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FABRIC DEVELOPMENT WITHIN EARLY CADOMIAN SHEAR ZONES: A REINTERPRETATION OF THE 'METASEDIMENT SCREENS' OF WESTERN GUERNSEY, CHANNEL ISLANDS

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At Lihou Island and Vazon Bay on western Guernsey, c. 2000 Ma Icart granite gneiss and c. 700 Ma Perelle foliated quartz diorite are separated by banded, fine-grained, predominantly plagioclase + quartz + biotite rocks previously interpreted as country rock metasediment screens. We demonstrate from field relationships and microtextural evidence that the 'screens' are mylonites derived largely from quartz diorite protoliths in oblique dextral shear zones sited along the Icart granite gneiss-Perelle quartz diorite contacts. Microcracking and low temperature plasticity of plagioclase and hornblende, dynamic recrystallization of alkali feldspar and annealing of quartz and biotite stringers indicate upper greenschist / low amphibolite conditions (brittle-ductile transition) during shear zone development. Mylonite belts record a complex history of ductile and brittle deformation and retrogression of hornblende to biotite. Grain size reduction of feldspar led to an early ductile fabric defined by elongate quartz / feldspar aggregates which was truncated by cataclastic shears and fractures filled with recrystallized mica and quartz / feldspar fragments. Ductile deformation is locally enhanced where biotite and plagioclase have altered to white mica. Fabric elements (L-S) within shear zones and host rocks are similarly orientated. Field and isotopic evidence suggests that the shear zones formed prior to c. 600 Ma, during the late Precambrian Cadomian orogeny.

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INTRODUCTION

The southern and central part of Guernsey is mainly composed of foliated granitic and quartz dioritic rocks collectively termed the Southern Metamorphic Complex by Roach (1957). The dominant rock types are the Icart granite gneiss and the Perelle quartz diorite (Figure 1). The Icart granite gneiss is represented by a foliated megacrystic granite which has yielded a U-Pb zircon age of c. 2000 Ma (Calvez and Vidal, 1978), and is thought to represent a fragment of Proterozoic basement. Recently acquired U-Pb data suggests that the Perelle quartz diorite was emplaced during the early stages of the Cadomian orogeny at c. 700 Ma (Dallmeyer *et al.,* 1991). $^{40}Ar/^{39}Ar$ amphibole cooling ages obtained from the Perelle quartz diorite show that the dominant regional deformation and metamorphism recorded in the Southern Metamorphic Complex occured prior to c. 600 Ma (Dallmeyer *et al.,* 1991). The Southern Metamorphic Complex is intruded by late- to post-tectonic igneous rocks, including the Bon Repos meladiorite, the Vazon dyke swarm and the Northern Igneous Complex (Figure 1; Lees and Roach, 1987; Topley *et al.,* 1990).

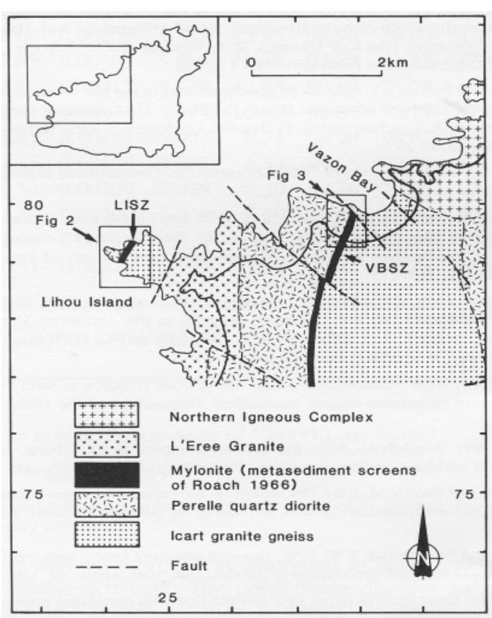

Figure 1: Simplified geological map of north-west Guernsey, showing location of Figures 2 and 3. LISZ, Lihou Island Shear Zone, VBSZ, Vazon Bay Shear Zone.

In Western Guernsey the Icart granite gneiss and the Perelle quartz diorite are separated by c. 50 m wide zones of rocks interpreted by Roach (1957, 1966 & 1977) to be the metasedimentary country rocks into which the precursor to the Icart granite gneiss and the Perelle quartz diorite were intruded (Figure 1). These differ from other metasediments such as those exposed in south-east Guernsey and Sark. We reassess the field relationships and structure at two specific localities (Lihou Island and Vazon *Bay;* Figures 2 and 3), and suggest that the rocks previously interpreted as metasediments are mylonites derived largely from a quartz diorite protolith in oblique dextral shear zones, formed during Cadomian regional deformation.

