THE GEOLOGY OF THE MORLAIX – ST MICHEL-EN-GREVE REGION,
N.W. BRITTANY, FRANCE

Vol II

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VOLUME 2

CHAPTERS 5 - 8

APPENDICES

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CHAPTER FIVE

THE LOCQUIREC SHEAR BELT

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(A) INTRODUCTION

(1) DEFINITION OF THE LOCQUIREC SHEAR BELT

The Locquirec Shear Belt is defined here as a large ductile shear zone that extends from the Locquirec area northeastwards to the Pte. de Séhar (Map 2). The rocks that lie within the shear belt are mylonites which, although variable in aspect, are considered to be derived, for the most part, from a granodioritic porphyry marginal facies of the Moulin de la Rive Orthogneiss Complex, and to a lesser extent from basic metavolcanic rocks of the adjacent Formation de Pte. de l'Armorique. The Locquirec Shear Belt (hereafter termed the LSB) is considered to be part of a major shear zone system in the Trégor and Petit Trégor regions of NW Brittany.

(2) LOCATION OF THE LOCQUIREC SHEAR BELT

The western boundary of the LSB with the Moulin de la Rive Orthogneiss Complex in the Locquirec area is taken to be some 200 m southeast of the Pte. du Corbeau (GR 1599 1266), and in the Pte. de Séhar region along the north side of the point (Map 2). A marked swing in the LSB is apparent as the shear belt is followed across the Grève-de-St. Michel.

The eastern boundary of the shear belt in the Locquirec area occurs at Toul Ar Goué (GR 1585 1263), in the southwest corner of the Baie de Locquirec, where granitoid mylonites are in contact with highly deformed metavolcanics and metasediments of the Brioverian Formation de Pte. de l'Armorique. The boundary at Toul Ar Goué has been described in Chapter 3, part (D).

The continuation inland of the LSB in a south-westerly direction is poorly defined due to the lack of exposure. Beyond the area mapped in this thesis, mylonitic rocks extend eastwards from the Pte. de Séhar region, possibly as far as Pors Éven, near Paimpol. Mylonitic rocks have been encountered along the estuaries of the River Jaudy at Tréguier and the River Trieux at Lézardrieux, and it seems probable that the LSB continues eastwards as a shear zone, here termed the Trégor Shear Belt (TSB). Work in progress by the author and R.A. Roach indicates that the TSB is developed at the southern margin of the Perros-Guirec Granitoid Complex (Fig. 5:36). In the Locquémeau-Trédrez area east of Pte. de Séhar, the LSB is truncated by the Hercynian Granite de Trédrez (Fig. 5:1).

(3) RELATIONSHIP OF THE LOCQUIREC SHEAR BELT LITHOLOGIES TO ADJACENT UNITS

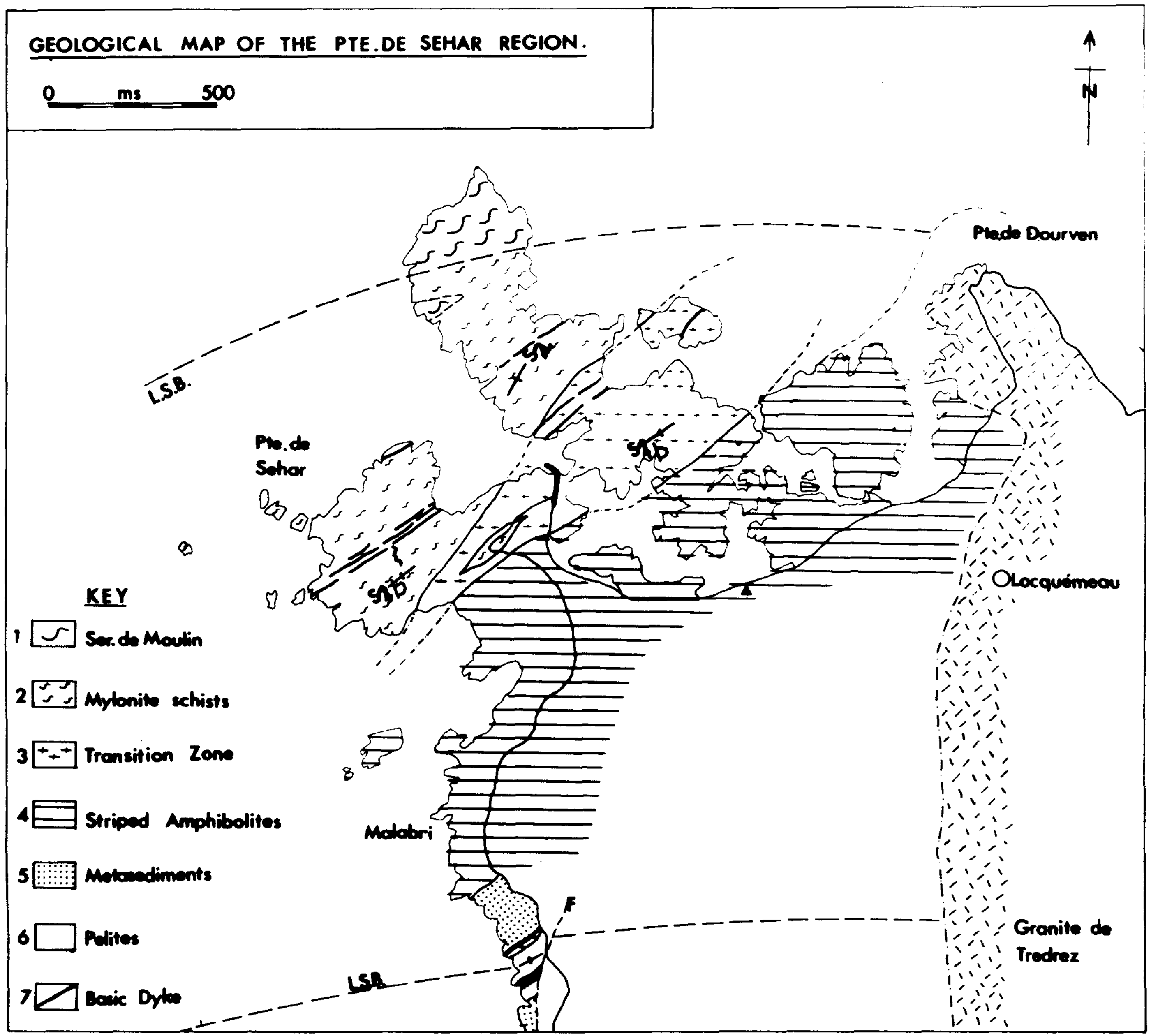
Four localities are cited that indicate the true nature of the LSB and its relationship to surrounding units. At the Pte. du Corbeau and the northern Pte. de Séhar area granitoid mylonitic rocks of the LSB pass gradationally northwestwards and northwards respectively into lithologies of the Moulin de la Rive Orthogneiss Complex. In the boundary area just east of the Pte. du Corbeau the granite and porphyritic microgranite components of the orthogneiss complex are increasingly heterogeneously deformed, with the development of mylonitic banding and a schistosity towards the boundary of the LSB (Fig. 5:15).

A number of shear zones have been recognized within the Moulin de la Rive Orthogneiss Complex (see Chapter 4, part (B) and (C)) and all are characterized by the presence of schistose mylonites derived from the various components of the complex. The LSB is the largest of these shear zones and is approximately 1.5 km wide (Fig. 4:17).

There is a preserved intrusive boundary relationship between the mylonitized granitoid lithologies of the LSB and the metasedimentary

Fig. 5:1 Geological map of the Pointe de Sehar area

Erratum: For Ser. de Moulin read Moulin de la Rive Orthogneiss Complex



GEOLOGICAL MAP OF THE PTE. DE SEHAR REGION.
0 ms 500
N
Pte.de Dourven
L.S.B.
Pte. de Sehar
Locquémeau
KEY
1 Ser. de Moulin
2 Mylonite schists
3 Transition Zone
4 Striped Amphibolites
5 Metasediments
6 Pelites
7 Basic Dyke
Malabri
F
Granite de Tredrez
L.S.B.

and basic metavolcanic rocks of the Brioverian Supergroup in the Toul Ar Goué area in the southwest corner of the Baie de Locquirec. Here, the boundary is located near to the southeast margin of the LSB where it is highly deformed. This boundary is discussed in more detail in Chapter 3, part (D).

The fourth locality cited is in the area of Malabri (GR 1645 1305), south of the Pte. de Séhar (Fig. 5:1). Here, within a sequence of basic metavolcanic rocks of the Formation de Pte. de l'Armorique, an increase in deformation can be observed northwards towards the boundary of the LSB. This formation is deformed in narrow shear zones which increase in frequency towards the boundary.

The Granite de Trédrez, which has yielded a K/Ar biotite age of 320 ± 10 m.y. and a Rb/Sr whole rock age of 300 ± 10 m.y. (Leutwein et al. 1968), has contact metamorphosed the Brioverian formations and the lithologies of the LSB in the Pte. de Séhar to Beg Ar Forn area and largely masks earlier metamorphic assemblages and fabrics. The development of millimetric and centimetric scale striped amphibolites (the contact metamorphosed equivalents of earlier striped/segregated greenschists, described in Chapter 3) is increasingly apparent towards Malabri from Beg Ar Naon (GR 1658 1279). To the south of this locality metasediments occur interbanded with metavolcanic lithologies.

The striped amphibolites of the Malabri-Pte. de Séhar section are described in part (B). Within the LSB these are in contact with granitoid mylonites and there is some evidence to suggest that these rocks were emplaced by sheet injection into the metabasic host prior to the formation of the mylonites and striped amphibolites.

(4) PREVIOUS LITERATURE CONCERNING THE LITHOLOGIES OF THE LOCQUIREC-PTE. DE SÉHAR AREA.

There has been much literature published concerning the geology of the Locquirec area and an extensive terminology for the various lithological units has been proposed. The terminology proposed by several previous authors and that used in this thesis is given in Table 4:1. A completely new interpretation for the relationship of the two major lithological units is proposed here based on the recognition of mylonites within the LSB.

Until recently the rocks that lay to the east of the Pte. du Corbeau were considered as a sequence of tuffs, and their reworked volcaniclastic equivalents, interbedded with epiclastic sediments. Barrois (1908c) correlated the LSB lithologies (his Tufs de Brélévenez) with lithologically similar rocks occurring in the Tréguier-Paimpol area, known as the Orthophyres et Tufs de Tréguier, which he considered to be largely of mixed volcanic and sedimentary origin (Barrois 1908b). Barrois (1908c) pointed to the occurrence in the Locquirec area of 'poudingues' (conglomerates in English) at, what he considered to be, the base of the sequence as support for its supracrustal origin. Other evidence cited in support of a mixed epiclastic-volcanic origin was the recognition of primary bedding and the presence of fragmented feldspars. Barrois writes (op. cit. p. 209) "Leur origine tuffacée est indiquée par leur gisement en lits alternants avec les poudingues de Locquirec, et par leur composition qui est celle de porphyrites (Guilben); les glandules de plagioclase sont les débris des phenocristaux des porphyrites..."

Sandrea (1958) described the Chloritischistes à Albite (Locquirec) as sodic tuffs, with the presence of common albite porphyroblasts attributed to metasomatic growth. Delattre et al. (1966) describe the Chloritoschistes à Albite de Locquirec (see Table 4:1) as consisting of bands of heterogeneous material that constitute a purely sedimentary assemblage and did not accept the presence of tuffs as implied in Barrois (1908b) description. Delattre et al. (1952, p. 47) describe "schistes cristallophylliens d'allure gneissique, sericitoschistes franes, chloritoschistes purs, schistes amphiboliques, grés phylliteux" and a "conglomerate a ciment schisteux".

The most detailed account to date of the Moulin de la Rive Orthogneiss Complex and the rocks of the LSB is that of Verdier (1968). His stratigraphical work can be seen to be influenced by that of Cogné (1959) in other parts of northern Brittany. Verdier (op. cit.) recognised a Lower Proterozoic basement, represented by the Gneiss de Moulin de la Rive, unconformably overlain by a Brioverian cover sequence of sediments (including poudingues) and acidic volcanics (described as porphyroids and interpreted as reworked crystal tuffs), which Verdier (op. cit.) termed the Series de Locquirec (Table 4:1). These pass conformably upwards into the basic volcanics of the Formation de Pte. de l'Armorique of this thesis. Verdier (op. cit. p. 12) described the boundary between the Pentevrian basement gneisses and Brioverian cover as a "zone de passage" which is located on the east side of the Pte. du Corbeau. Auvray's boundary is co-incident with the boundary of the LSB as described in this thesis. He described (op. cit. p. 13) the boundary in the following way:- "La pointe du Corbeau est constituée d'orthogneiss et granodiorites relativement massifs. Sur quelques dizaines de mètres vers l'Est ceux-ci présentent des traces d'altérations ou d'arénitisations anciennes conservant des blocs ou boules restés intacts, dans une masse microfissurée et altérée, mais reconsolidée maintenant par recrystallisation. On passe de facon très floue et progressive à des ardènes remaniées (arkoses) de plus en plus fines, auxquelles se mêlent des passées "porphyroides" de facies encore filonien (Pors Villiec). Ce passage très progressif entre socle cristallin ancien et couverture arkosienne efface toute trace évidente de discordance entre les deux ensembles. Ce sont les conditions memes dans lesquelles se font les relations Pentévrien-Briovérien decrites par J. COGNÉ (1959a) à Jospinet, en baie de Saint-Brieuc".

This has been translated as:-

"The Pte. du Corbeau is made up of relatively massive orthogneisses and granodiorites. For some tens of metres towards the east the rocks present show traces of alteration or arenitization with blocks or balls preserved intact within the altered matrix, reconsolidated through recrystallization. They pass in a blurred, progressive fashion into reworked sands (arkoses) which get finer and finer, and pass into "porphyroides" which are again veined (Pors Villiec). This very progressive transition between the ancient crystalline basement and the arkose cover obliterates all trace of the discordance between the two assemblages. These are the same conditions to that which make up the Brioverian-Pentevrian relations at Jospinet, Baie de St. Brieuc, described by Cogné (1959a)".

Verdier (op. cit.) believed that the porphyroides of the series de Locquirec were of volcanic origin and that a characteristic feature was the presence of albite in these pyroclastic rocks. Associated with the pyroclastic rocks are sedimentary rocks, the origin of which he says is "incontestable" and he envisaged a sodic volcanic (keratophyric) source for the reworked material. The Series de Locquirec he attributes to the lowermost Brioverian, and the series is placed in the same geological relationship to that described by Cogné (op. cit.) at Jospinet, Baie de St. Brieuc, where Pentevrian basement gneisses are overlain by a Brioverian cover of metamorphosed sediments and basic volcanics.

Cogné (1972) correlated the Étage de Locquirec (with its conglomerates) with the Étage de Cesson (also with conglomerates) which crop out near St. Brieuc and placed this series at the base of the Brioverian. Cogné's stratigraphy envisaged the conglomerates interbedded with other epiclastic and pyroclastic rocks which were overlain in turn by a thick sequence of spilitic lavas and pillow-lavas. The sequence was deposited upon a Pentevrian basement.

