal to the single girdle of quartz *c*-axes, is contained in the foliation plane and trends close to N–S, In this handspecimen, the NW–SE orientation of the glaucophane–garnet lineation is not likely to result from sheath folding as invoked by Quinquis (1980). Given the limited amount of strain necessary to imprint a new lattice fabric in quartz, which is a highly ductile mineral (Lister & Price 1978), it is thought that the N–S deformation selectively affects the thin quartz-rich layers and does not affect the far more rigid eclogitic rocks around them. Consequently, in this paper, the N–S to NNW-trending lineations and associated folds will be referred to as *L*2 and *F*2 (*D*2 episode) and the NW–SE trending high-pressure lineations as *L*1 (*D*1 episode).

The distinction of two synmetamorphic episodes with different transport directions was first adopted by Boudier & Nicolas (1976). They further proposed that the change in transport directions occurred along with a change of the metamorphic climate: from blueschist- to greenschist-facies. However, the occasional growth of glaucophane crystals in the axial plane of *F*2 isoclinal folds (Quinquis 1980) indicates that the *D*1 to *D*2 transition occurred before the peak of the greenschist-facies metamorphism. Other evidence, such as tension gaps filled with high-pressure minerals and related to the *D*1 episode or lying in an intermediate position (Nicolas & Boudier pers. comm.), suggests a progressive change of the transport direction.

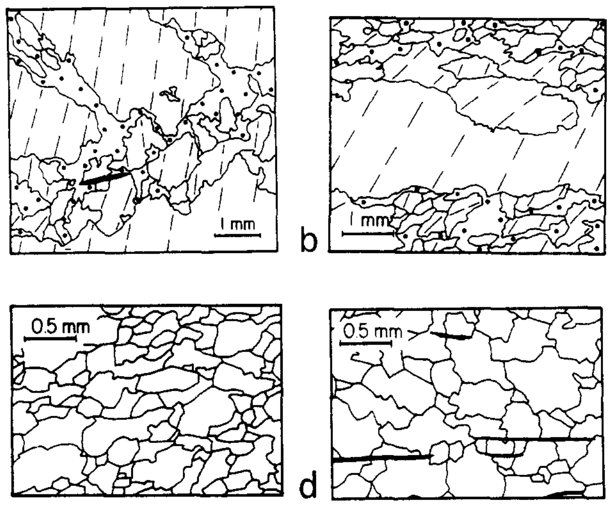


Fig. 4. Quartz microstructures. a, Type I; b, Type II. Dashed lines, trace of subboundaries in relict porphyroclasts; dots, 50–100 μm polygonal neoblasts. c, Type III; d, Type IV.

QUARTZ MICROSTRUCTURES

27 samples have been studied in thin sections cut parallel to the *XZ* plane of the finite-strain frame. The quartz microstructures belong to four main types (Fig. 4). Type I (Fig. 4a) presents relict porphyroclasts with moderate syntectonic recrystallization in the form of polygonal grains 50–100 μm in size. In the Type II microstructure (Fig. 4b), the relict porphyroclasts are more elongate and the syntectonically recrystallized grains are polygonal to tabular in shape and smaller than 100 μm in size. Type III (Fig. 4c) is an elongate mosaic microstructure with grainsize smaller than 0.5 mm. Type IV (Fig. 4d) is an equant mosaic microstructure with grain size smaller than 1 mm. The difference between the Types III and IV results from the incipient post-tectonic grain-growth observed in Type IV.

The microstructural evolution from Type I to Type II can be ascribed with confidence to increasing strain. The recrystallization observed in the Types III and IV microstructures could have been enhanced by higher strain, higher temperature or higher water content (Poirier & Nicolas 1975, Garcia Celma 1983). The influence of water is not thought to be determinant as no correlation exists, in the studied samples, between the development of the recrystallized microstructures and the nature, or water content, of the surrounding rocks. According to Carpenter & Civetta (1976), no significant temperature gradient existed on the island during the greenschist-facies metamorphism. The transition to the recrystallized Types III and IV will therefore be attributed to increasing strain. The possible influence of temperature will be reconsidered later on, however, in view of the quartz L.P.O.