ICART GRANITE GNEISS

The Icart granite gneiss in western Guernsey is typically represented by a deformed megacrystic granite which displays a single, steeply dipping, north-north-east-south-south-west striking mylonitic fabric. This fabric is defined by elongation of megacrystic K-feldspar porphyroclasts, enhanced by sub-parallel elongate aggregates of recrystallized quartz and feldspar and micaceous foliae. A variably developed lineation is defined by quartz / feldspar aggregates and plunges gently to the south-south-west. A variety of kinematic indicators, including asymmetric porphyroclasts and shear bands (Simpson and Schmid, 1983), demonstrate that the main fabric in the Icart granite gneiss formed as a result of dextral simple shear.

PERELLE QUARTZ DIORITE

The Perelle quartz diorite consists of plagioclase (50 to 60%), quartz (10 to 20%), hornblende (10 to 20%) and variable amounts of biotite and

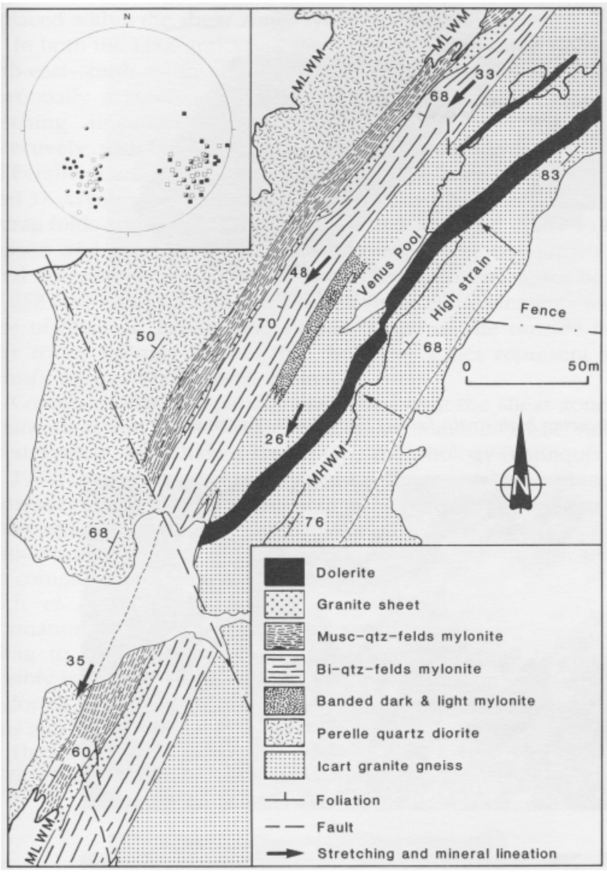

Figure 2: Detailed geology of Lihou Island Shear Zone, with structural data plotted on stereonet in inset (circles represent plunges of stretching lineations: open circles, Perelle quartz diorite, half circles, Icart granite gneiss, filled circles, mylonite; squares represent poles to foliation: open squares, Perelle quartz diorite, half squares, mylonite, filled squares, Icart granite gneiss).

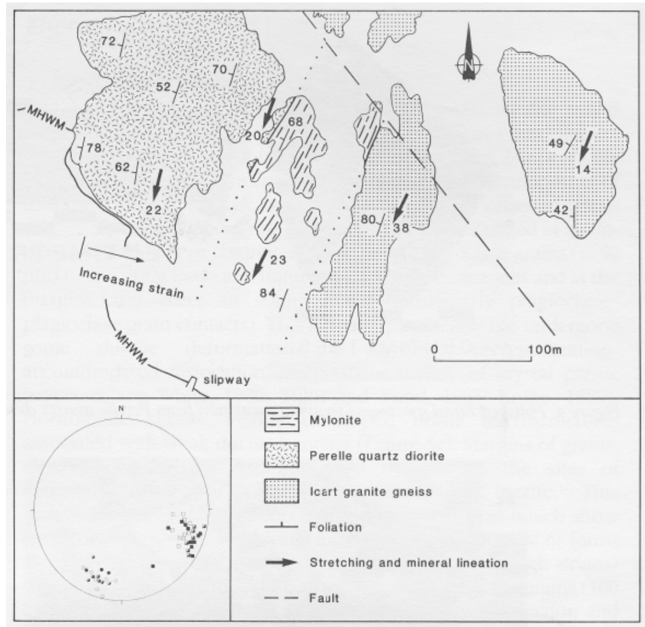

Figure 3: Detailed geology of Vazon Bay Shear Zone as exposed on foreshore at the west end of Vazon Bay. Stereonet symbols as in Figure 2. Vazon dykes and other minor intrusions omitted.