Auvray (1979) assigned the Tufs de Locquirec and equivalent Tufs de Tréguier to the Middle Brioverian. This correlation was based on the interpretation of a rather poorly-defined 665 m.y. Rb/Sr isochron obtained for the Granodiorite de Talberg, the Granite de Pomelin-Bréhat and the Granite de Port-Blanc of the Perros-Guirec Granitoid Complex of the Trégor. The Granodiorite de Talberg was correlated with the Granodiorite de Beg An Forn which truncates the Brioverian formations in the Baie de Lannion area (discussed in Chapter 3, part D).

The evidence that Auvray (op. cit.) uses for the tuffs being of volcanic/volcaniclastic origin is largely microscopic; he states (Auvray op. cit. p. 111), "la nature tufaceé est un caractère evident et constante dans toute la formation, il est conservé malgré le developpement plus ou moins important de la schistosité". Auvray also points to the existence of phenocrysts and angular fragmented phenocrysts as being characteristic of a pyroclastic rock.

In an attempt to resolve the relative age of formations within the Brioverian Supergroup Autran et al. (1979) proposed a lithostratigraphy for the Baie de Lannion region (Table 3:2). Their ideas largely follow those of Verdier (1968) whereby a gneissose basement (Icartian in their terminology) is overlain by a volcaniclastic cover, termed the Formation de Locquirec, which they consider to be of Lower Brioverian age. Within this formation Autran et al. (op. cit. p. 279) have recognised "trois unites à caractere volcaniclastique plus on moins marqué". They consider the conglomerates previously recognised by other authors, to be composed of pebbles of orthogneiss within a volcanic detritus matrix, and classify rocks in the Men Brein area (GR 1568 1229) as being composed of (p. 279) "siltite micacée et de wacke quartzeuse à subfeldspathique (in the scheme of Dott 1964)". They also recognise basic horizons within a dominantly keratophyric succession.

Dixon (1982) was the first to formally describe lithologies in the Locquirec area as being mylonites and he has discussed deformation mechanisms within the mylonites. Others have previously discussed the mylonitic origin of these rocks (T.S.G. field meeting 1980 and Roach, pers. comm.).

There has been some offshore dredge sampling and Auvray and Lefort (1971) have reported a large area of metasediments of possible Palaeozoic age in the Pte. de Beg An Fry to Trébeurden region, (Fig. 1:1). Lefort (1975) has demonstrated the existence of several NE-SW faults in the offshore area north of the Petit Trégor.

(5) OUTLINE OF DEFORMATION AND METAMORPHIC EVENTS IN THE LOCQUIREC SHEAR BELT

The sequence of deformational and metamorphic events is briefly described here and a fuller account is given in part (C). The LSB is a major ductile shear zone within which shearing deformation has produced a variety of granitoid mylonitic rocks. Within the shear zone the heterogeneous nature of the deformation is marked by the presence of relatively low-strained rocks, protomylonites, though more highly deformed rocks, represented by mylonites to ultramylonites, using Sibson's (1977) nomenclature. The ultramylonites are volumetrically the least significant group.

The protomylonites display a gneissose fabric, termed S1a, and microshears, while the mylonites and ultramylonites possess a single well-developed mylonitic banding, termed S1b. The penetrative gneissose fabric may pre-date or may have developed simultaneously with the S1b mylonitic fabric. The same sequence is recognised in the adjacent orthogneiss complex (see Chapter 4). The S1a fabric is rarely seen, and the closely-spaced S1b foliation is the dominant NE-SW trending fabric in the LSB. Both fabrics are assigned to a D1 episode (Table 5:1).

In some areas a third fabric is present, termed S1c. This is a crenulation fabric that is restricted to high-strain zones (where the ultramylonites are developed), and is interpreted as a shear-band structure. This fabric is distinguished from an S2 crenulation fabric that is associated with a later deformation episode (D2). The D2 episode resulted in significant folding and the development of the S2 fabric in the striped-amphibolites and granitoid mylonites. The D2 structures are particularly well-developed in the Pte. de Séhar region.

The D3 episode resulted in the production of more brittle structures, particularly kink-bands and microfaults.

The mylonites contain a lower greenschist facies assemblage which was formed during the development of the LSB. Important contact metamorphism of the LSB lithologies in the Pte. de Séhar region is associated with the emplacement of the late Hercynian Granite de Trédrez, which has also hornfelsed the Brioverian formations along the eastern side of the Baie de Lannion. In particular, the metabasic lithologies along the southern margin of the LSB in the Pte. de Séhar region have been transformed from segregated greenschists to striped amphibolites.

(B) FIELD RELATIONSHIPS AND PETROGRAPHY OF THE ROCKS COMPRISING THE LOCQUIREC SHEAR BELT

(1) INTRODUCTION

The Locquirec Shear Belt is composed of a number of different lithologies that are largely derived from the multi-component Moulin de la Rive Orthogneiss Complex together with some material from the Formation de Pte. de l'Armorique. The mixed nature of the host material and the effect of heterogeneous deformation within the shear belt have resulted in different types of mylonites, the original nature of which cannot always be accurately stated. In this section the nature of the mylonites is described, and in part (C) discussion is given as to the microstructures present within the LSB.

In the Locquirec area the granitoid mylonites are derived from the Moulin de la Rive Orthogneiss Complex, and in the boundary zone with the LSB a number of different components are recognised that may contribute to some of the host material deformed within the LSB. In the eastern sector of the orthogneiss complex at Les Sables Blancs (GR 1595 1284), to the southwest of Pte. du Corbeau, the dominant lithology is the granite component (described in Chapter 4). Towards the boundary of the LSB a second component is volumetrically also important, the porphyritic micro-granite component (Fig. 5:15). These two components are seen to become progressively deformed along the boundary of the LSB, but other components may also be included.

In the Pte. de Séhar to Malibri area (GR 1645 1305; Fig. 5:1) the LSB incorporates rocks of granitic-granodioritic composition that are also part of the orthogneiss complex, together with metabasic and possible metasedimentary rocks that are part of the Brioverian Formation de Pte. de l'Armorique.

There is some evidence that these granitoid rocks were intrusive into the Brioverian metavolcanic and metasedimentary formation prior to deformation within the LSB. Critical localities for this evidence are at Toul Ar Goué, Pte. de Séhar and Beg Ar Forn as discussed in Chapter 3, part (C).

(2) COMPONENTS OF THE LOCQUIREC SHEAR BELT

Within the LSB several distinctive lithologies can be identified.

(a) Granitic protomylonite

This lithology is equated with the extensive granite component of the orthogneiss complex. The granite has a medium-coarse grain size, and is variably deformed (Figs. 5:2 and 5:3). In zones of low strain the mineralogy, in order of importance, is plagioclase (An_{10}) + K-feldspar (microcline sometimes perthitic) + quartz + chlorite + muscovite (Fig. 5:4). With increasing strain the quartz is largely recrystallized but may show core and mantle structure. Plagioclase and K-feldspar may display extension (micro-boudinage), kinking and offset fracturing (Fig. 5:6).

Two fabrics are present along the margin of the shear belt; 1) S1a is a gneissose foliation defined by anastomosing and discontinuous mica-rich foliae that separate domains rich in K-feldspar, albite and quartz; 2) the S1b foliation is defined by irregular crush zones that modify the S1 fabric (Figs. 5:2 and 5:15). These are quartz and chlorite-rich bands, c. 1-2 mm thick, that may be related to the mylonitic fabric of the shear belt or they may also be later developed structures.

The granitic protomylonites are restricted in their outcrop and occur at the boundary area (some 200 m east of Pte. du Corbeau), at Le Chateau (GR 1612 1281) and in the northern Pte. de Séhar area, and at Pors Villiec beach (GR 1605 1277; 250 m east of the westernmost boundary).

Fig. 5:2 Granitic Protomylonite, Pte. de Corbeau

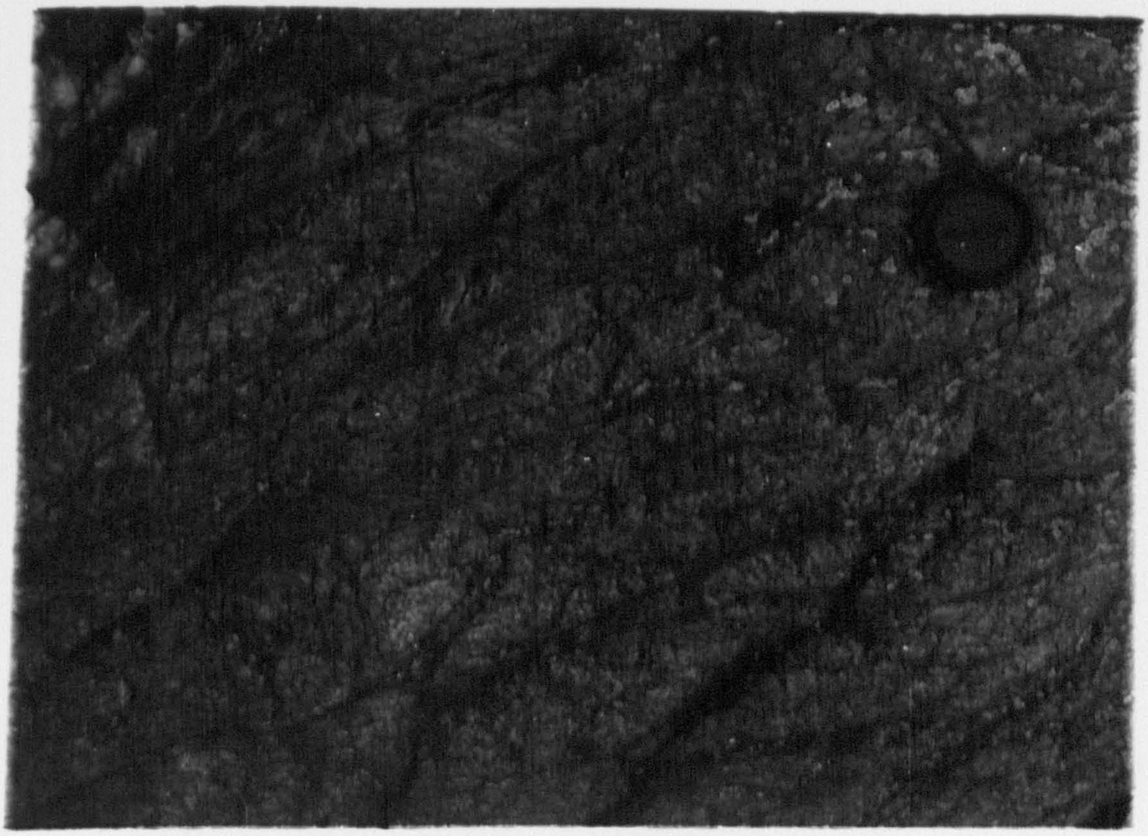
This lithology is deformed by Slb microshears which modify the Sla penetrative gneissose foliation. The Slb foliae envelope gneissose pods and depict a lozenge fabric.

Scale: Lens cap 54 mm

Fig. 5:3 Granitic protomylonite and porphyroclastic mylonites, E. of Pte. du Corbeau

At the boundary of the Moulin de la Rive Orthogneiss Complex with the LSB, the granite component is deformed to the granitic protomylonite seen in the upper centre and left of the photograph (g). Primary contacts become increasingly difficult to recognise and it is difficult to say whether the porphyroclastic mylonite (pm) seen in the lower centre of the photograph is more highly strained granite component or a deformed porphyritic granitoid component. The dominant Slb foliation is dipping steeply to the southeast. Compare with Figs. 4:9 and 4:10.

Scale: Hammer shaft 36 cm



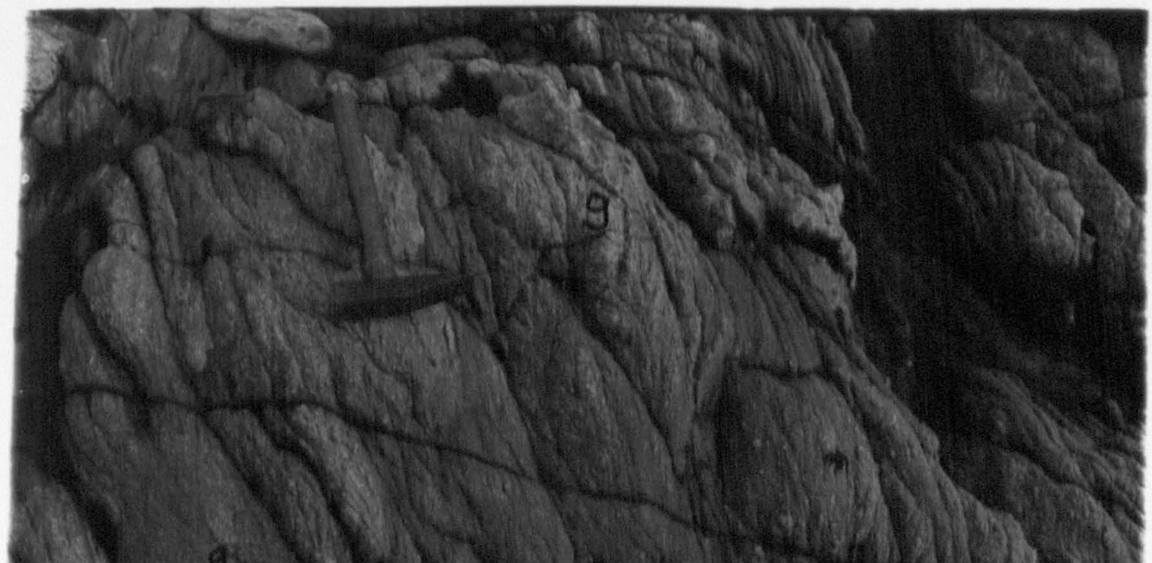

g
g
pm
g

Fig. 5:4 Granitic protomylonite within LSB; 200 m E of boundary Pte. du Corbeau

Thin section of specimen from a low strain zone. The foliated granite (protomylonite) has retained primary igneous relationships. Large K-feldspar shows myrmekitic intergrowth. Plagioclase grains display slight kinking.

Scale: x16 XPL

Fig. 5:5 Moderately deformed plagioclase porphyroclastic mylonite, LSB

$S1b$ foliae (domain B) are rich in chlorite + muscovite + quartz and anastomose plagioclase-rich domains. Discussion on the development of domains A and B is given in section (C).