The distribution of the microstructural types on the map (Fig. 1) defines four NNE–SSW trending zones. Following the interpretation of the microstructural evolution in terms of increasing strain, the dominance of the Types III and IV in the Locmaria area indicates intense strain. The strain intensity decreases in the Locqueltas and Kerrohet areas (dominance of Types II and III) and increases again further west in the Port St Nicolas area (Types III and IV). Two samples, taken in the mica-schists of the northwestern part of the island,

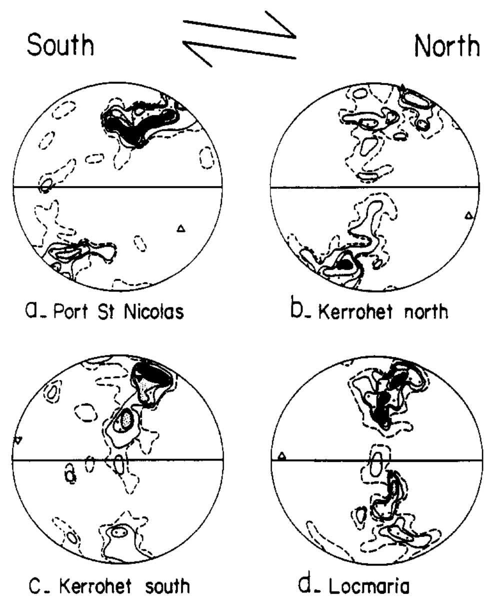


Fig. 5. Quartz *c*-axis fabrics in the Port St Nicolas, Kerrohet and Locmaria areas. 100 measurements. Lower hemisphere projection. Solid line, trace of foliation; closed circle, lineation; closed triangle, best axis of the distribution; open triangle, pole to the best plane. Contours: a—1, 2, 3, 4, 5% per 0.45% area; b—1, 2, 4, 5, 8% per 0.45% area; c—1, 2, 4, 5, 7% per 0.45% area; d—1, 2, 3, 5, 6% per 0.45% area.

display Type I microstructures indicative of low strain.

Given the subhorizontal attitude of the foliation throughout the island, the vertical polarity of the sequence can be established (Boudier & Nicolas 1976), the highest levels cropping out in the Locmaria area, the lowest further west. Large-scale postmetamorphic folds perturb this polarity in the Port St Nicolas area. Consequently, the microstructural zonation of quartz in the southeastern extremity of the island (Fig. 1) can be attributed to an upward positive gradient of strain. This inference is consistent with the conclusions of the geometrical analysis made by Boudier & Nicolas (1976) based on the style of *F*2 folds along the southern coast of the island.

QUARTZ C-AXIS FABRICS

For most samples, the sense of shear was determined using the gypsum-plate technique (Bouchez 1977), all thin sections being cut in the *XZ* plane of finite strain. A rough appreciation of the dominant *c*-axis orientation is given by the colour range of the quartz grains under crossed polarizers with and without the gypsum plate. The sense of shear is also given by the obliquity between the mean orientation of the prismatic subboundaries and the trace of the foliation. The results of these determinations are summarized in Fig. 6. U-stage measurements of quartz *c*-axis orientations were also made in four selected samples (Fig. 5), in order to determine the activated slip systems. In addition, quartz L.P.O. measurements were necessary for the three following types of samples: (1) samples in which the strain frame is related to the *D*1 episode (NW–SE striking high-pressure lineation) and does not correspond to the *D*2 kinematic frame (Fig. 3); (2) samples displaying evidence of *F*2 isoclinal folding, because the flow mechanism of the *F*2 folds is not known *a priori* (Fig. 7) and (3) samples taken in cm- to dm-thick quartz-rich lenses within the eclogites (Fig. 8). The interest in this third group comes from the observation, using the gypsum plate technique, of a common domainal pattern of the quartz fabric inside the lenses.

In the Port St Nicolas area (Fig. 1), the *c*-axis maxima fall close to the *Z*-direction of the finite strain frame (Figs. 5a and 7a & c). This pattern indicates slip on basal planes along the *a* crystallographic axes. The obliquity of the *c*-axis maxima to the *YZ* plane reflects the rotational nature of the deformation and indicates northward displacement of the upper block. In two samples (Figs. 5a and 7a), the *c*-axes are asymmetrically distributed along small circles centered on *Z*. Based on experimental work by Tullis (1971), this pattern is thought to reveal a substantial amount of flattening during the *D*2 rotational deformation.