chlorite (0 to 20%) with minor accessories. Microdioritic enclaves are common. Also present are rare enclaves of amphibolite and a foliated, fine grained (300 µm) equigranular lithology consisting of plagioclase + quartz + biotite, interpreted here to represent metasediment. We have not observed any enclaves of Icart granite gneiss. The Perelle quartz diorite contains a single penetrative deformation fabric which is defined by quartz / feldspar aggregates and aligned mafic minerals. This fabric generally steepens toward the mutual contacts with the Icart granite gneiss. The planar and linear components of this fabric are subparallel to those in the Icart granite gneiss. This concordance of fabric elements has been interpreted by successive authors as indicating that the Icart granite gneiss and Perelle quartz diorite were deformed during the same regional event (Roach, 1966, 1977; Roach *et al.,* 1991; Dallmeyer *et al.,* 1991).

In contrast to the Icart granite gneiss, the Perelle quartz diorite preserves relict igneous textures in areas of low tectonic strain. (Power *et al.,* 1990; Dallmeyer *et al.,* 1991). Although there may be a magmatic (i.e. pre-full crystallization) alignment of plagioclase and hornblende laths (Figure 5A), the dominant petrographic features are consistent with pervasive crystal plastic strain (nomenclature of Hutton, 1988) during post-solidification deformation of the quartz diorite (see also Roach, 1957; Power *et al.,* 1990; Dallmeyer *et al.,* 1991, 1992).

CONTACT ZONES

At Lihou Island and Vazon Bay the Icart granite gneiss and Perelle quartz diorite are separated by c. 50 m wide belts of a dark, fine-grained and banded lithology, composed predominantly of plagioclase, quartz and biotite, and interpreted by Roach (1957, 1966) to be of metasedimentary origin (Figures 1, 2 & 3). Contacts between the Icartian granite and the 'metasediments' are sharp. In contrast, the contacts between the Perelle quartz diorite and the 'metasediments' are gradational and interpreted by Roach (1957, 1966) to result from lit-par-lit injection of quartz diorite into metasediment. Our observations lead us to conclude that the 'metasediments' are in fact mylonites, and that these formed during intense deformation and recrystallization of the Perelle quartz diorite within two shear zones (Lihou Island Shear Zone, LISZ and Vazon Bay Shear Zone, VBSZ) located along the mutual contacts between the Icart granite gneiss and the Perelle quartz diorite (Figure 1). Although we describe two spatially separate shear zones they may represent the same shear zone displaced during subsequent faulting.

Field relationships

The margins of the shear zones are defined by the incoming of high strain fabrics, approximately 50 to 200 m west and east of the mylonite belts. As the shear zones are approached, the Icart granite gneiss progressively develops a penetrative, platy mylonitic fabric (the `banded marginal facies' of Roach, 1957) defined by extreme elongation of porphyroclastic feldspar augen and quartz/feldspar aggregates (Figure 7). Locally, light coloured aplitic veins and plagioclase rich, dark bands and lenses lie within the foliation. Similarly, the fabric in the Perelle quartz diorite intensifies towards the shear zones (Figure 4). An increase in the elongation of dioritic enclaves demonstrates the progressive increase in strain towards the shear zones. Deformation is increasingly partitioned into cm to dm wide high- and low-strain bands which are particularly well developed and become more numerous within 10 to 20 m of the mylonite zones. The fabric is defined by progressively finer-grained, tightly-packed ovoid plagioclase and elongate stringers of quartz and mafic aggregates (Figure 4), occasionally defining a prominent stretching lineation. At both Lihou Island and Vazon Bay the Perelle quartz diorite grades over a distance of up to 4 m into a dark, fine-grained, banded mylonite. The mylonitic foliation is defined by elongate quartz / feldspar and micaceous aggregates which enclose plagioclase porphyroclasts (Figures 4 and 6). Localised areas of finer grained mylonite are inferred to represent zones of more intense strain. Variably deformed and concordant, mm to dm thick granitic lenses and sheets are common within the mylonites (Figure 2). Their apparent restriction to the mylonite belts and the heterogeneous nature of the fabrics within them, suggests that they may have been