Scale: x16 PPL

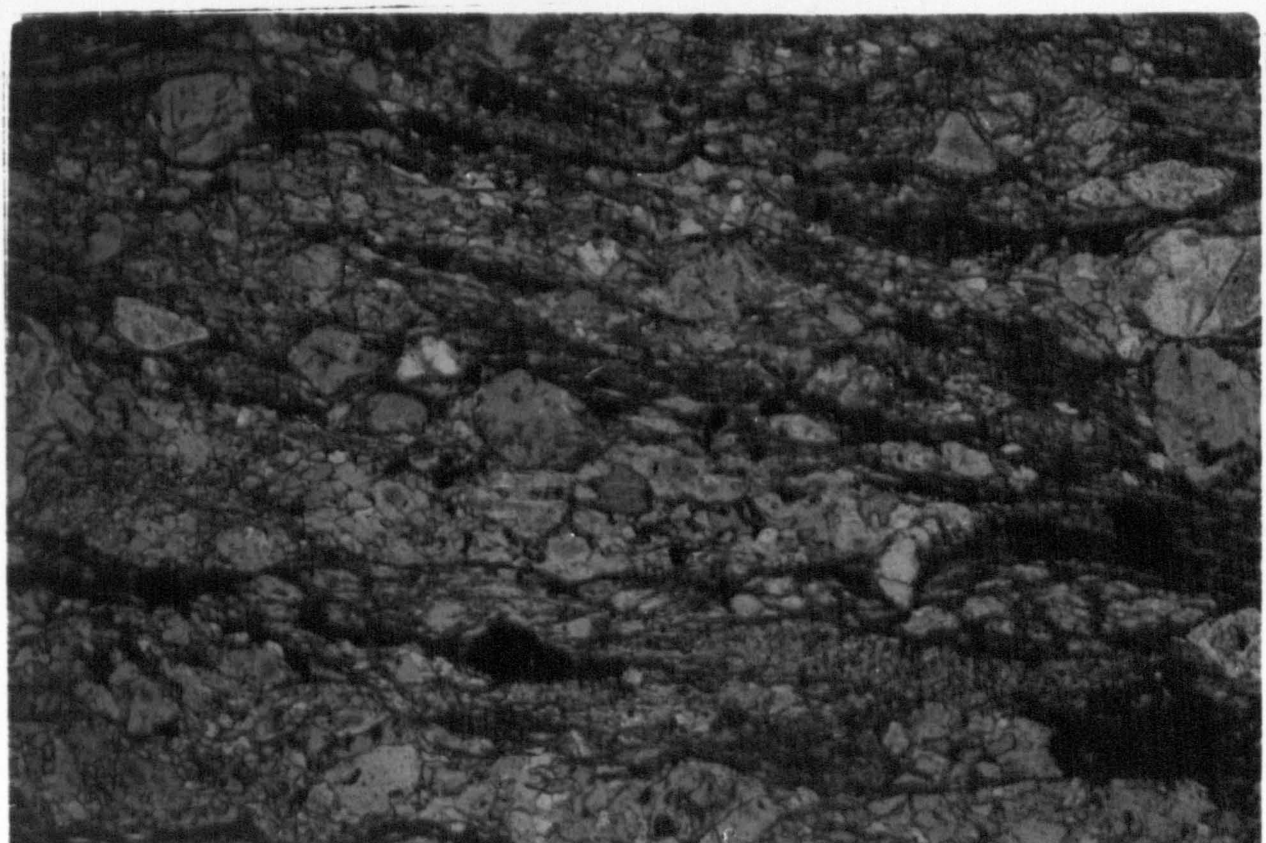


FIG. 5 : 6. PROTOMYLONITE.

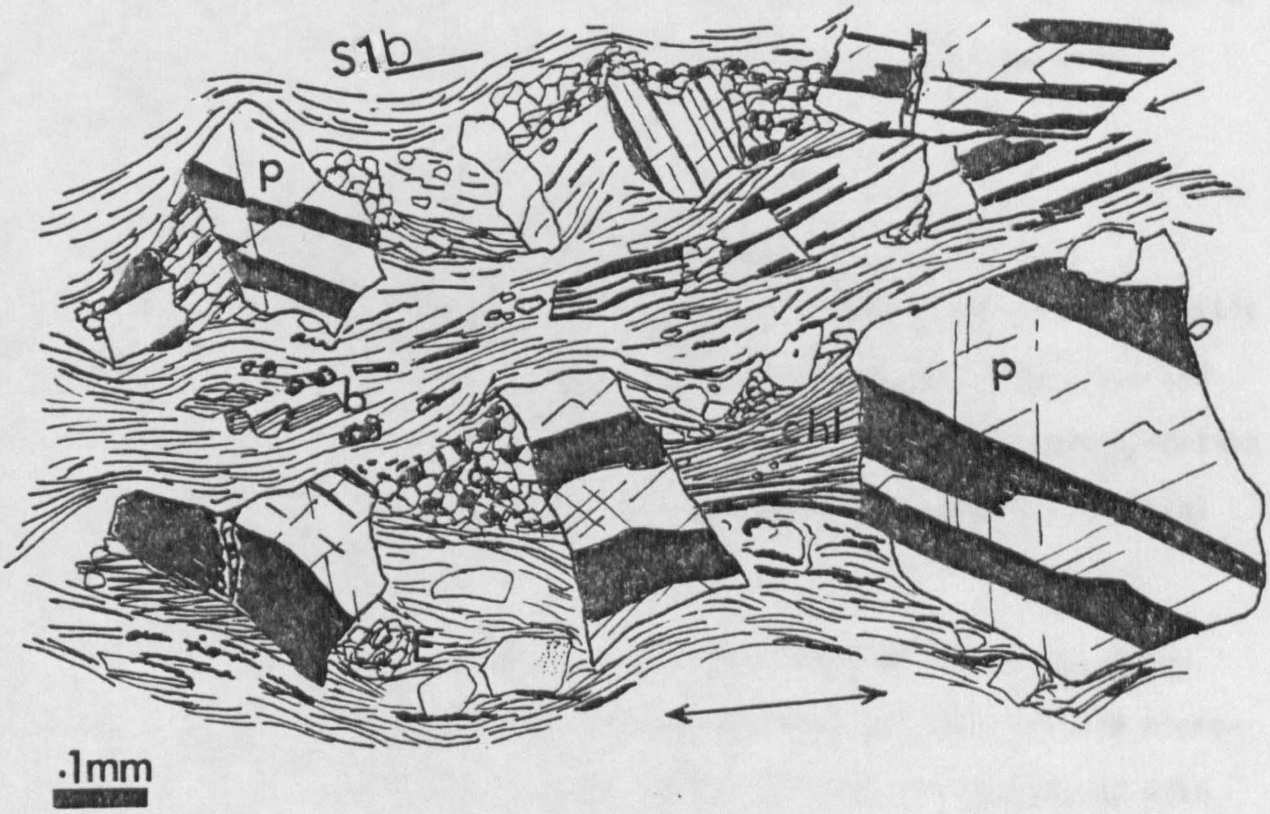


Fig. 5 : 6. Protomylonite showing development of S1b mylonitic foliation. Albite (p) has deformed in a brittle manner and displays fracturing and boudinage. Chlorite and quartz are developed in the pull-apart fractures. The S1b foliae are chlorite, muscovite and quartz-rich.
(Loc. 200 m E of boundary at Pte. du Corbeau 1607 1264).

The protomylonite crops out within the LSB as pod-like masses (c. 12x8 m diameter) within anastomosing finer-grained and strongly foliated mylonites.

(b) Feldspar prophyroclastic mylonites

The dominant lithology within the LSB is a feldspar porphyroclastic mylonite which has a characteristic 'gritty' appearance (Figs. 5:3 and 5:12). This lithology, although showing partial or complete modification of its matrix, is petrographically a granodioritic porphyry. Chemical data supports this conclusion.

Plagioclase (An_{10}) forms c. 0.5-3 mm porphyroclasts (Fig. 5.16-5:21). These large grains are commonly deformed and show brittle micro-fracturing and microboudinage. The porphyroclasts are associated with a white mica + chlorite + calcite + quartz + plagioclase matrix. Occasionally, biotite occurs in pressure shadows where it may be rimmed or part altered to chlorite.

The development of the Slb mylonitic foliation is variable within the lithology, so that in highly deformed varieties a segregated matrix consisting of bands rich in quartz and calcite alternate with chlorite and white mica-rich bands. In the highly deformed types the porphyro-clasts are smaller in size and are elongated parallel to the foliation. In the lower strained varieties the feldspars are not as well aligned and the segregation of the fine-grained matrix is not conspicuous.

The primary igneous nature of this lithology is preserved in low-strained varieties (Fig. 5:5), where crystal intergrowths and a medium to fine-grained relict porphyritic texture occur (Fig. 5.18, 5:19). In some specimens matrix plagioclase grains may still exhibit their primary lath-like form.

The mineralogy of the feldspar porphyroclastic mylonite is consistent. The development of white mica (muscovite?) + calcite + quartz + chlorite is important in the highly deformed mylonites and the neocrystallization of large calcite grains (<0.5 mm) in pressure shadow areas is of note. Mylonitic banding may be developed on a millimetric to centimetric scale.

In the boundary area near the Pte. du Corbeau the feldspar porphyroclastic mylonites are difficult to separate from the granitic protomylonite as this becomes more highly strained. Occasionally, however, zones or pods of granitic protomylonite can be distinguished (Fig. 5:15). The grain size is finer in the feldspar porphyroclastic mylonites and they possess a closer spaced and more regular NE-SW trending schistosity. To the east of the boundary, within the shear belt, feldspar porphyroclastic and the closely comparable quartz-feldspar porphyroclastic mylonites (see section C) become dominant, and it appears that the mylonites are derived principally from a granodioritic porphyry which represents a marginal facies of the Moulin de la Rive Orthogneiss Complex. Both the petrographic and geochemical data suggest that mylonitic rocks closer in composition to the granitic components are volumetrically much less important (discussed in part E).

The LSB appears therefore to be located principally within a marginal component of the Moulin de la Rive Orthogneiss Complex of granodioritic composition with a primary porphyrytic texture.

(c) Quartz-feldspar porphyroclastic mylonites

In this lithology conspicuous quartz and plagioclase (An_{10}) prophyroclasts occur together, set within a fine-grained, variably deformed matrix. The quartz porphyroclasts may be 1-2 mm in diameter (Figs. 5:7 and 5:8) and may be either strained and cracked, showing undulose extinction, or apparently unstrained. Plagioclase grains may show kinking, microboudinage or fracturing in relatively high-strain zones, or remain unaltered with a euhedral shape in low-strained zones. The mineralogy is albite + quartz, as porphyroclasts, with quartz + white mica + feldspar comprising

Fig. 5:7 Quartz-plagioclase mylonite, Pte. du Chateau

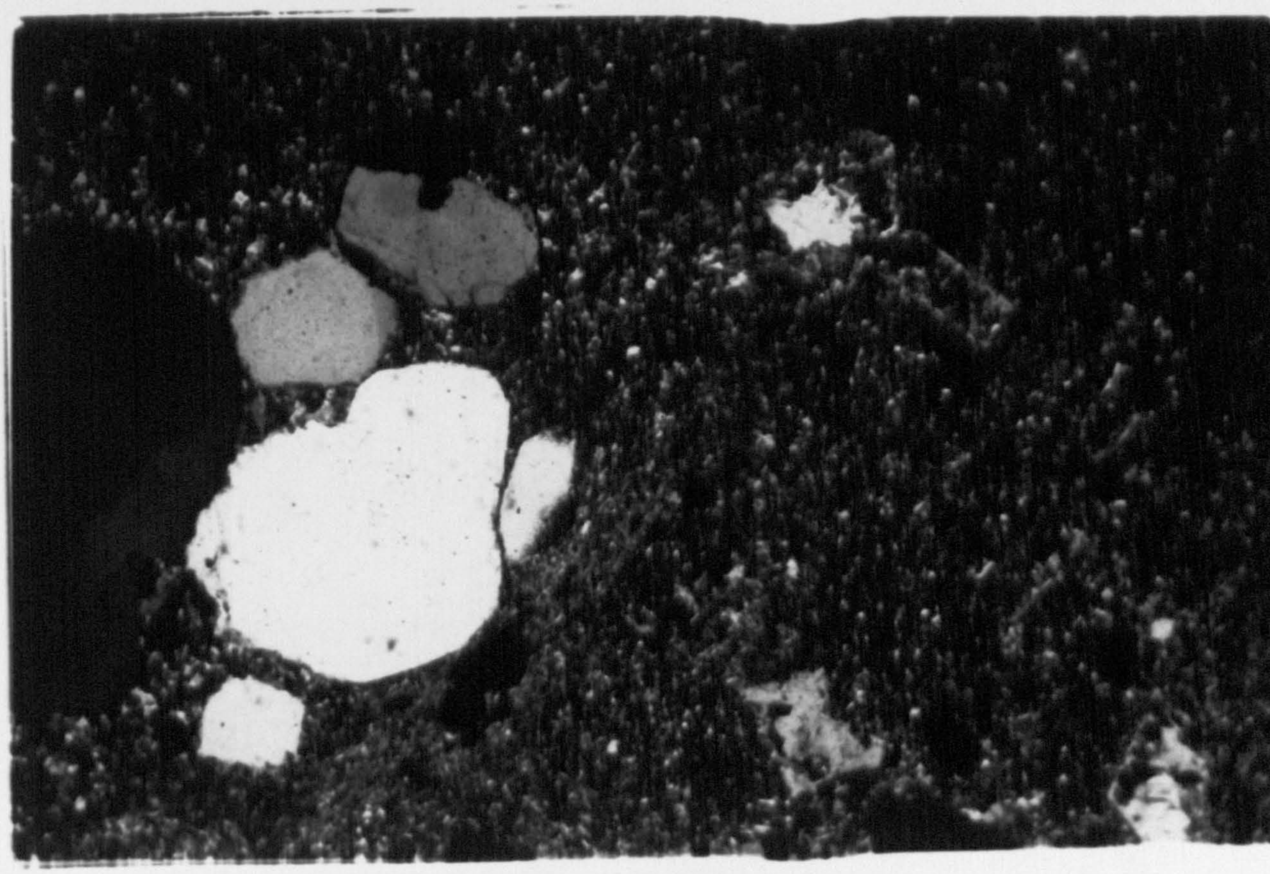
Quartz phenocrysts preserved in moderately deformed mylonites. The quartz grains may display undulose extinction and may be also preserved as relic cores of larger primary grains.

Scale: x16 XPL

Fig. 5:8 Quartz-plagioclase mylonite, Pte. du Chateau

Moderately deformed mylonite with typical mylonitic texture. A large albite grain is modified with rounded edges, quartz grains may show cracking and undulose extinction. The quartz + phyllosilicate-rich matrix may show a certain degree of segregation.

Scale: x16 XPL



the fine-grained matrix. The matrix can show either a marked foliation, with strong alignment of prismatic plagioclases and platy phyllosilicate minerals, or a relatively poor alignment.

The quartz-feldspar porphyroclastic mylonites occur throughout the LSB and macroscopically it is often difficult to distinguish between this component and the feldspar porphyroclastic component cited above in section (b). The lithology is heterogeneously deformed and the quartz and feldspar porphyroclasts occur even within strongly foliated varieties, where they are still considered to be a primary mineral phase rather than a metamorphic growth or a relic core that has been preserved during the mylonitization.

This lithology is in parallel contact with other mylonites and is laterally consistent, although the development of mylonitic banding is variable.

(d) Chlorite-rich mylonites

Several thin (<60 cm) often discontinuous bands of chlorite-rich material occur within the LSB which are arranged parallel to the mylonitic banding and schistosity. Chlorite is the dominant mineral phase in these bands and they may be almost monomineralic. Some associated quartz and quartzo-feldspathic aggregates or clasts usually occur within the chlorite-rich bands and these are in part similar to the conglomerates described in section (i). The chlorite-rich bands are strongly foliated, and the quartz + albite + chlorite clasts may be lens-shaped and elongated parallel to the foliation, or single fragmented grains or clusters of grains with poor alignment. The clasts and single grains are up to 3x2 cm in length.