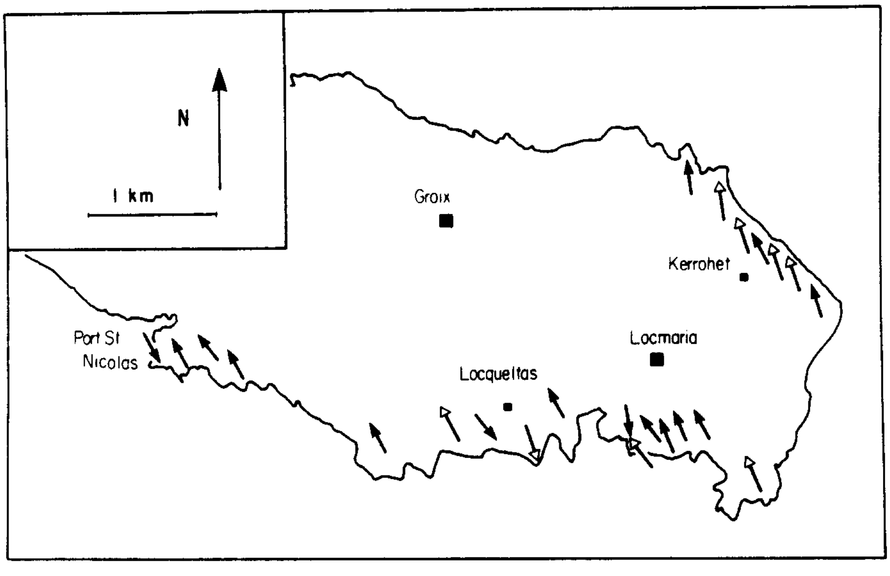


Fig. 6. Map of the senses of shear indicated by quartz fabrics. Open headed arrows: senses of shear indicated by quartz fabrics in domain A of zoned quartzite lenses.