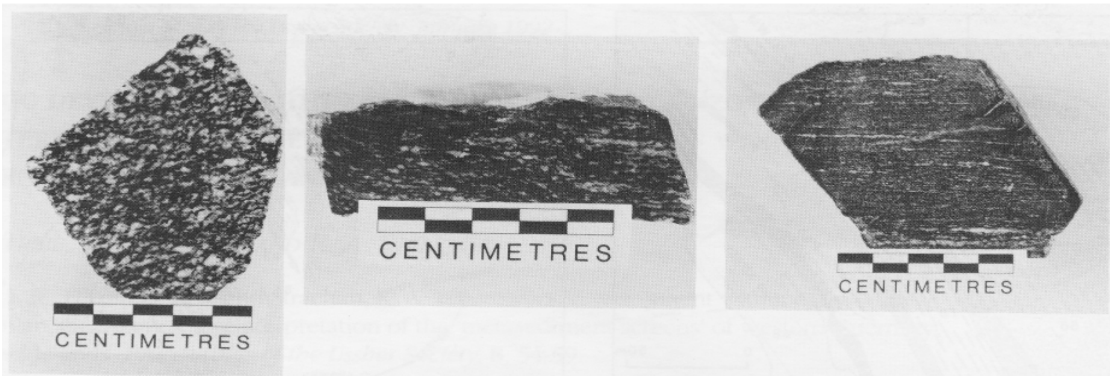

Figure 4: Polished hand specimens showing transition from Perelle quartz diorite showing high strain fabrics to mylonite, Vazon Bay.