The origin of the chlorite-rich bands is difficult to establish and the origin of the quartzo-feldspathic clasts and fragments is likewise problematical. However, two possibilities are considered and they may represent; 1) mylonitized metabasic sheets, or 2) segregated chlorite-rich bands (possibly derived from enclaves of basic material within a more granitic host). Several metabasic sheets are recorded in the LSB but these truncate the mylonitic banding and are therefore not related to the chlorite-rich bands. In addition, these sheet intrusions are distinct in that they are foliated with a quartz + chlorite + epidote + sphene mineral assemblage and they are equated with the widespread metabasic dyke suite that truncates the orthogneiss complex.

An origin for the chlorite-rich bands involving segregation of primary basic material from granitic material is required to account for the quartzo-feldspathic clasts that are often associated with the chlorite-rich bands. Segregation banding is usually developed on a millimetric-centimetric scale in the mylonites derived from granitoid parents, but does not reach the 60 cm thickness that is encountered in the chlorite-rich bands. The similarity of some of the chlorite-rich bands to some of the poudingue horizons possibly points to a comparable origin. These are discussed in more detail in section (i).

(e) Quartz-rich aplitic mylonites

Several bands of quartz-rich mylonite occur within the LSB. The bands are c. 50 cm thick, foliated and usually arranged parallel to the mylonitic banding and foliation. The mineralogy of this lithology is quartz + K-feldspar (microcline) + white mica ± chlorite. The feldspars form small (<1.5 mm) porphyroclasts. These bands may represent the late aplitic sheets recorded within the Moulin de la Rive Orthogneiss Complex.

(f) Ultramylonites

This term applies to the highest deformed lithologies present within the LSB. Here, grain-size reduction and almost complete recrystallization and neomineralization has occurred. Volumetrically, these rocks are not extensive and the best exposed ultramylonites crop out at the Pte. de Locquirec (GR 1609 1264).

The ultramylonites are very fine-grained but with remnant pods of coarser-grained material. In thin section, annealed quartz is enveloped by a matrix of white mica + quartz + titano-magnetite (Figs. 5:26 and 5:22c). The pods consist of elongate strings of quartz grains, of even grain-size (c. 0.1 mm), arranged parallel to the foliation. White mica is the dominant mineral and is aligned with strong preferred orientation parallel to the S1b mylonitic banding.

A crenulation fabric (Fig. 5:9) interpreted as a shear-band structure (White et al., 1980) is developed in some of the ultramylonites and is discussed in part (C). This is distinguished from a later S2 crenulation fabric.

The ultramylonites are developed in zones in which strain softening has occurred at an increased rate relative to the host and surrounding mylonites. They pass into lesser deformed lithologies but are laterally continuous.

(g) Striped amphibolites

In the Pte. de Séhar region two further groups of rocks are recognised that do not occur within the Locquirec area. These are striped amphibolites and feldspathic striped amphibolites, the latter are mapped in a transition zone between the dominant granitic mylonites of the Pte. de Séhar and the striped amphibolites (Fig. 5:1). The former are considered first.

Fig. 5:9 Ultramylonite Pte. de Locquirec

Strongly foliated quartz + white mica-rich ultramylonites. The dominant S_{1b} mylonitic fabric is crossed by a crenulation fabric considered to be a shear-band structure, termed S_{1c}. This fabric is best-developed in the ultramylonites with a finely spaced foliation.

Scale: Lens cap 54 mm

Fig. 5:12 + 12b Poudingues de Locquirec, W. Pte. de Locquirec

Type 1 poudingues in which granitic type clasts are enclosed within a chlorite + quartz-rich foliated matrix. S_{1b} parallel to the pencil and key. Note the sharp contact with moderately deformed mylonite.

Scale: Pencil = 14 cm

Fig. 5 : 9

Fig. 5 : 12

Fig. 5 : 12b

A thick sequence of striped amphibolites dominates the southern part of the LSB in the Pte. de Séhar area. The amphibolites vary in character, as they are affected to varying degrees by significant contact metamorphism associated with the emplacement of the nearby Granite de Trédrez.

Typically the striped amphibolites consist of alternations of dark-coloured amphibole ± biotite ± epidote - rich layers and light coloured quartz and plagioclase-rich layers, developed on a millimetric to centimetric scale (Fig. 5:10). The epidote and amphibole can be seen to overgrow the S1b mylonitic banding and were formed during contact metamorphism by the Granite de Trédrez.

In the area of Malabri the dominantly basic metavolcanic Formation de Pte. de l'Armorique is increasingly deformed towards the boundary of the LSB. Striped amphibolites occur within the hornfelsed metavolcanic formation in the region north of Beg Ar Naon (GR 1658 1279), but are infrequent. The recognition of striped metabasic lithologies points to the primary nature of these rocks in the LSB as belonging to the Formation de Pte. de l'Armorique, which is of Lower Brioverian age (see Chapter 3).

The well-developed segregation banding may to some extent reflect primary inhomogeneiites within the deformed lithology. Fig. 5:11 shows a banded rock that has developed, in which epidote-rich, c. 10-20 cm thick bands define an elliptical shape which may reflect highly flattened original pillow forms with calcium-enriched rims.

The segregation banding is considered to be the product of the mylonitization. This banding has been modified, and the early greenschist facies assemblage has been largely replaced. Amphibolization of the striped amphibolites is associated with significant hornfelsing, this can be demonstrated in the Pte. de Séhar as metamorphic grade increases

Fig. 5:10 Striped amphibolites, Pte. de Séhar

Finely banded striped amphibolites in which dark coloured epidote + amphibolite ± biotite-rich layers alternate with light-coloured quartzo-feldspathic layers. The banding is a segregation fabric, S1b, developed during the major D1/M1 episode. Subsequent D2/F2 folds and kink-bands deform the early banding.

Scale: Hammer handle 36 cm

Fig. 5:11 Striped amphibolites, Pte. de Séhar

Unusual segregation banding within the striped amphibolites. The epidote-rich bands, developed in a localized area, depict lenticular or pod-shaped masses that may reflect a primary structure, possibly highly deformed pillow lavas.

Chevron type microfolds are well-developed and deform S1bsegregation banding.

Scale: Lens cap 54 mm

towards the late Hercynian Granite de Trédrez at Locquémeau (Fig. 5:1).

(h) Transition zone feldspathic striped amphibolites

A sequence of feldspathic striped amphibolites occurs in the Pte. de Séhar area that are distinct from other rocks within the LSB. The lithology is banded on a millimetric scale,and larger plagioclase grains (up to 3 mm) occur within light coloured quartz + albite (An_{10}) bands that alternate with slightly thinner, dark, epidote ± amphibolite-rich bands. This sequence of rocks is mapped as a transition zone,that occurs between the striped amphibolites and the granitoid mylonites.

It is considered that the granitoid mylonites at Pte. de Séhar were also derived from a marginal facies of the Moulin de la Rive Orthogneiss Complex, which was emplaced into the dominantly basic meta-volcanic Formation de Pte. de l'Armorique. The outcrop pattern of the granitic (feldspar-rich) mylonites may indicate a primary intrusive relationship into the metabasic lithologies prior to the mylonitization. A similar relationship is observed at Toul Ar Goué at the eastern boundary of the LSB in the Locquirec (Chapter 3).

The origin of the feldspathic striped amphibolites is not clear. They may represent a sheared primary mixed lithology in which granitoid mylonites and striped amphibolites occurred together (originally basic lavas veined by granite), or they may be derived from a deformed parent of more intermediate composition.

(i) Conglomerates

One of the principal arguments used by previous authors (Verdier 1968; Autran et al. 1979; Auvray 1979) for the existence of a sequence of tuffs or volcaniclastics, represented by the Schistes or Series de Locquirec, is the occurrence of several 'poudingue' (conglomerate) bands which are developed within the LSB as defined within this thesis. The origin of these poudingues, together with the Pors Rodou Breccias (discussed in Chapter 4) remains highly problematical. Two types of poudingue are recognised within the LSB, both types possess a mylonitic fabric and occur in bands parallel to the SB foliation. They are discussed below:-

Type 1. Chlorite-rich bands with granitic clasts: Fig. 5:12 illustrates this lithology, in which clasts of granitic composition (quartz + K-feldspar ± albite ± chlorite) occur within a dark-coloured matrix composed largely of chlorite with some quartz and white mica. The conglomerate bands are laterally regular and are from 25-100 cm thick. Eight bands have been recorded between a point some 20 m from the boundary near Pte. du Corbeau (Fig. 5:15) to the east of the Pte. de Locquirec (GR 1610 1263). The clasts may be elliptical to rounded in shape (1-8 cm in diameter), or irregularly-shaped as fragmented quartzo-feldspathic aggregates which have a gritty appearance and are usually less foliated. These are somewhat similar to the chlorite-rich bands which contain occasional clasts as discussed in section (d). The elliptical clasts show marked extension parallel to the common northeasterly plunging lineation developed in the shear belt. Occasionally, individual clasts may be slightly boudinaged.

Type 2. Mixed clast pseudo-conglomerates: Figs. 5:13 and 5:14 illustrate this lithology which is quite different to the type (1) conglomerates. This lithology comprises apparent clasts of several types of material with no interstitial matrix. The clasts vary in colour from dark grey to grey-green, light-grey or pale cream. The size of the clasts in the X:Y plane varies considerably from c. 1 cm x 3 mm to 120 cm x 4 cm. Length : width ratios are up to 1:27. The X extension direction of the clasts plunges to the northeast at a steep angle.

Fig. 5:13 Poudingues de Locquirec, Port de Locquirec

Type 2 poudingues in which apparent clasts of light coloured and darker coloured material occur. The clasts are markedly elongated parallel to S1b

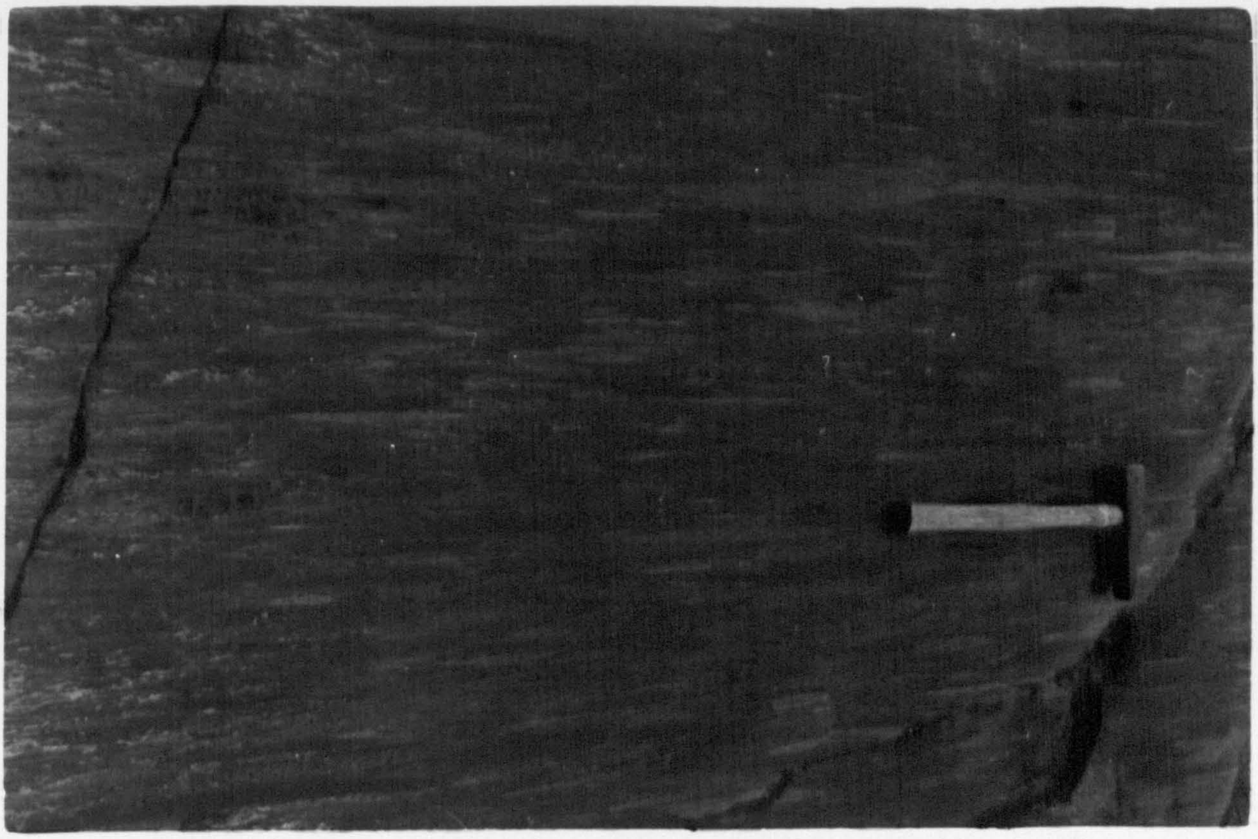
Scale: Hammer shaft 36 cm

Fig. 5:14 Poudingues de Locquirec, Port de Locquirec

Detail showing feathered and interfingering of the different clasts. Some clasts show delicate contacts on one side of the clast and most pointed 'tails' on the opposite side. Note the lack of any matrix material.

Scale Lens cap 54 mm

N.B. Fig. 5:12 attached to Fig. 5:9



The composition of the clasts is as follows; a) pale-cream coloured clasts are K-feldspar + quartz + white mica; b) light-grey coloured are K-feldspar + albite + quartz + chlorite; c) grey-green coloured, albite + quartz + chlorite, and; d) dark coloured, very-fine grained aggregate of epidote + sphene + titanomagnetite + felsic minerals.

A foliation is present within some of the clasts at an angle of approximately 30^{o} to the main S1b foliation which is parallel to the X:Y plane of the clasts. This may be a later crenulation fabric but the relationship is not clearly defined.

The occurrence of the type (2) conglomerates is more restricted than the type (1) bands, with a single thick c. 3 m band developed in the Port de Locquirec area, an 80 cm thick band in the same area (separated by granitoid mylonite), and a single band (1 m thick recognised at Pte. de Séhar. A single isoclinal fold has been recognised in this unit at the Port de Locquirec. The clasts display feathered edges, which may develop at both ends of the clast or more commonly at one end, where it interfingers with a separate clast usually of different composition.

The origin of the conglomerates is problematical, as any primary textures or relationships that might have been present in a sedimentary conglomerate (other than its pebbly aspect) have been destroyed during strong deformation. No infolding or faulting has been observed thay may account for the current juxtaposition of polymictic conglomerates within granitoid rocks of the LSB. The two types of conglomerates discussed here have different characteristics and are considered to have a different mode of origin. The chlorite-rich bands (discussed in section d) may contain quartzo-feldspathic clasts and fragments, and thus are similar in aspect to the chlorite-rich conglomerates. They may therefore have a common origin.

The following models are considered that may account for the origin of a mixed, clast-rich lithology which has subsequently undergone ductile deformation within the LSB:-

1. Sedimentary. True conglomerates of debris flow origin, with matrix-rich and matrix-poor types. Pebbles and cobbles up to 60 cm x 60 cm would have been present to account for the current clasts preserved (assuming no volume loss).