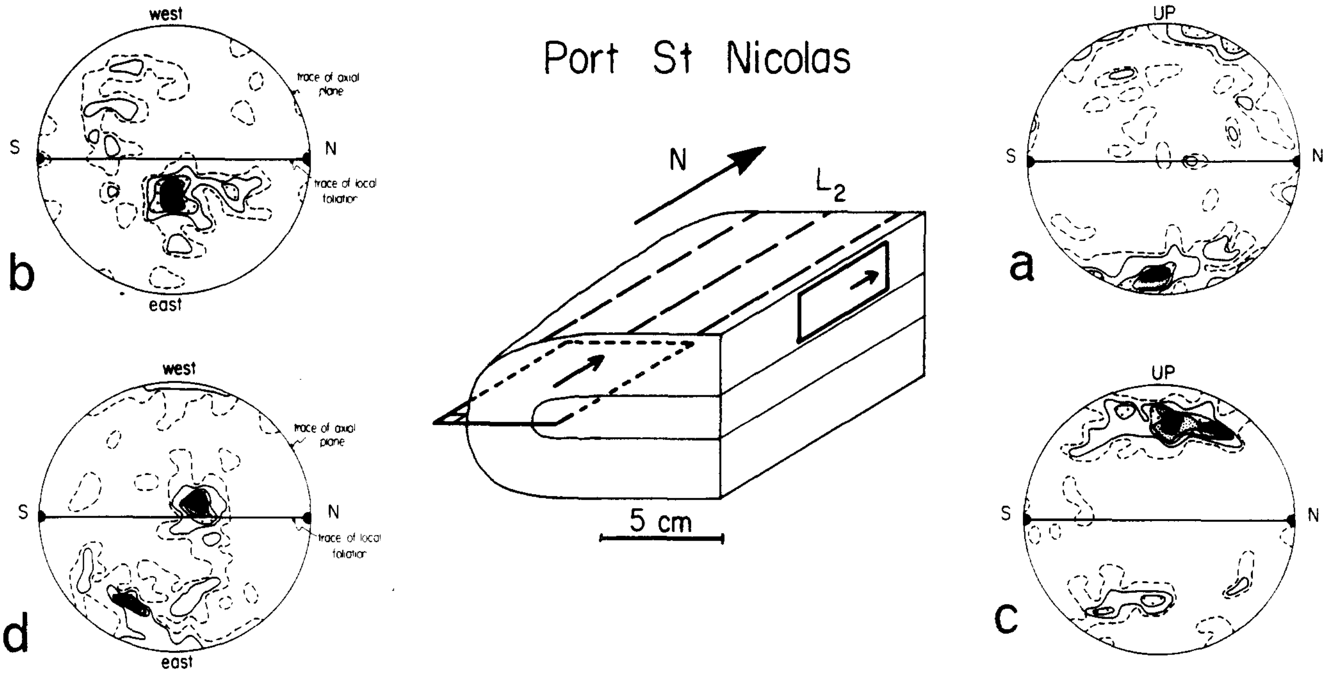
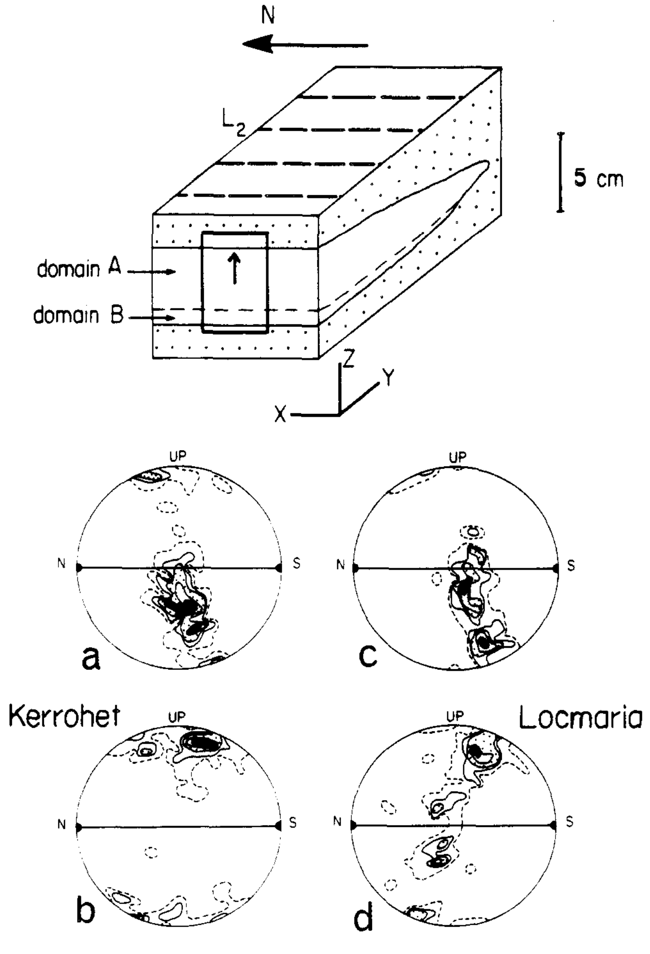


Fig. 7. Quartz *c*-axis fabrics in *F*2 folds. Schematic representation of an *F*2 fold in mica-schist. Stereonets: *c*-axis fabrics in the two studied folds; lower hemisphere projection; 100 measurements. *First fold.* a, normal limb; solid line, trace of *S*1 and *S*2 foliations; solid circle, *L*2 lineation. b, hinge; solid line, trace of *S*1; horizontal plane, *S*2; solid circle, *L*2. Contours: 1, 2, 4, 6, 8% per 0.45% area. *Second fold.* c, normal limb; solid line, *S*1 and *S*2; solid circle, *L*2. b, hinge; solid line, *S*1; horizontal plane, *S*2; solid circle, *L*2. Contours: 1, 2, 4, 5, 6% per 0.45% area.



In the Kerrohet (Figs. 5b & c and 8a) and Locmaria (Figs. 3, 5d and 8c) areas, the *c*-axes are distributed along single girdles parallel or slightly oblique to the *YZ* plane of the finite-strain frame. Similar single girdles have been described by Bouchez & Pécher (1981) in quartzites from the Himalayan thrust in Nepal, where the deformation probably does not differ greatly from simple shear. Following the interpretation of these authors, this single girdle pattern will be attributed to slip along the *a*-direction on a combination of basal, prism and rhomb planes. The term 'basal' is used for intracrystalline slip in grains whose *c*-axes fall close to the *Z* direction of the finite-strain frame; the term 'prism' is used for slip in grains whose *c* axes fall close to the *Y* direction; finally, the term 'rhomb' is used for slip in grains whose *c*-axes fall in an intermediate position between *Z* and *Y*.