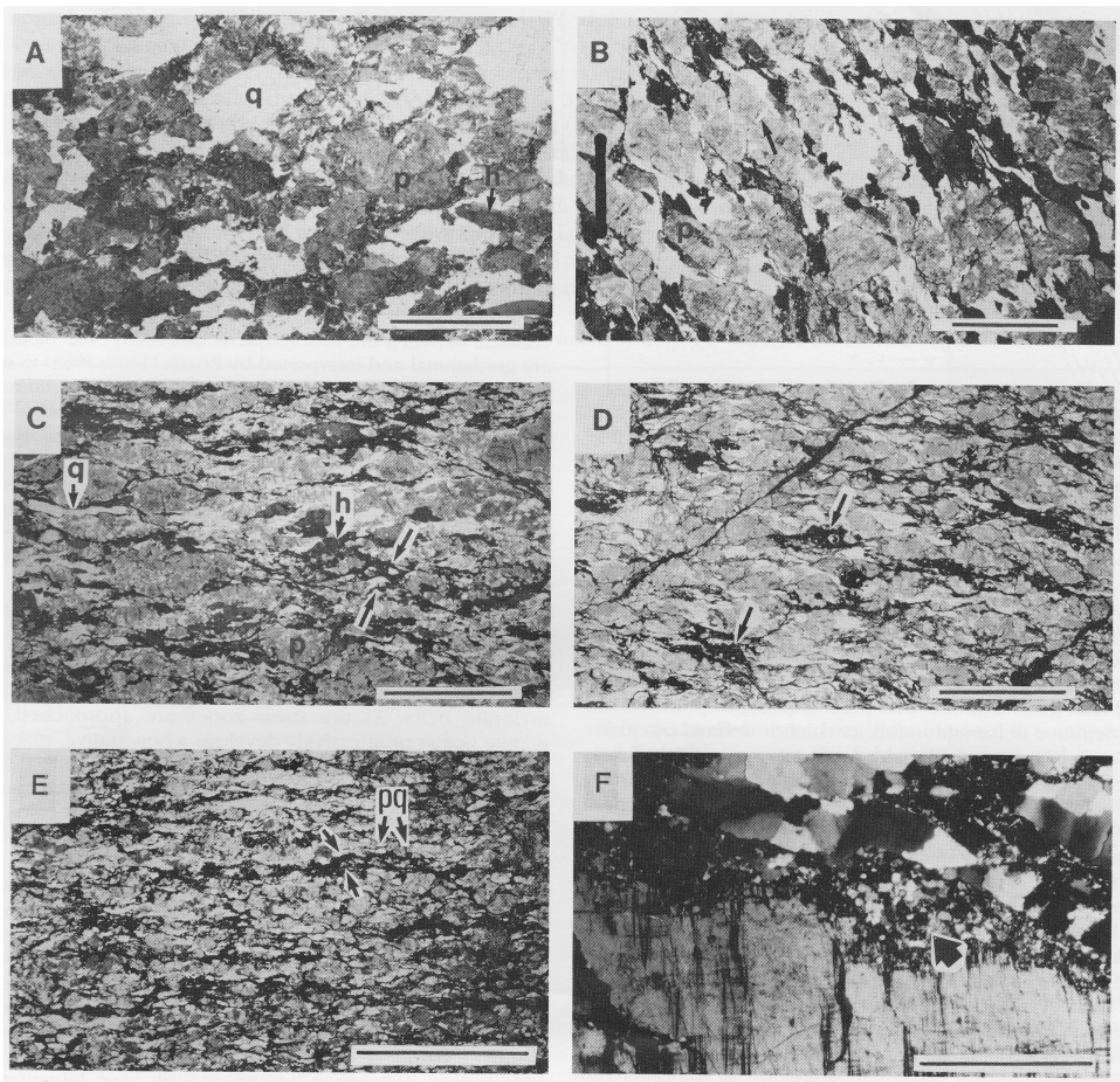

Figure 5. Transition from Perelle quartz diorite to mylonite. p = variably sericitised plagioclase, h = hornblende, q = quartz. All scale bars 5mm except F = 1mm. a-e in PPL; f in XPL. A) Low strain sample; fabric defined by weakly aligned subhedral plagioclase and hornblende laths and elliptical quartz aggregates; B) Brittle-ductile fabric within shear zones; quartz has undergone ductile deformation and recovery and aggregates are more elongate. Ovoid plagioclase show brittle microcracks developed at consistently high angles to the foliation (e.g. arrow, crack filled with quartz). C) High strain quartz diorite, fabric defined by stringers of mafic and quartz (q) aggregates and tightly packed plagioclase augen. Quartz and feldspar fragments occur within biotite filled intergranular cataclastic shears (between arrows). D) Transition zone; hornblende showing advanced recrystallization to biotite and/or chlorite (arrows). E) Within mylonite zones; hornblende is absent; grain-size reduction of plagioclase has led to an early ductile fabric defined by stringers of quartz/plagioclase aggregates (pq) which are truncated by inter and transgranular cataclastic shears and fractures filled with biotite aggregates and quartz/plagioclase fragments (arrows). F) Ductile deformation of alkali feldspar within Icart granite gneiss; c. 50 μm dynamically recrystallized grains (arrow) have developed around the margins of an alkali, feldspar augen which is wrapped by stringers of quartz aggregates.

emplaced within the shear zones syn-tectonically.

In both the LISZ and VBSZ the mylonite zones carry a north-north-east-south-south-west striking west-dipping foliation and occasionally a south-south-west gentle to moderately plunging stretching lineation. These are co-parallel and colinear, respectively, with fabrics measured in both the Icart granite gneiss and Perelle quartz diorite outside the mylonite zones (see Figures 2 and 3). Asymmetric porphyroclasts, shear bands, vergence sense on drag folds and S-C fabrics (Figures 6 and 7; Berthé *et al.,* 1979; Simpson and Schmid, 1983) indicate a consistent oblique right lateral sense of shear, parallel to the stretching lineation, for both the LISZ and VBSZ. The concordance of these fabric elements with those of the Icart granite and Perelle quartz diorite outside the shear zones strongly implies that the shear zones represent an intensification of the regional strain field.

Complex folds are spatially associated with the shear zones. Granitic veins and the mylonitic foliation are sometimes isoclinally folded. Locally, these have a sheath-type morphology (Quinquis *et al.* 1978), with strongly curvilinear hinges which plunge subparallel to the stretching lineation in the mylonites. Moderately north-north-east-plunging drag folds verge east and fold the foliation and lineation (and Icart granite contact at Lihou Island). This complexity of folding was interpreted by Roach (1966) and Roach *et al.* (1991) to reflect a prolonged and polyphase deformation history. However, the restriction of this complex folding to the shear zones suggests that they may be more plausibly interpreted as polyphase syn-mylonitization folds which developed progressively during a single deformation event (cf. Evans and White, 1984).

The VBSZ is intruded by members of the Cadomian Vazon dyke swarm (cf. Lees and Roach, 1987; Roach *et al.,* 1991).