2. Volcanic. A volcanic breccia might account for the mixed clast-rich type (2)conglomerates. but would not account for the granitic type clasts in a matrix of chlorite (type (1) conglomerates).

3. Igneous breccia or agmatite. A mixed parent may be achieved by injection of acidic/intermediate composition magma into a more basic host to give an agmatite. Occasional agmatite zones occur within the orthogneiss complex as for example in the southeast corner of the Baie de Moulin de la Rive. An agmatitic origin appears to be a strong prossibility for the type (2) conglomerates.

4. Metamorphic. A deformed augen gneiss may provide clasts and matrix for type (1) conglomerates.

Models 1 and 2 would require either tectonic juxtaposition or rafting of conglomerate horizons within invading granitic magma prior to mylonitization. It is interestingto note the close proximity of the mixed type (2) conglomerates to the eastern boundary of the LSB with the Formation de Pte. de l'Armorique. Metasedimentary rocks within the Toul Ar Goué area sometimes exhibit small-scale folds (Chapter 3), and it may be argued that if the conglomerates are of sedimentary origin then similar small-scale folds may be expected to be present within the conglomerates. However, only one small isoclinal fold has been recognised within the conglomerates, which is insignificant when compared to the thickness of the succession.

A model that involves segregation, during mylonitization within the LSB of a primary mixed igneous or metamorphic rock (agmatite or an inhomogeneous metamorphic rock) is preferred to account for the development of the conglomerate bands. The two conglomerate types and the Pors Rodou Breccias occur within variably deformed plutonic rocks and there is no evidence to support a volcanic or epiclastic origin.

(3) SUMMARY

A number of different mylonite types are recognised within the LSB. The least deformed rocks are the protomylonites which are developed in the granite component of the Moulin de la Rive Orthogneiss Complex. Variably deformed mylonites are developed in primary igneous porphyritic lithologies that are largely of granitic to granodioritic composition. Granitoid mylonites are volumetrically the most important lithologies of the shear belt. In addition, chlorite-rich bands, aplitic mylonites and poudingues also occur. Striped amphibolites crop out in the Pte. de Séhar area. These were derived from the Formation de Pte. de l' Armorique.

The occurrence of several conglomerate bands within and on the margins of the LSB is important and problematical. A model that involves deformation and segregation of plutonic or metamorphic parent rather than a supracrustal parent within the shear belt is preferred to account for their origin, although their exact nature is not known.

The following evidence is cited in support of a mylonitic origin for the rocks within the LSB:-

1. Mylonitic banding and textures indicate a ductile mode of deformation within a delimited shear zone.

2. There is a lack of any relict features indicative of a tuffaceous or volcaniclastic origin (e.g. pumice fragments, shards, sedimentary structures etc.).

3. Shear zones are present in the adjacent Moulin de la Rive Orthogneiss Complex in which mylonitic rocks occur.

4. Zones of 'low-strained' protomylonites within the LSB are of intrusive igneous origin (with relict porphyritic and trachytic textures and granophyric intergrowths).

5. Similar granitoid rocks of Cadomian age, which are intrusive into the Brioverian sequence, occur nearby at Rocher L'Argent and Beg Ar Forn.

6. Brioverian bedded rocks are folded and there is a lack of folds within the supposed bedded Formation de Locquirec (sensu Autran et al. 1979) i.e. the LSB lithologies of this thesis.

   (N.B. Points 5 and 6 have been discussed in Chapter 3).

(C) DEFORMATION AND METAMORPHISM WITHIN THE LOCQUIREC SHEAR BELT

(1) INTRODUCTION

The LSB is a major ductile shear zone that has involved the southerly margin of the composite Moulin de la Rive Orthogneiss Complex and part of the Brioverian Formation de Pte. de l'Armorique. Two principal foliations are present within the LSB, Sla is a gneissose foliation present within the granitic protomylonites and Slb is a well-developed more continuous mylonitic foliation. In the orthogneiss complex (discussed in Chapter 4) the same two foliations are recognised, where Sla is dominant, and it is considered that the two foliations developed simultaneously or sequentially during the same deformation episode.

The mylonitic rocks of the LSB have a complicated deformational history and two further fabrics are present in addition to those described above. A foliation, termed S1c, is present in the ultramylonite bands and is therefore restricted and relatively unimportant. A crenulation fabric, termed S2, is more widespread in its development and was produced during a separate deformation episode (D2), subsequent to the gneiss and mylonite fabric producing episode (D1).

(2) THE D1 EPISODE

The D1 deformation was the most important foliation producing episode and led to the development of mylonitic rocks within the LSB. The major features of the D1 episode in the LSB are described here where they are recognised as being:-

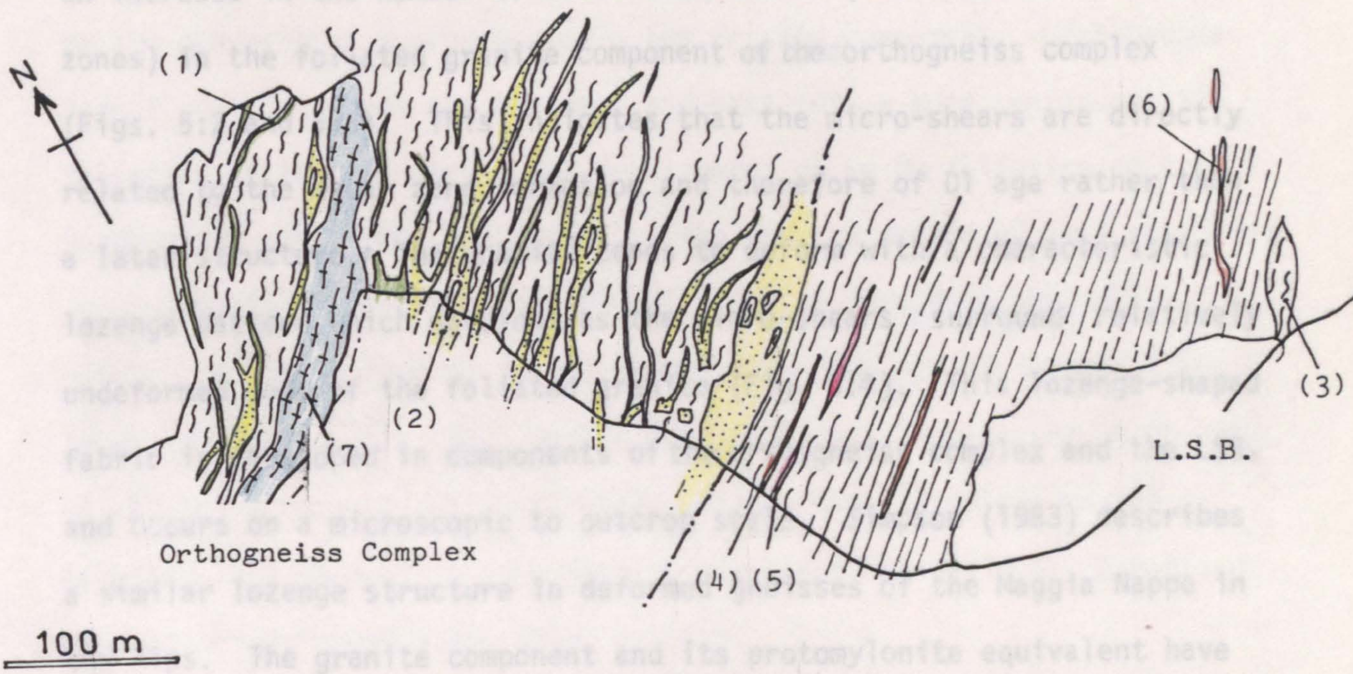
a) Gradational boundaries of the LSB with adjacent units.
b) Formation of the S1b foliation.
c) Development of a segregation banding.
d) Grain-size reduction.
e) Heterogeneously deformed mylonites; zones of low and high strain.
f) Development of shear band structures in the ultramylonites.
g) Development of a linear fabric.

A description of these features associated with the D1 mylonitisation, and the deformation mechanisms possibly involved in the formation of the LSB, is given below.

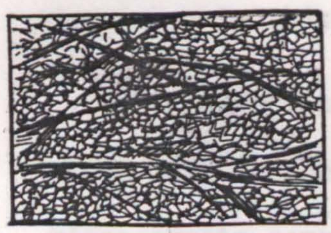
a) Gradational boundaries of the LSB with adjacent units

Observations across the boundaries of the LSB (Figs. 5:1 and 5:15) in the Pte. du Corbeau and Pte. de Séhar areas show that there is an overall increase in strain towards the boundary of the shear zone.

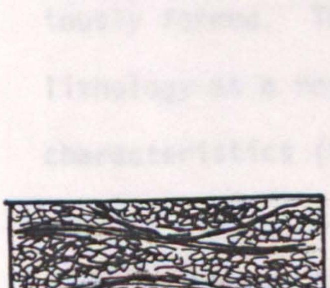
FIG. 5 : 15 BOUNDARY OF THE LSB NEAR PTE DU CORBEAU.



1) Metabasic dyke
2) Porphryritic microgranite
3) Protomylonite (granitic)
4) Conglomerate (type 1)
5) Chlorite rich band
6) Aplitic band (foliated)
7) Gabbro



A) Granite Component (poorly - moderately deformed)



B) Granite Component (highly deformed)

The Porphyritic microgranite is volumetrically more important towards the boundary of the LSB. The foliated granite component is progressively deformed (A - B) and is recognised within the shear belt as protomylonite. The importance of the granite component as a parent lithology is difficult to establish and other lithologies (particularly the micrograniite) appear to be present as parent lithologies. The boundary is gradational but is marked at the limit of recognisable granite and porphyritic microgranite.

From the Pte. du Corbeau southeast towards the boundary there is an increase in the number of small shear zones (micro-shears or crush zones) in the foliated granite component of the orthogneiss complex (Figs. 5:2 and 5:3). This indicates that the micro-shears are directly related to the shear zone formation and therefore of D1 age rather than a later structure. The granite tends to deform with a characteristic lozenge pattern, which develops as the micro-shears surround relatively undeformed pods of the foliated granite (Fig. 5:4). This lozenge-shaped fabric is developed in components of the orthogneiss complex and the LSB, and occurs on a microscopic to outcrop scale. Simpson (1983) describes a similar lozenge structure in deformed gneisses of the Maggia Nappe in the Alps. The granite component and its protomylonite equivalent have deformed in a brittle manner as indicated by the presence of the micro-shears. At the boundary of the LSB the S1b foliation is partially developed in this lithology (Figs. 5:3, 5:6 and 5:15).

An important consideration with regard to the development of the shear zone in the Locquirec area is the increase of the porphyritic microgranite component at the eastern margin of the orthogneiss complex (Fig. 5:15). This lithology appears to deform much more readily than the granite component, with a well-developed S1b foliation ubiquitously formed. The S1b foliation may be preferentially developed in this lithology as a result of; 1. heterogeneous deformation; 2. lithological characteristics (the mineralogy and grain size); 3. the existence of an earlier fabric (a primary flow banding as noted in similar lithologies in the Plage de Tréstignel region) along which further slip-planes may develop.

The boundary of the LSB in the Pte. du Corbeau and northern Pte. de Séhar areas is characterised by an increase in the deformation, marked by the presence of micro-shears in the granite component, which become more frequent towards the boundary and pass into a more continuous S1b foliation at the boundary. The development of an S1b foliation in the porphyritic microgranite is aided by the primary nature of this component (discussed in Chapter 4). The S1b foliation is developed throughout the outcrop of this lithology in the orthogneiss complex and increases in intensity towards the LSB. In the Pte. du Corbeau region the porphyritic microgranite becomes, as just noted, an important lithology at the boundary, but elements of the granite component can still be recognised in a higher deformed state (Fig. 5:15).

The importance of the granite component within the LSB is difficult to establish, but at its margin near Pte. du Corbeau there are low strain pods of granitic protomylonite that are similar to the granite component of the orthogneiss complex. Within the shear belt it becomes progressively more difficult to separate both granite and porphyritic microgranite components from the abundant feldspar porphyroclastic mylonites and the closely related quartz-feldspar porphyroclastic mylonites, the parent of which appears to have been a granodioritic porphyry (see geochemistry, section E). These latter rocks form the bulk of the LSB.

In the Pte. de Séhar area the southern boundary of the LSB is developed within dominantly basic metavolcanic rocks of the Formation de Pte. de l'Armorique. The boundary is taken to be at Malabri (GR 1654 1292) where striped amphibolites are well exposed northwards as far as the Pte. de Séhar (Fig. 5:1). The boundary is gradational, in that banded rocks similar to the striped amphibolites occur in relatively narrow (c. 2-6 m) shear zones as far south as Beg Ar Naon (GR 1658 1279).

The LSB broadens significantly in the Pte. de Séhar to Malabri area. The swing in the LSB in this area is complicated to some extent by the presence of a NE-SW trending shear belt recognised in the Pte. de Bihit area (discussed in part D) which may be related to the LSB (Fig. 5:36).

(b) Formation of the S1b planar foliation

The mylonites possess a strong foliation termed S1b (Fig. 5:6), the orientation of which rotates from NE-SW (030-050^{o}) in the Locquirec area to an E-W trend (090-102^{o}) in the Pte. de Séhar region. The S1b foliation of the LSB is approximately parallel to the S1a gneissose foliation of the orthogneiss complex although in localized areas the S1a fabric is seen to swing into the plane of the S1b foliation.

In detail, the S1b foliation is a planar and fairly continuous fabric, that is defined by fine-grained, mica-rich foliae that anastamose feldspar (plagioclase and K-feldspar) and quartz grains or grain aggregates (Figs. 5:5, 5:16, 5:17, 5:18 and 5:19). The highest deformed mylonites contain an increased amount of muscovite ± chlorite, so that a stronger foliation is developed and the spacing of the individual foliae is decreased (Fig. 5:20). The foliae are composed of muscovite, chlorite, quartz, epidote and albite. The actual assemblage that develops varies according to the intensity of the deformation. The spacing of the foliae also decreased with increased deformation, so that in the highest deformed mylonites the foliae are less than 1 mm thick.

(c) Development of a segregation banding

Associated with the formation of a planar foliation in the mylonites is a segregation or mylonitic banding. This is best developed in the highest deformed lithologies, the ultramylonites, in which domains of quartz occur set in a fine-grained, strongly aligned muscovite-dominated host.

Fig. 5:16 Feldspar-rich mylonites, Pte. de Locquirec

Moderately deformed mylonites with deformed albite grains which display fracturing and neocrystallization at grain boundaries. Quartz and chlorite are developed in pressure shadows adjacent to the albite grains.

Scale: x16 XPL

Fig. 5:17 Feldspar-rich mylonites, Pte. du Chateau

Moderately deformed mylonites displaying mylonitic texture and large extended albite grain with fracture infill of quartz + calcite.