Slip on basal planes along the *a*-direction has been obtained experimentally at low to moderate temperatures (Heard & Carter 1968). The prism and rhomb slip planes are found to be activated at high temperatures (Baëta & Ashbee 1969). The quartz fabrics discussed above may therefore reflect an eastward increase in

Fig. 8. Quartz *c*-axis fabrics in zoned quartz-rich lenses. Schematic representation of a quartz lens in the eclogites. Stereonets: c-axis fabrics in the two studied lenses, lower-hemisphere projection. Solid line, trace of foliation; closed circle, *L*2 lineation. First lens: a, Domain A; b, Domain B. Second lens: c, Domain A; d, Domain B. a, 102 measurements, contours: 1, 2, 3, 5, 7% per 0.45% area. b, 50 measurements, contours: 2, 4, 6, 10, 14% per 0.45% area. c, 150 measurements, contours: 1.3, 2, 3.3, 4.6, 6.6% per 0.45% area. d, 70 measurements, contours: 1.3, 2.6, 3.9, 6.5, 7.8% per 0.45% area.

temperature during the greenschist-facies metamorphism. This temperature gradient would have been very small since it is not confirmed by petrological observations (Carpenter & Civetta 1976). Incidentally, the existence of such a gradient would confirm the interpretation of the quartz microstructural evolution in terms of increasing strain. The recrystallized Types III and IV are found in the Port St Nicolas area (Fig. 1) where the dominance of basal slip suggests moderate temperatures during the $D2$ episode.

The senses of shear, determined either by U-stage measurements or through the gypsum-plate technique, indicate a northward displacement of the upper block in 19 samples, against the opposite sense in four samples (Fig. 6).

Quartz c*-axis fabrics in* F2 *folds and in quartz rich lenses from the eclogitic sequence*

Isoclinal folds with axes parallel to the $L2$ stretching lineation are abundant on the island. These folds (Fig. 7) deform the original $S1$ foliation. The $S2$ axial-plane cleavage, not visible at the scale of the samples, is defined in thin sections by the moderate flattening of quartz grains. The way the quartz fabric behaves in such $F2$ folds has important implications for determination of the sense of shear. If the fabric pattern is passively rotated around the fold axis, the normal and inverted limbs will display opposite senses of shear. On the other hand, if the axial plane of the fold acts as an active flow plane during shearing, a new fabric pattern, related to this flow plane, develops in quartz; both limbs of the fold then indicate the same sense of shear. The aim of the following study is the determination of flow mechanisms in two dm-sized isoclinal folds collected in the Port St Nicolas area. Two quartzite lenses from the eclogitic sequence have also been studied, because the observed domainal pattern of the quartz c-axis fabric in such lenses suggests the rotation of a pre-existing fabric around an axis parallel to the lineation.

Quartz c*-axis fabrics in* F2 *folds*

The evolution of quartz c-axis fabrics from limbs to hinges of dm-sized $F2$ isoclinal folds from the Port St Nicolas area has been studied in thin sections cut perpendicular to the local foliation and parallel to the $L2$ lineation (Fig. 7). Two samples were chosen for c-axis fabric measurements (Figs. 7a & b and 7c & d). The c-axis patterns in the normal limbs of the folds (Figs. 7a & c) indicate slip on basal planes with respect to the $S1$ foliation and axial plane of the fold. The obliquity between the c-axis maxima and the trace of the foliation indicates a northward displacement of the upper block. Identical senses of shear and dominant slip systems have been determined in the inverted limbs of the same folds, using the gypsum-plate technique. The c-axis patterns in the hinges of the folds are characterized by strong maxima lying in a prism position with respect to the rotated $S1$ foliation (Figs. 7b & d). Since slip in the limbs of the folds, where the finite-strain frame is clearly defined, occurs predominantly on basal planes, the strong maxima observed in the hinges are interpreted as lying in a basal position with respect to the axial plane of the folds. The distribution of the c-axes is therefore considered to be independent of the local attitude of the foliation; instead, the intracrystalline slip plane in quartz lies close to the axial plane of the fold which then acts as an active flow plane for the rock. In the fabric, from the hinge zone of the second fold (Fig. 7d), a subsidiary c-axis maximum would indicate basal slip with respect to the $S1$ foliation. Using the same reasoning as above, this subsidiary maximum is interpreted as a relic of a rotated pre-folding pattern. The persistence of this relict maximum may be explained by the fact that the grains presenting this inherited orientation lie in a position favorable to slip on prism planes with respect to the axial plane of the fold.