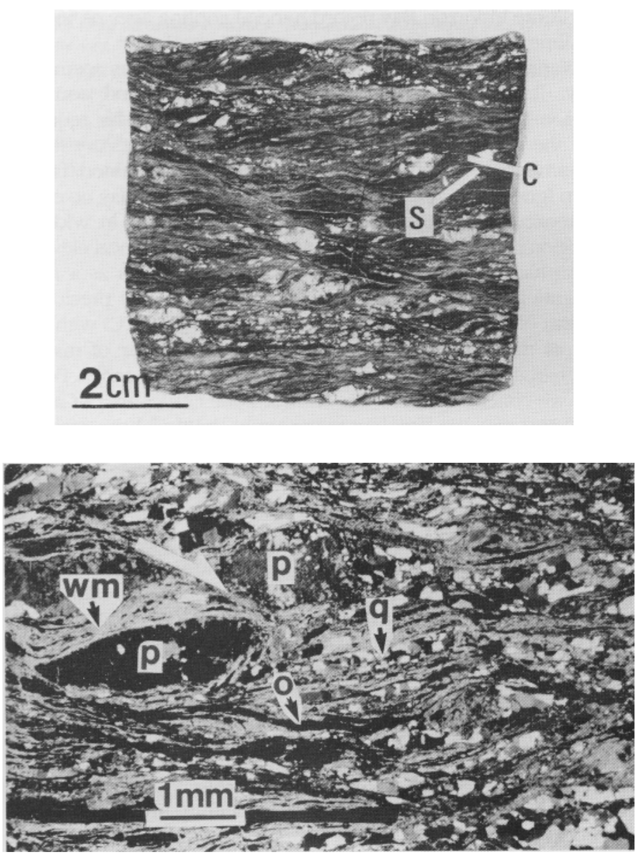

Figure 6. Hand specimen and XPL photomicrograph of white mica rich mylonites derived from the Perelle quartz diorite within the LISZ. S-C fabric suggests an oblique right-lateral sense of shear. Plagioclase porphyroclasts (p) have been recrystallized to white mica probably due to fluid-rock interaction within shear zones. Ductile fabric defined by alternating opaque (o) and recrystallized quartz (q) and white mica (wm) stringers.

Microstructures

1) Perelle quartz diorite

With increasing strain within the shear zones, ovoid, weakly zoned plagioclase becomes progressively finer-grained (9 to 1 mm) (Figure 5) and shows evidence for intracrystalline deformation. Minor ductile bending (undulose extinction) is post-dated by the development of dilatant brittle microcracks which show little or no offset of grains (Figure 5b). These cracks may be healed with recrystallized or strainfree quartz, biotite or chlorite. Recrystallized plagioclase grains (c. 50 μm) occur along intra- and transgranular microshear zones and at the margins and cores of some grains (particularly plagioclase-plagioclase grain contacts). This suggests plagioclase has undergone some ductile deformation by dynamic recrystallization-accommodated dislocation creep (for a review of crystal plastic processes see White, 1976; Tullis and Yund, 1985; Knipe, 1989). Hornblende shows weakly developed brittle microstructures associated with weak ductile bending (Figure 5c). Margins of grains, cleavage planes and strain-induced defects are the sites of recrystallization to actinolitic amphibole or biotite. This recrystallization is more pronounced in quartz diorites which show strong fabrics. Quartz is typically located in strain shadows or forms elongate stringers of grains (up to 15:1 aspect ratios at high strains) which wrap around plagioclase augen (Figure 5c). Quartz grains (100 to 500 μm) are equigranular, show weak, undulose extinction and straight to weakly crenulate grain boundaries with common triple junctions. Recrystallized biotite laths (<100 μm) occur in discrete elongate aggregates of decussate laths and fill c. 300 μm anastomosing intercrystalline fractures (Figure 5c). These fractures and aggregates are the focus for cataclasis of plagioclase, hornblende and quartz: angular fragments of these minerals occur surrounded by biotite aggregates (Figure 5c). The contrast of microstructures in quartz and biotite at high and low strains suggests that both have undergone ductile deformation primarily by recovery-accommodated dislocation creep (cf. D'Lemos, 1987).

2) Perelle quartz diorite to mylonite

The transition from highly strained quartz diorite to mylonite is characterized by changes in both composition and texture (Figure 5c,d,e). Hornblende is retrogressed to biotite and/or chlorite (Figures 5d,e), and mylonites show a small increase (c. 7%) in quartz content possibly due in part to the formation of biotite and quartz during retrogression. The mylonites consist mainly of 40 to 50% plagioclase (c. An_{33}), 20 to 30% quartz and 25 to 30% brown/tan biotite with accessory alkali feldspar, chlorite, opaques, apatite, green biotite, zircon, actinolite and rare garnet and andalusite. The fabric is defined by round to oval plagioclase grains (150 to 1000 μm) and larger (mm) porphyroclasts set in, and wrapped by, quartz stringers (Figure 5e). The quartz stringers exhibit similar microstructures to those in the highly strained Perelle quartz diorite except that they generally exhibit greater aspect ratios. Trans- and inter-crystalline <50 μm wide shears and fractures filled with recrystallized biotite laths form anastomosing aggregates parallel to and cross-cutting the quartz / feldspar aggregates (Figure 5e). These shears truncate recrystallized quartz grains suggesting that quartz had annealed prior to cataclasis.