Scale: x16 XPL

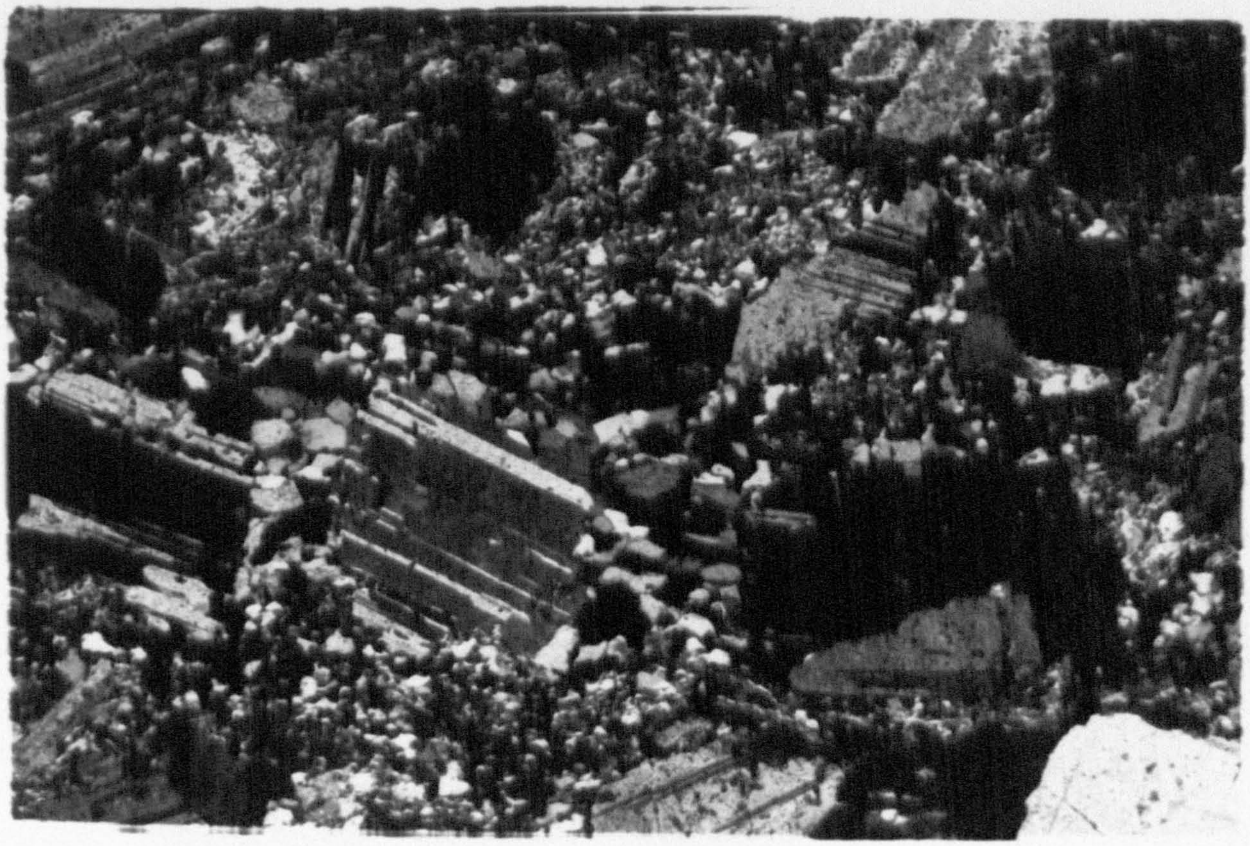


Fig. 5:18   Feldspar-rich mylonites, LSB

Deformed porphyroclast of albites which has been modified within the plane of the S1b mylonitic foliation. The fine-grained matrix (Domain B) is composed of albite + quartz + chlorite + white mica an anastomoses the relic (domain A) porphyroclast.

Scale: x16 XPL

Fig. 5:19   Feldspar-rich mylonites, LSB

Deformed albite porphyroclast with well preserved shape in moderately deformed mylonite. Note primary feldspar intergrowth.

Scale: x16 XPL

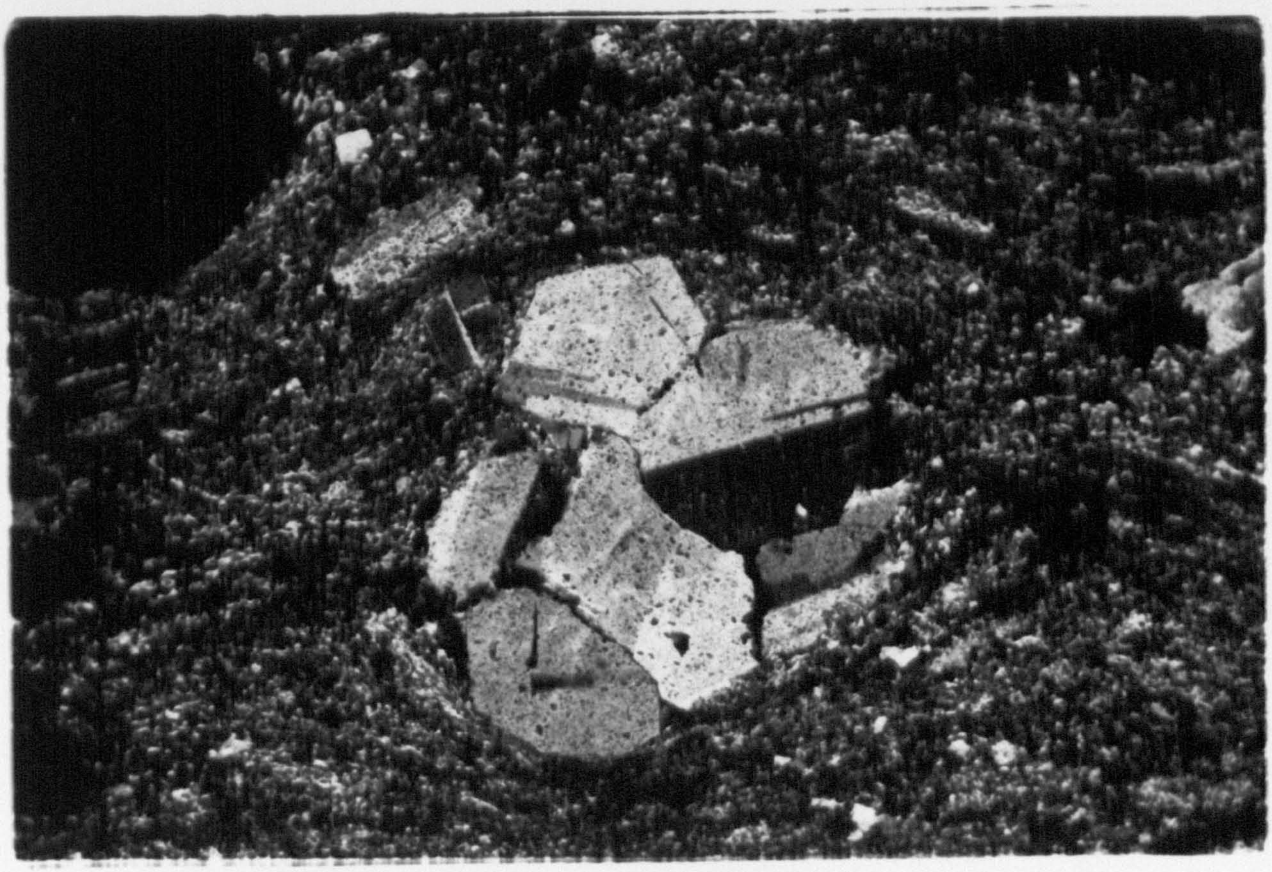


Fig. 5:20 Feldspar-rich mylonites, LSB

Medium-highly deformed mylonite displaying marked grain-size reduction and semi-brittle behaviour of albite. The albite is microboudinaged, with subsequent quartz infill, fractured and kinked. S1bis well-developed in the fine-grained matrix.

Scale: x16 XPL

Fig. 5:21 Feldspar-rich mylonites, LSB

Detail of pressure-shadow area adjacent to a euhedral albite grain orientated parallel to S1b. Quartz largely occupies the pressure-shadow area together with some chlorite + calcite. The S1b foliation anastomoses the large grain.

Scale: x16 XPL

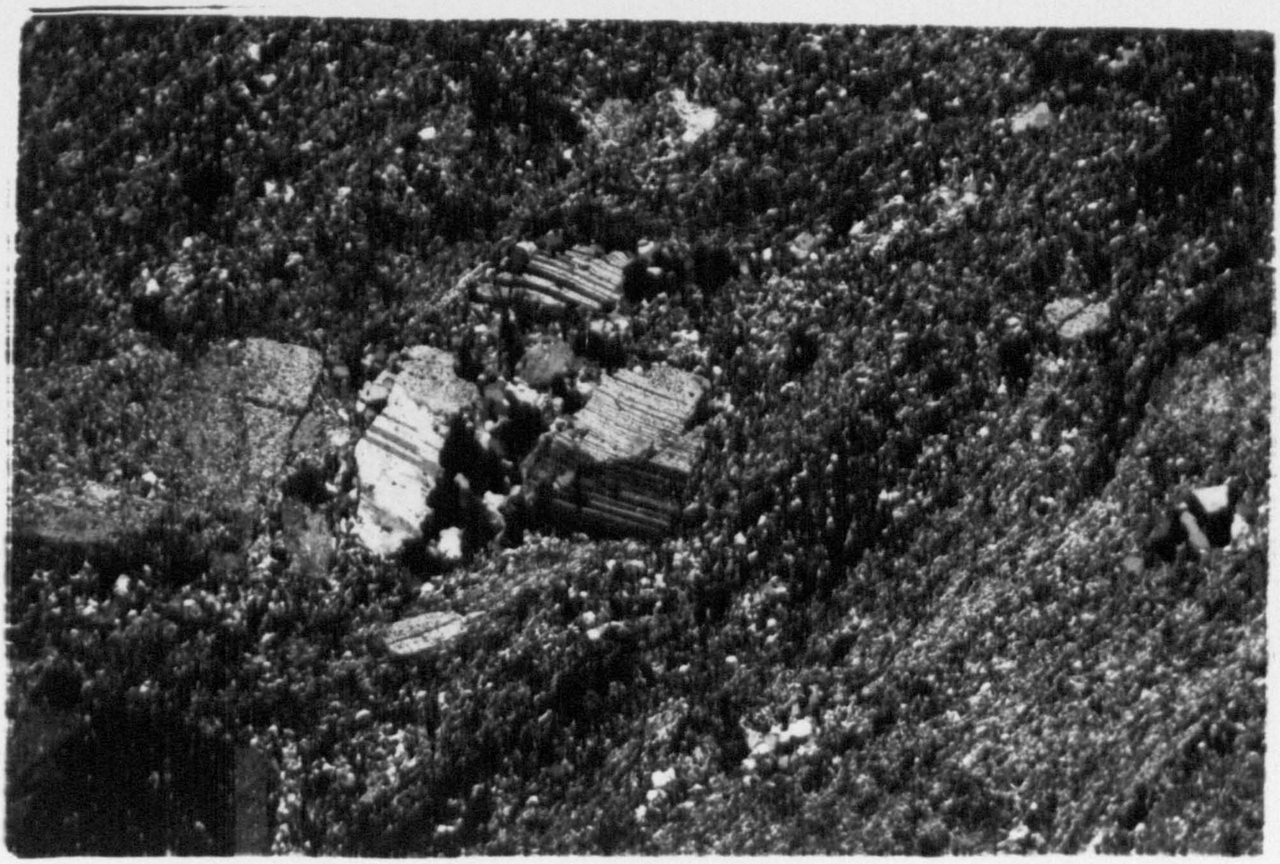


Fig. 5:22 shows a series of diagrams in which metamorphic segregation occurs with increased deformation in the shear zone regime. Three stages are illustrated that show the increased importance of 'domain B' (the mica-rich foliae) to 'domain A' (the feldspar ± quartz-rich lenses or bands). Two major mineralogical changes are considered to occur within the granitoid mylonites:-

1. Plagioclase and K-feldspar → white mica + quartz + calcite
2. Quartz → goes into solution? or recrystallizes.

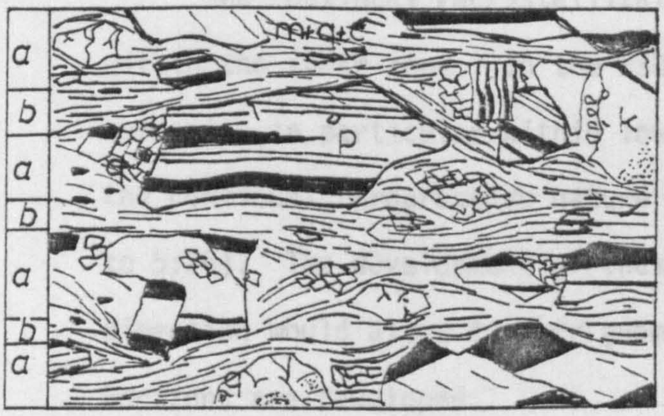
Of relatively less importance is the breakdown of biotite and/or amphibole to give chlorite, epidote and ore.

The actual mechanism of deformation in the production of mylonites and mylonitic banding are considered to be achieved by strain softening. Softening mechanisms have been summarized by White et al. (1980) who consider ductile shear zones to form in zones of strain softening, which occurs when the hardening capacity of the material that is being deformed is exceeded. In the LSB the following processes are considered important; 1) geometric or fabric softening; 2) continual recrystallization; 3) reaction softening; 4) pore-fluid affects.

1. <u>Geometric, or fabric softening</u>

Softening is aided by the ability of different minerals to slip or glide within the shear zone. Slip is enhanced by the re-orientation of grains, and this may occur with the mechanical reorientation of mica grains and elongated quartz grains in domain B. In some lithologies, e.g. the porphyritic microgranite component of the orthogneiss complex and the granodioritic porphyry a well-developed mineral orientation and therefore a slip surface may have existed prior to the development of the S1b foliation. This would further promote slip and softening.

FIG. 5 : 22 THE DEVELOPMENT OF MYLONITE BANDING IN THE L.S.B.

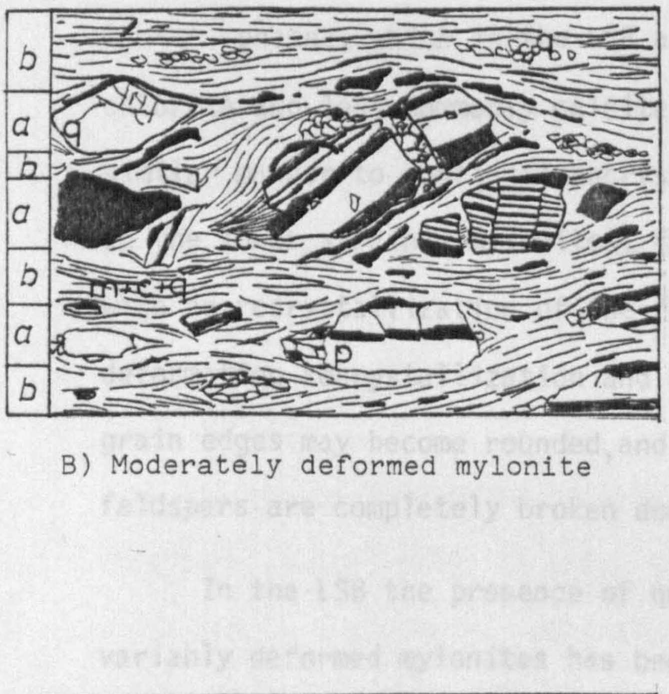


Dom. A. Alb + K-felds + Qtz. Feldspars ; fractured, kinked and boudinaged Quartz ; core and mantle, recrystallized in strain shadows and as fracture infill.