The quartz fabric in these $F2$ isoclinal folds therefore developed after the folding of the foliation, during the final stages of the $D2$ progressive deformation. This result completes the observations made by Quinquis (1980) in the 'nose' regions of $F2$ sheath folds in the Port St Nicolas area. In these 'noses', the fold axis orientation is close to the Y-direction of the finite strain frame. Quinquis (1980) found the quartz c-axis pattern to be folded together with the $S1$ foliation. The post-folding quartz L.P.O., observed here in $F2$ folds with axes parallel to the X-direction, is absent. This confirms the now classical interpretation of folds with axes parallel to the X direction as resulting from progressive rotation of fold hinges towards X, from initial orientations close to Y (Carreras *et al.* 1977, Quinquis *et al.* 1978, Brunel 1980).

Quartz c*-axis fabrics in quartz-rich lenses from the eclogitic sequence*

A domainal pattern of the quartz fabric parallel to the foliation is commonly present in quartz lenses from the eclogitic sequence (southeastern part of the island). Two samples have been selected for c-axis fabric measurements (Figs. 8a & b and 8c & d). In the upper part of the two studied lenses (Fig. 8, domain A), the c-axis pattern is made of a single girdle with basal, rhomb and prism submaxima (Figs. 8a & c). The obliquity of this girdle with respect to the foliation is consistent with the dominant northward displacement of the upper block. On the other hand, the quartz fabrics of the lower zones (domain B) indicate dominant slip on basal planes, with an opposite sense of shear (Figs. 8b & d). The difference between the two domains could be attributed to bulk rotation of a predefined fabric pattern as a result of folding of the lenses around an axis parallel to $L2$. In this hypothesis, domain A would represent a broad hinge zone, whereas domain B would be a thinned inverted limb. Three main observations oppose this hypothesis, however. (1) Thin sections cut normal to $L2$ do not show any trace of a hinge zone. (2) The preceding study of quartz fabrics in the hinges of $F2$ isoclinal folds shows that rotated c-axis patterns are replaced by new ones related to the axial planes; there is no reason why it should be otherwise here. (3) If the fabric pattern of domain A was obtained by rotation of the domain B fabric, which has a dominant basal maximum, the c-axis maximum in domain A would mainly locate in a prism position in the thin section under consideration. This is not the case as rhomb and basal positions are also observed.

The c-axis pattern observed in domain A is thought not to have undergone rotation, therefore, but to have resulted from slip on basal, rhomb and prism planes. The origin of domain B (slip on basal planes with an opposite sense of shear) and of the asymmetry of the c-axis maxima relative to the Y direction in domains A and B, is not fully understood. It may be looked for in heterogeneities of the flow regime during or after the $D2$ deformation. These heterogeneities may have been due to small-scale post-$D2$ movements with an inversion of the sense of shear. It is not seen why such late movements would only be accommodated in the quartz grains of Domain B. These heterogeneities are therefore thought to have come from the strong rheological contrast between the quartzite and the surrounding eclogite. This contrast could have induced differential movements at the quartzite/eclogite contact during the $D2$ deformation.

CONCLUSIONS

A northward displacement of the upper block in Groix is established for the $D2$ episode occurring under greenschist-facies metamorphic conditions. This result completes and confirms the sense of shear determined by Quinquis (1980) for the deformation under high-pressure metamorphic conditions. Thus, the syn-metamorphic deformation in Groix did not occur in a N-dipping subduction zone (Fig. 2a). The model of continental collision, proposed by Quinquis (1980) and Quinquis & Choukroune (1981), is preferred (Fig. 2b).