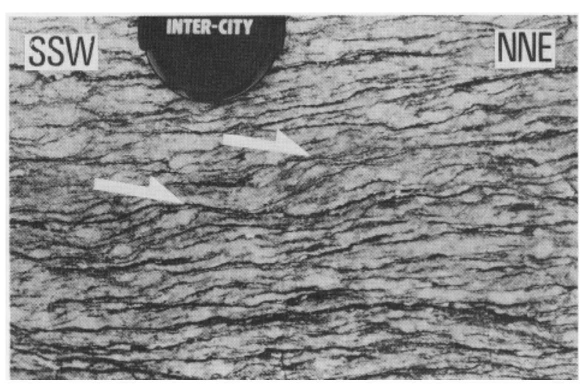

Figure 7: Down-dip view of mylonitic Icart granite gneiss within LISZ. Shear bands indicate an oblique right-lateral sense of shear. Lens cap diameter = 5cm.

Recrystallization of plagioclase to form a mosaic of fine (<60 µm) grains is locally common. This recrystallization is concentrated around margins of grains or along intra-crystalline microshears suggesting local ductile deformation by dynamic recrystallization-accommodated dislocation creep and the new grains are often associated with biotite forming an annealed groundmass of very fine (<20 µm) grains. mm to cm thick granitic veins which are elongate along the foliation introduce alkali feldspar into the mylonites.

Narrow bands (c. 1000 µm) of brittle deformation cut the earlier fabrics. They consist of sub-angular to round fragments of quartz and feldspar set in a very fine groundmass of recrystallized biotite, quartz and feldspar [referred to as `bands of granulation' by Roach (1957) p.35].

At Lihou Island on the west side of a prominent 4 to 5 m wide foliated granite dyke a muscovite-rich mylonitic lithology occurs (Figures 2 and 6). Recrystallized quartz stringers, sometimes only 1 grain wide but several grains long, alternate with 50 to 500 µm thick bands of extremely fine (<20 µm) white mica laths which contain elongate trails of opaques (Figure 6). Quartz aggregate / mica foliae contacts were sites for dissolution of quartz which has produced stringers of oblong shaped quartz grains. Plagioclase occurs as *c*.mm sized porphyroclasts which are variably pseudomorphed by white mica and may have pressure shadows of quartz.

3) Icart granite gneiss mylonites

With increasing strain within the shear zones quartz displays all transitions between undulose extinction, deformation bands, formation of subgrains and recrystallization to new grains. Sericitised plagioclase aggregates are elongate. Alkali feldspar augen may show undulose extinction, brittle microcracks and recrystallization to fine (c. 50 µm) feldspar grains around margins of grains (Figure 50 and along intra-crystalline shears and fractures. Thin, anastomosing inter-and trans-crystalline foliae comprising white mica, biotite and accessory chlorite and apatite are subparallel to the quartz / feldspar aggregates and form the focus for local cataclasis. These microstructures suggest dominantly ductile deformation of quartz and alkali feldspar with local brittle failure in alkali feldspar and along mica-filled shears and fractures.

4) Late cataclastic rocks

Locally north-south trending mm to dm thick dark cataclastic bands truncate the main fabrics in both the Icart granite gneiss and the Perelle quartz diorite. These bands comprise fragments of altered feldspar and quartz, and metamorphic chlorite and actinolite. This implies that cataclasis probably occurred within the lower greenschist facies (cf. Wang, 1987).