Dom. B. Musc + Chl + Alb + Qtz.

Foliae are not always continuous and envelope Dom. A.

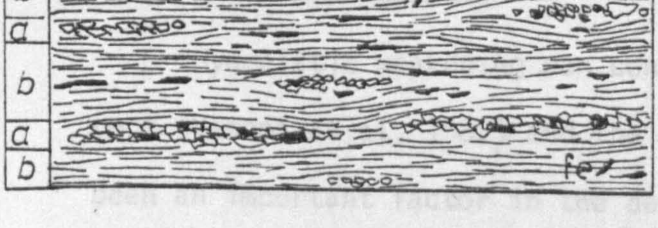
A) Poorly deformed mylonite



Dom. A. Alb + Qtz ± K-felds
Reduced grain size.
Albite ; increased microboudinage, offset fracturing, rounded edges, neomineralization.
Quartz ; core and mantle, recrystallized and elongate.

Dom. B. Musc + chl + Qtz + Alb.
Thicker foliae, more continuous, albite less conspicuous.

B) Moderately deformed mylonite



Dom. A. Qtz ± Alb.
Reduced grain size.
Albite ; largely absent, occasional grain preserved ⟶ muscovite.
Quartz ; regular grain size, slight undulose extinction, elongate pods.

Dom. B. Musc + Qtz ± Chl.
Continuous foliae, very fine grain size some segregation within the domain of mica + Qtz.

C) Highly deformed mylonite

2. Continual recrystallization

The continual recrystallization of mineral phases aids softening within the shear zone. In the LSB the recrystallization of quartz and muscovite,in particular within low to high-strained mylonites,indicates the continual, progressive nature of the recrystallization (Figs. 5:21 to 5:26). The development of these minerals parallel to the shear direction would allow further geometric softening,as well-defined slip horizons are developed.

3. Reaction softening

During metamorphism in active shear zones White and Knipe (1978) have noted that 'hard' phases, principally feldspars, break down to 'soft' phases, which in the LSB are principally quartz, muscovite, chlorite and less commonly calcite, and so promote deformation in a similar manner to continual recrystallization and geometric softening. In the lower strained mylonites, feldspars may be cracked or fractured with no recrystallization of the feldspar grain, but with increasing deformation recrystallization and neomineralization occurs, so that grain edges may become rounded,and in the highest deformed mylonites the feldspars are completely broken down (Fig. 5:26).

In the LSB the presence of quartz porphyroclasts in some of the variably deformed mylonites has been previously noted. These also apparently acted as a hard phase and been preserved during the mylonitization (Figs. 5:7 and 5:8).

4. Pore-fluid affects

Hydrolitic weakening can considerably reduce the strength of a rock (Vernon et al. 1983) and the presence of a hydrous phase may have been an important factor in the development of the LSB. The important role of a fluid phase in the breakdown of feldspars has been indicated by Dixon (1982) for the Locquirec mylonites, and in other mylonites (White and Knipe 1978). The reduced grain size that occurs in the mylonites would lead to an increased fluid mobility as also would the alignment of mica (001) planes.

The presence of a hydrous phase within the shear zone significantly increases the reaction potential, and the breakdown of plagioclase and K-feldspar to muscovite + calcite + quartz can be achieved in lower greenschist conditions with a hydrous phase involved (White 1982).

The development of the mylonites is related to strain softening, the microstructures indicating that the various processes discussed above may have been operative.

(d) Grain size reduction

Grain size reduction was achieved during progressive deformation in the LSB by similar processes that gave rise to the mylonitic banding. Extensive reduction in grain size was achieved by recrystallization and neominerallization of minerals, principally quartz, feldspar and mica.

1. Quartz

In the protomylonites,quartz commonly displays core and mantle structure (White 1976), in which a core of undulose strained quartz is enveloped by a mantle of sub-grains and recrystallized grains. The quartz is sometimes fractured (Figs. 5:22 and 5:28).

In the mylonites the quartz grain-size is decreased as elongate, ribbon quartz and sub-grains become dominant, although core and mantle structure may still occur. All of these textures are indicative of plastic deformation. Undulose extinction is common and is characteristic of strain hardening rather than softening processes (White 1977).

In the highest deformed rocks quartz is of fine grained and completely recrystallized where it occurs largely within domain A (see Fig. 5:22). The grain size is fairly constant and White (op. cit.) suggests that this indicates grain boundary sliding as an important process in the mylonite formation.

2. Plagioclase and K-feldspar

The feldspars, as previously indicated, have acted in a dominantly brittle manner, although some kinking of the twin lamallae occurs which may indicate more ductile behaviour.

Feldspar (largely albite, but some K-feldspar) has acted as a resistant mineral in domain A (Figs. 5:21, 5:24 and 5:25). It has suffered grain size reduction by effectively being rounded-off by neo-minerallization at grain boundaries (Fig. 5:18 and 5:19). There is a tendency for the plagioclase to be pulled apart in a form of boudinage and this together with the presence of micro-fractures indicates its brittle behaviour (Figs. 5:17, 5:23 and 5:29).

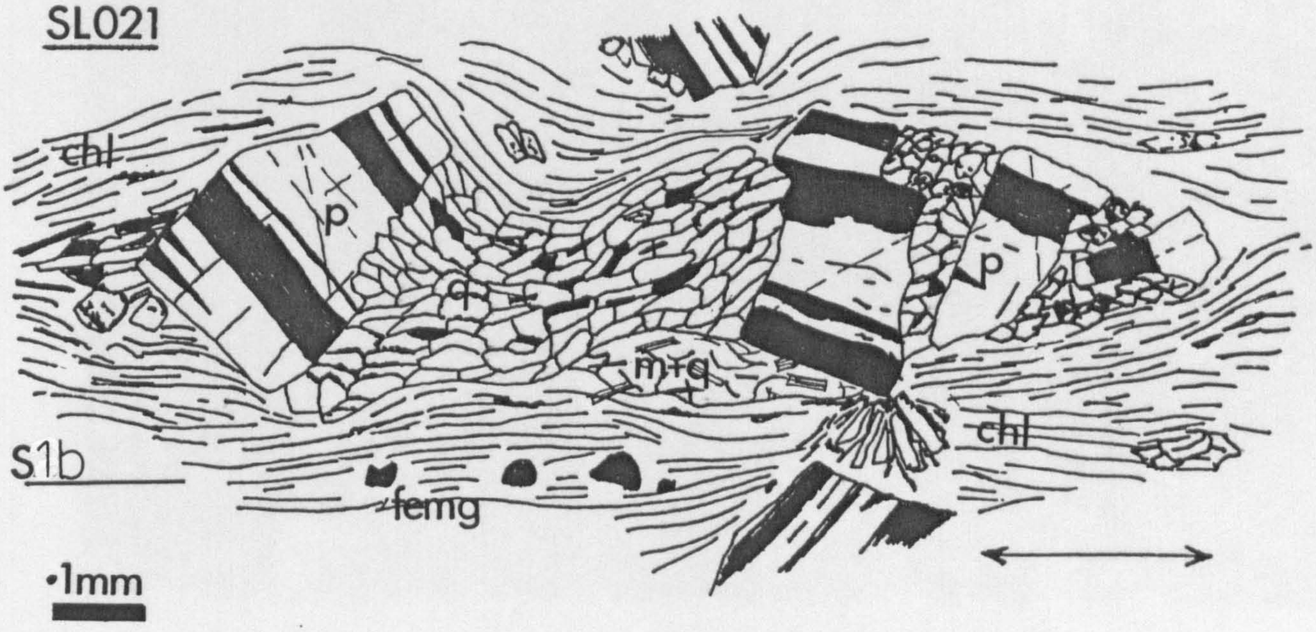
3. Muscovite

Muscovite reduces in grain size and increases in abundance with increased deformation (Figs. 5:22, 5:24 and 5:25). In the least deformed lithologies the mica grains are arranged parallel to the gneissose fabric and occasionally bent grains occur. In the higher deformed mylonites the mica dominates in domain B (Fig. 5:26) and the strong preferred orientation defines the S1b foliation.

(e) Heterogeneously deformed mylonites; zones of low and high strain

Within the LSB there is commonly a rapid transition from zones of low strain to zones of high strain that are represented by different types of mylonite with varying degrees of foliation development, banding etc. This transition occurs on a variety of scales, from a single thin-

FIG. 5 : 23 MODERATELY DEFORMED MYLONITE.



A large albite (p) grain displays microboudinage with extension in the plane of the S1b foliation. Quartz has recrystallized in the fractures of the original grain which have rotated slightly. The quartz is slightly strained and is elongate parallel to S1b. The foliae consist of muscovite (m) + chlorite (chl) + quartz (q) which envelopes the larger grains. Femg minerals are concentrated in the foliae.

(SL 021)

Fig. 5:24 Feldspar-rich mylonites, LSB

Typical mylonite texture in feldspar-rich component, S1b foliae with fine-scale segregation banding are well-developed.

Scale: x16 XPL

Fig. 5:25 Feldspar-rich mylonites, LSB

Typical mylonite texture in moderately-highly deformed feldspar-rich component. Note calcite and quartz largely developed at the expense of the feldspar grains. The asymmetry of the pressure shadow areas may indicate the sense of movement within the LSB.

Scale: x16 XPL

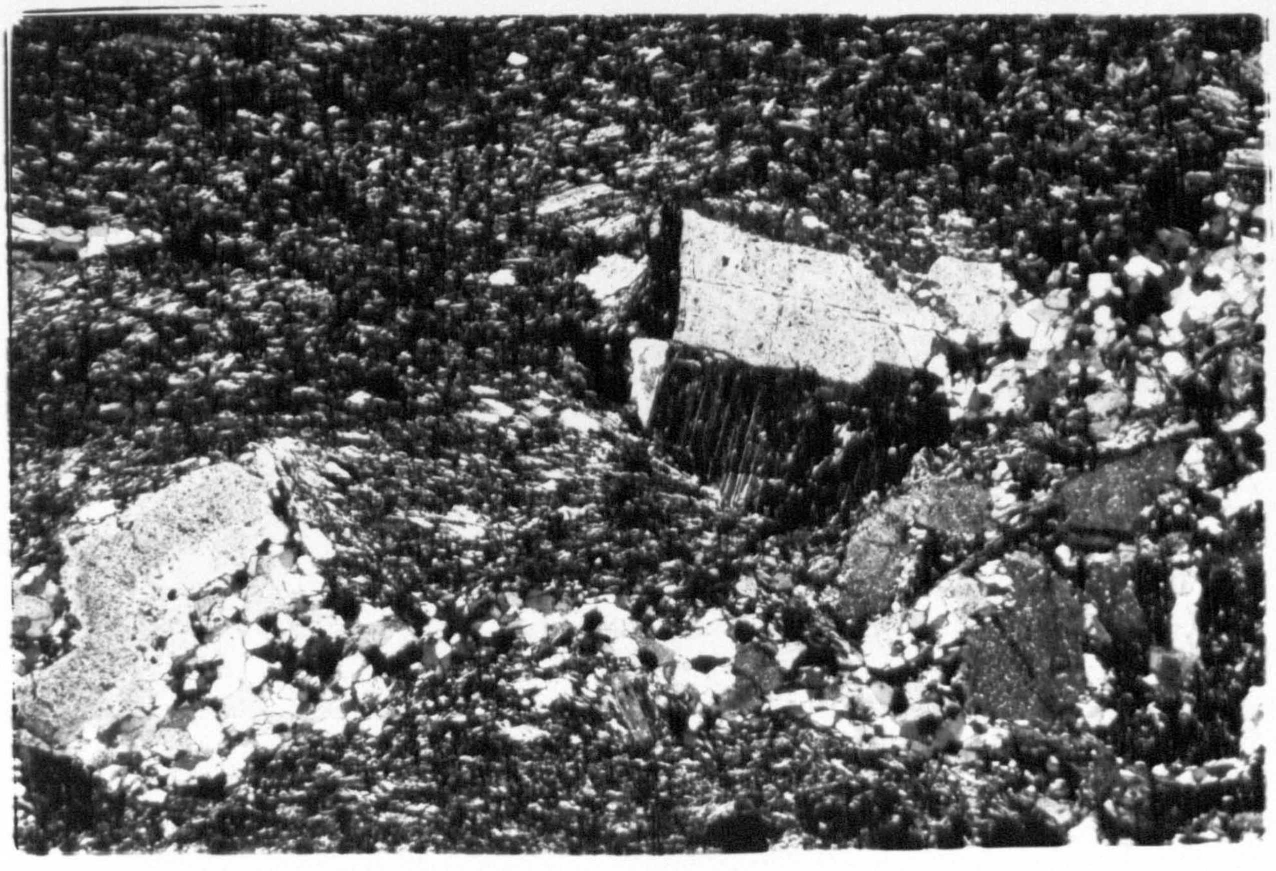


Fig. 5:26   Ultramylonite Pte. de Locquirec

Fine-grained ultramylonite in which two domains are present. Domain A is largely composed of quartz, which is of regular grain size, and occasional albite grains. Domain B is the dominantly micaceous matrix composed of muscovite + quartz ± chlorite + ore minerals.