The change in transport direction from NW–SE to NNW–SSE in the course of this collision, proposed by Boudier & Nicolas (1976), is supported by the quartz L.P.O. analysis. This change of direction occurred progressively, after the peak of the high pressure metamorphism (375–340 Ma, Peucat & Cogné 1977) and before the peak of the greenschist-facies metamorphism (294 Ma, Carpenter & Civetta 1976, 320 Ma, Peucat & Cogné 1977). The $D1$ episode, with a NW–SE transport direction, compares in age and in geometry with the Devonian phase of northwestward thrusting observed in the Vendée region (Ters 1979, Burg 1981, Brun & Burg 1982). No late Devonian to early Carboniferous phase of northward thrusting, comparable to the $D2$ episode of Groix, has as yet been described in the Armorican region.

The microstructural zonation of quartz in the south-eastern part of the island is attributed to an upward positive gradient of strain during the $D2$ episode. This result is consistent with the conclusions of Boudier & Nicolas (1976), based on the style of $F2$ folds along the southern coast of the island. The orientation of this strain gradient indicates that the rocks of Groix belonged mostly to the underthrust plate during the $D2$ deformation. A suitable location for the thrust plane during the $D2$ deformation could therefore have been the base of the eclogitic sequence, in the easternmost part of the island. The sketch in Fig. 9 illustrates this hypothesis schematically. The thrust fault separates two portions of oceanic crust. In Groix, the underthrust portion mainly consists of metamorphosed pelitic rocks (mica-schists). Infolded metamorphosed basic rocks crop out close to the thrust plane. The attitude of the foliation in the underthrust plate is drawn after synthetic cross-sections of the island established by Boudier & Nicolas (1976).

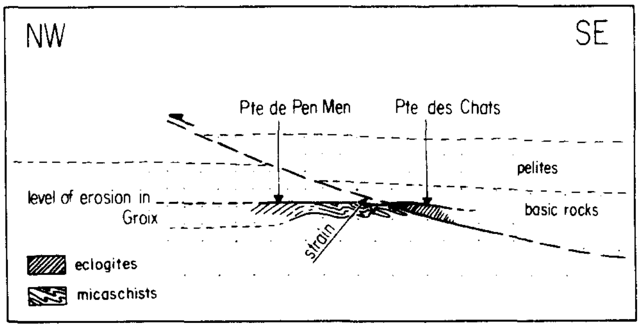


Fig. 9. Possible location of the thrust fault in Groix during the $D2$ episode.

Acknowledgements—I am greatly indebted to J. L. Bouchez, F. Boudier and A. Nicolas for their help and many fruitful discussions. I also wish to thank the students who collected some of the samples.

REFERENCES

Baëta, R. D. & Ashbee, K. H. G. 1969. Slip systems in quartz. *Am. Mineral.* **54**, 1551–1582.

Bard, J. P., Burg, J. P., Matte, P. & Ribeiro, A. 1980. La chaîne hercynienne d'Europe occidentale en termes de tectonique des plaques. *Colloque C6, 26th Int. geol. Congr. Paris* (edited by Bur. Rech. geol. min. Fr.), 233–246.

Bouchez, J. L. 1977. Le quartz et la cinématique des zones ductiles. Thèse d'état, Université de Nantes.

Bouchez, J. L. & Pècher, A. 1981. The Himalayan Main Central Thrust pile and its quartz-rich tectonites in central Nepal. *Tectonophysics* **78**, 23–50.

Boudier, F. & Nicolas, A. 1976. Interprétation nouvelle des relations entre tectonique et métamorphisme dans l'Ile de Groix (Bretagne). *Bull. Soc. géol. Fr.* **18**, 135–144.

Brun, J. P. & Burg, J. P. 1982. Combined thrusting and wrenching in the Ibero-Armorican arc: a corner effect during continental collision. *Earth Planet. Sci. Lett.* **61**, 319–332.

Brunel, M. 1980. Quartz fabrics in shear-zone mylonites: evidence for a major imprint due to late strain increments. *Tectonophysics* **64**, 33–44.

Burg, J. P. & Matte, P. 1979. A cross-section through the French Massif Central and the scope of its Variscan geodynamic evolution. *Z. Dt. geol. Ges.* **129**, 429–460.