DISCUSSION

Conditions of formation of the shear zones

Contrasting mineralogical response to deformation (low temperature plasticity and brittle fracturing of hornblende and plagioclase contemporaneous with ductile deformation and annealing of quartz and biotite, dynamic recrystallization of alkali feldspar and incipient plagioclase recrystallization) suggests that fabric development occurred under brittle-ductile conditions (Simpson, 1985). It has been recognised that plagioclase (Simpson, 1985; Tullis and Yund, 1987) and amphibole (Brodie and Rutter, 1985) grains are relatively strong and resistant to ductile deformation in rocks at greenschist to mid-amphibolite facies especially in the presence of minerals with a weaker theology such as quartz and mica. With the onset of amphibolite facies conditions dynamic recrystallization occurs in plagioclase (Simpson, 1985; Tullis and Yund, 1987) but is already common in alkali feldspar (Simpson, 1985). Additionally, the presence of hornblende recrystallizing to actinolite or biotite and the occurrence of white mica mylonites within the LISZ and VBSZ suggests that the dominant fabrics formed under upper greenschist/low amphibolite facies conditions.

Fabric development

The sequence of events that has affected the Perelle quartz diorite during formation of the mylonites appears to have commenced with grain-size reduction of plagioclase by fracturing and rounding dissolution. Within shear zones retrogression of hornblende to biotite (and plagioclase to white mica in parts of the LISZ) by incoming fluids may have promoted weakening of the rock (cf. White and Knipe, 1978; Simpson, 1986; Tobisch *et al.,* 1991). A switch from brittle-ductile to more ductile deformation has been enhanced and focussed within quartz and the finer-grained feldspar matrix. The quartz aggregates annealed prior to the formation of sub-parallel and cross-cutting cataclastic shears and fractures filled with recrystallized biotite. Further brittle deformation was concentrated in narrow zones along the pre-existing mylonitic foliation. Within these bands dynamic recrystallization in all minerals suggests a transfer to ductile deformation (cf. brittle-to-ductile shear bands; Simpson, 1986). Rare garnets locally overgrow the fabric and suggest that metamorphic mineral growth outlasted deformation within the mylonite belts.

Age of the shear zones

The following field and isotopic evidence indicates that the shear zones formed during the late Precambrian Cadomian orogeny: a) The complete concordance of L-S fabrics and coeval kinematic indicators recorded in the shear zone mylonites and host rocks suggests that the shear zones result from the focussing and intensification of regional Cadomian strain. Mineral cooling ages obtained from the Perelle quartz diorite demonstrate that regional Cadomian deformation predated c. 600 Ma (Dallmeyer *et al.,* 1991), b) the VBSZ is intruded by members of the Vazon dyke swarm. Amphiboles within two Vazon dykes which intrude the Perelle quartz diorite in Vazon Bay record mineral cooling ages of 560 to 550 Ma (Dallmeyer *et al.,* 1992).

A Variscan (Carboniferous) age for the shear zones seems highly unlikely. Renewed Palaeozoic crustal thickening and consequent depression of Guernsey to mid-crustal levels would be required to achieve the elevated temperatures and pressures necessary for shear zone formation. $^{40}Ar/^{39}Ar$ mineral age spectra obtained from the Northern Igneous Complex and Vazon dyke swarm display no evidence for Palaeozoic reheating, which would have resulted in widespread rejuvenation of argon systems (Dallmeyer *et al.,* 1992). Local elevation of metamorphic conditions may occur along shear zones as a result of shear heating but theoretical modelling (Reitan, 1968) precludes the generation of significant temperature differences (>100°C) within shear zones less than c. 2 km across-more than an order of magnitude greater than the width of the western Guernsey shear zones. For these reasons we conclude that the main shear zone fabrics are of Cadomian (pre-600 Ma) age; the late, low temperature, brittle fabrics recorded in the shear zones may be of either late Cadomian or Variscan age.

CONCLUSIONS

Field evidence indicates that the Icart granite gneiss and Perelle quartz diorite are separated at Lihou Island and Vazon Bay by *c.* 100 m wide zones of mylonite situated within oblique dextral shear zones. The fine grained, dark rocks which occupy the central parts of these shear zones, formerly considered to be metasedimentary country rocks to the Icart granite gneiss (Roach, 1957), are most reasonably reinterpreted as mylonites derived **largely** from quartz diorite and granite protoliths, although we cannot preclude absolutely the occurrence of some metasedimentary material within these mylonite belts. Shear zone development occurred within the brittle-ductile transition, i.e. upper greenschist to low amphibolite facies conditions. Fabric development within mylonite belts is complex and characterized by retrogressive metamorphism and interactive ductile and brittle deformation processes. The shear zones may represent the focussing and intensification of regional Cadomian strain during deformation prior to c. 600 Ma. Many fine grained dark rocks in similar tectonic settings may be mistaken for metasediments. A close examination of field and microstructure characteristics may help to resolve the true origin of such rocks.

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