Burg, J. P. 1981. Tectonique tangentielle en Vendée littorale: signification des linéations d'étirement E–W dans les porphyroïdes à foliation horizontale. *C. r. hebd. Séanc. Acad. Sci. Paris* **293**, 849–854.

Carpenter, M. S. N. & Civetta, L. 1976. Hercynian high pressure/low temperature metamorphism in the Ile de Groix blueschists. *Nature, Lond.* **262**, 276–277.

Carreras, J., Estrada, A. & White, S. 1977. The effects of folding on the *c*-axis fabrics of a quartz mylonite. *Tectonophysics* **39**, 3–24.

Cogné, J., Jeannette, D. & Ruhland, M. 1966. L'Ile de Groix. Etude structurale d'une série métamorphique à glaucophane en Bretagne méridionale. *Bull. Serv. Carte géol. Als. Lorr.* **19**, 41–95.

Cogné, J. 1977. La chaîne hercynienne ouest-européenne correspond elle à un orogène par collision? Propositions pour une interprétation géodynamique globale. In: *Colloque international du C.N.R.S., Géologie de l'Himalaya*. C.N.R.S., Paris, 111–129.

Félix, C. 1972. Etude structuro-minéralogique des pseudomorphes de présumée lawsonite des glaucophanoschistes de l'Ile de Groix (Bretagne, France): considérations sur la possibilité d'une paragénèse à glaucophane et lawsonite. *Annls. Soc. géol. Belgique* **95**, 345–391.

Garcia-Celma, A. 1983. *c*-axis and shape fabrics in quartz mylonites of Cap de Creus (Spain); their properties and development. Unpublished thesis, University of Utrecht.

Heard, H. C. & Carter, N. L. 1968. Experimentally induced "natural" intragranular flow in quartz and quartzites. *Am. J. Sci.* **266**, 1–42.

Lister, G. S. & Price, G. P. 1978. Fabric development in a quartz–feldspar mylonite. *Tectonophysics* **49**, 37–78.

Makanjuola, A. A. & Howie, R. A. 1972. The mineralogy of the glaucophane schists and associated rocks from the Ile de Groix, Brittany, France. *Contr. Miner. Petrol.* **35**, 83–118.

Maluski, H. 1976. Intérèt de la méthode Ar/Ar pour la datation des glaucophanes. Exemple des glaucophanes de l'Ile de Groix (France). *C. r. hebd. Séanc. Acad. Sci., Paris* **283**(D), 223–226.

Mattauer, M. 1974. Existe-t'il des chevauchements de type himalayen dans la chaîne hercynienne du Sud de la France? *4ème Réun. Sci. Terre*, Nancy (edited by Soc. géol. Fr.), 279.

Peucat, J. J. & Cogné, J. 1977. Geochronology of some blueschists from Ile de Groix, France. *Nature, Lond.* **268**, 131–132.

Peucat, J. J., Le Métour, J. & Audren, C. 1978. Arguments géochronologiques en faveur de l'existence d'une double ceinture métamorphique d'âge siluro-dévonien en Bretagne méridionale. *Bull. Soc. géol. Fr.* **20**, 163–167.

Poirier, J. P. & Nicolas, A. 1975. Deformation induced recrystallisation by progressive misorientation of subgrain-boundaries, with special reference to mantle peridotites. *J. Geol.* **83**, 707–720.

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.

Quinquis, H. 1980. Schistes bleus et déformation progressive. Thèse Université de Rennes.

Quinquis, H. & Choukroune, P. 1981. Les schistes bleus de l'Ile de Groix dans la chaîne hercynienne: implications cinématiques. *Bull. Soc. géol. Fr.* **23**, 409–418.

Ters, M. 1979. Les synclinoriums paléozoïques et le Précambrien sur la façade occidentale du Massif Vendéen. Stratigraphie et structure. *Bull. Rech. géol. min. Fr.* 2ème Sér., I, **4**, 293–301.

Triboulet, C. 1974. Les glaucophanites et roches associées de l'Ile de Groix (Morbihan, France): étude minéralogique et pétrogénétique. *Contr. Minér. Pétrol.* **45**, 65–90.

Tullis, J. 1971. Preferred orientations in experimentally deformed quartzites. Unpublished Ph.D. thesis, University of California at Los Angeles.