Scale: x15 XPL

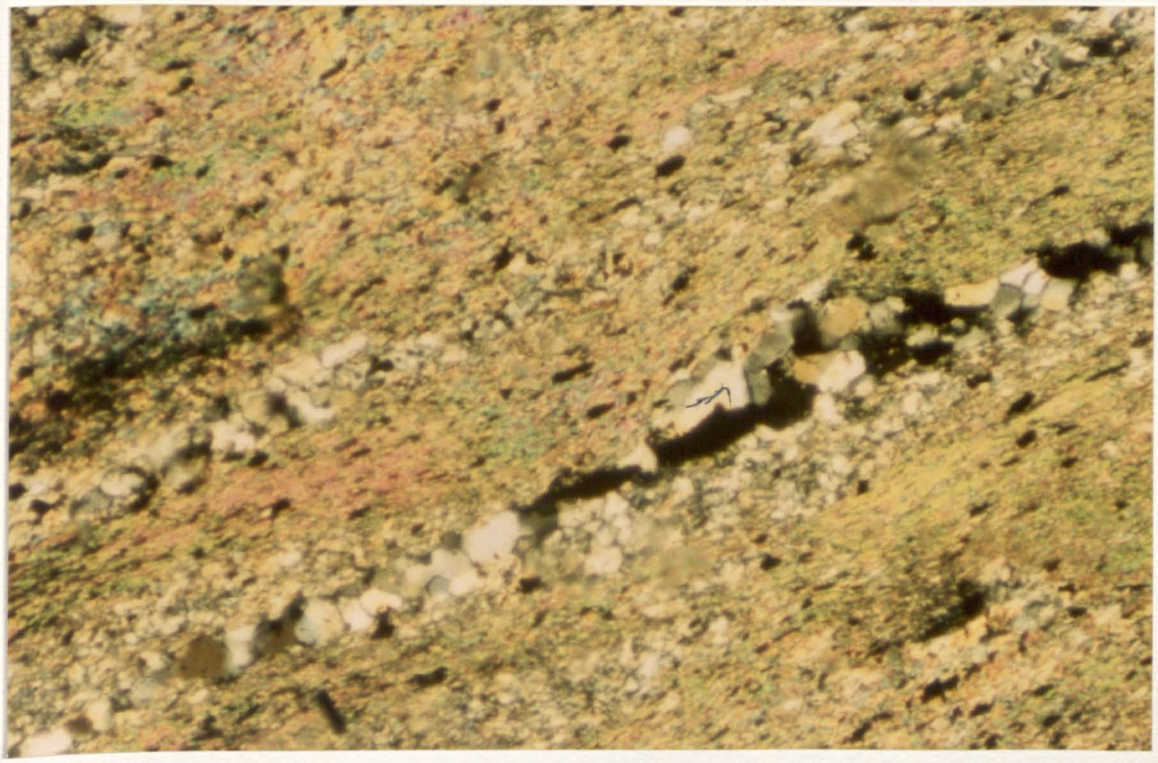


Fig. 5:27 Feldspar-rich mylonites, LSB

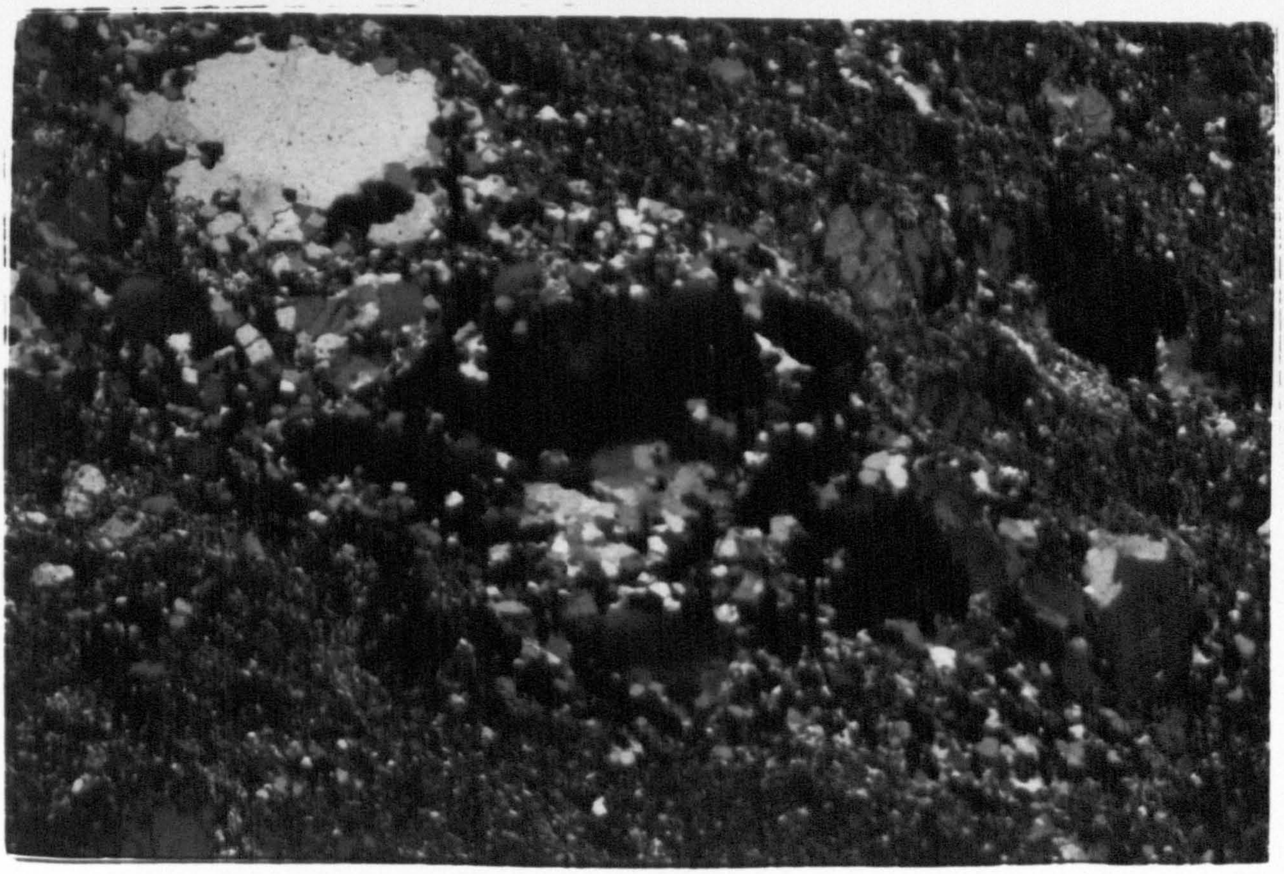
Highly fractured albite and K-feldspar grains in poorly foliated matrix.

Scale: x16 XPL

Fig. 5:28 Quartz and Feldspar-rich mylonite

Core and mantle structure in quartz grain. A highly strained core is rimmed by smaller recrystallized grains. The quartz rich porphyroclast is attenuated within the Slb foliation.

Scale: x16 XPL



section (Fig. 5:5) to several metres. In effect, the boundary of the LSB with the Moulin de la Rive Orthogneiss Complex represents such a transition from foliated granitic rocks to protomylonites then to mylonites. Within the LSB a good example of the transition can be seen at (GR 1603 1276), some 200 m from the western LSB boundary near Pte. du Corbeau. At this locality granitic protomylonite is present with an S1a fabric that is disrupted and modified by S1b micro-shears (Fig. 5:2). The protomylonite has the form of a large pod or lozenge that is enveloped by mylonitic rocks in a higher deformed state.

In thin-section domain A quartz and feldspar pods are surrounded by domain B mica-rich foliae. The foliae represent zones of high strain, in which there is neomineralization and recrystallization, while domain A represents relatively low strained areas (Fig. 5:5).

(f) Development of shear-band structures in the ultramylonites

A crenulation foliation, termed S1c, is developed in the ultramylonites and some of the mylonites of the LSB and the orthogneiss complex. The fabric occurs at an angle of 25-35^{o} to the S1b mylonite foliation and is therefore generally orientated NNE-SSW. This fabric is considered to be a shear-band structure as defined by White et al. (1980). In detail, the structure is defined by the alignment and slight segregation of quartz and muscovite (and sometimes chlorite). The structure may form as an accommodation structure with continued shear movement after the development of the main mylonitic foliation, or it may form in response to a change in the shear direction.

Fig. 5:9 shows the nature of this crenulation fabric, which is distinguished from a later non-penetrative fabric that is associated with the D2 deformation episode and crenulates the S1c and S1b foliations. This S2 foliation is particularly well developed in the Pte. de Séhar region.

(g) Development of a linear fabric

Two lineations have been observed in the LSB, the first is directly related to the mylonitization, while the second, later fabric is the product of the intersection of S1b and S2.

The first lineation is variably developed and is frequently defined by the alignment of prismatic plagioclase feldspars within the S1b foliation. A common feature of these grains is their extension and boudinage in the stretching direction at a moderate plunge to the north-east (Fig. 5:31). Subsequent neomineralization within the fractured grains is principally of quartz, chlorite or calcite (Figs. 5:29, 5:30 and 5:23). Undulose extinction and ribbon texture is sometimes developed within these infill minerals and this indicates continued stretching post-crystallization of the infill phases. The nature of the D1 deformation is summarised on p. 179.

(3) THE D2 EPISODE

The D2 episode resulted in the development of a foliation in only certain lithologies and folding of the striped amphibolites (Table 5:1). Structures associated with this episode are best developed in the Pte. de Séhar region, where the striped amphibolites are folded and a crenulation foliation, termed S2 in the structural sequence, is relatively well-developed in some mylonite bands.

Folds are restricted to the finely-banded striped amphibolites in the southern part of the Pte. de Séhar area. The folds are open to tight, upright to slightly overturned (to the east) with angular hinge zones (Fig. 5:10). Small accommodation folds are well developed and they have a chevron form, similar to kink-bands developed in the granitoid mylonites. The larger folds plunge at a moderate angle to the northeast.

Fig. 5:29 Feldspar-rich mylonite, LSB

Highly extended albite grain with recrystallized edges and subsequent calcite infill. The foliation is not well developed in this poorly-moderately deformed mylonite.

Scale: x16 XPL

Fig. 5:30 Feldspar-rich mylonite, LSB

Detail of pressure-shadow area adjacent to a euhedral albite grain showing the development of chlorite and elongated quartz grains parallel to Slh.

Scale: x16 XPL

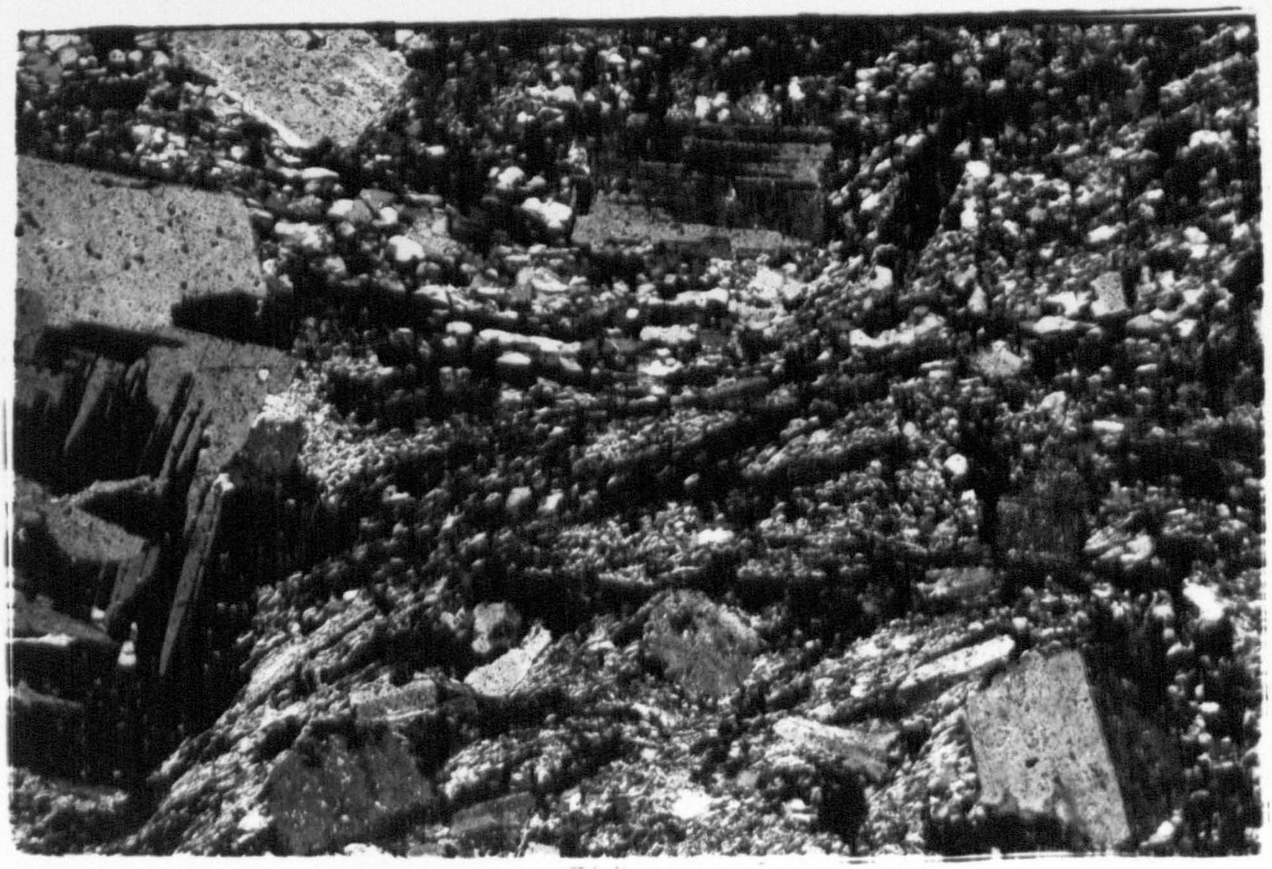


Fig. 5:31 DEVELOPMENT OF A LINEAR FABRIC

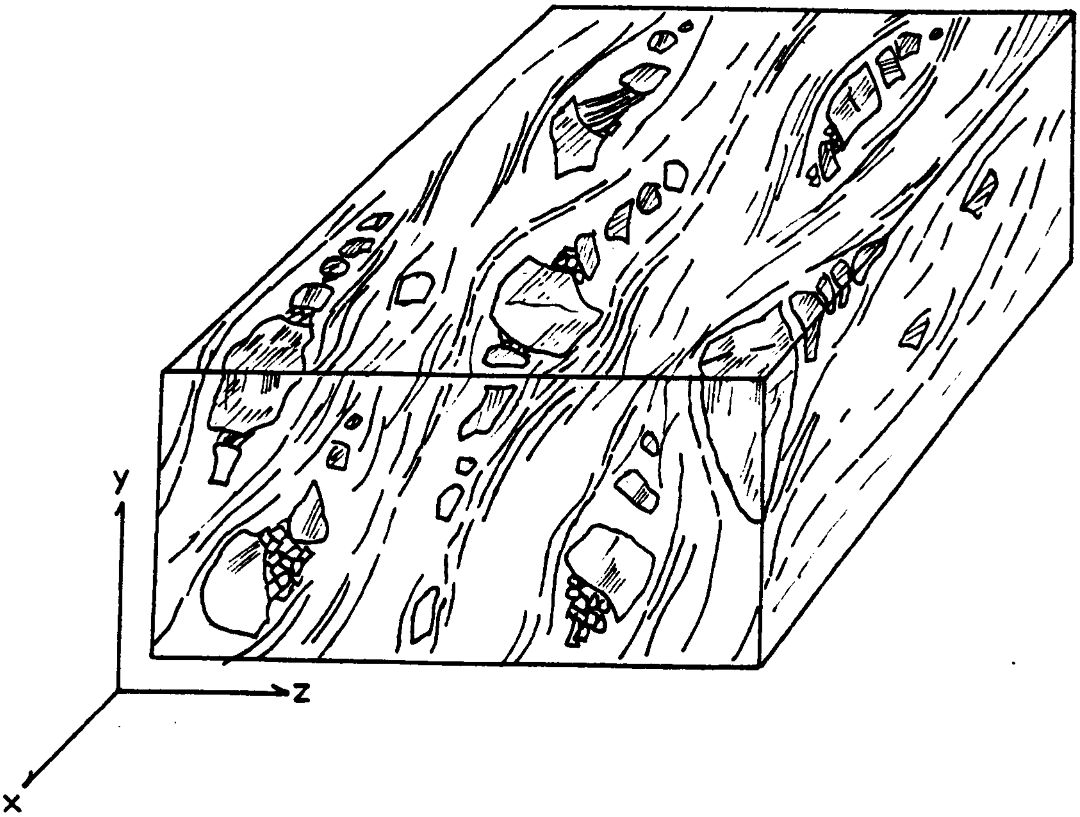


FIG. 5 : 31 DEVELOPMENT OF A LINEAR FABRIC

Block diagram to show the mesoscopic fabric of a moderately deformed mylonite. The linear fabric is developed in the plane of the S1b foliation and is depicted by the extension of the brittle albite grains. Neominerallization of quartz $\pm$ calcite $\pm$ chlorite occurs in the fractures.

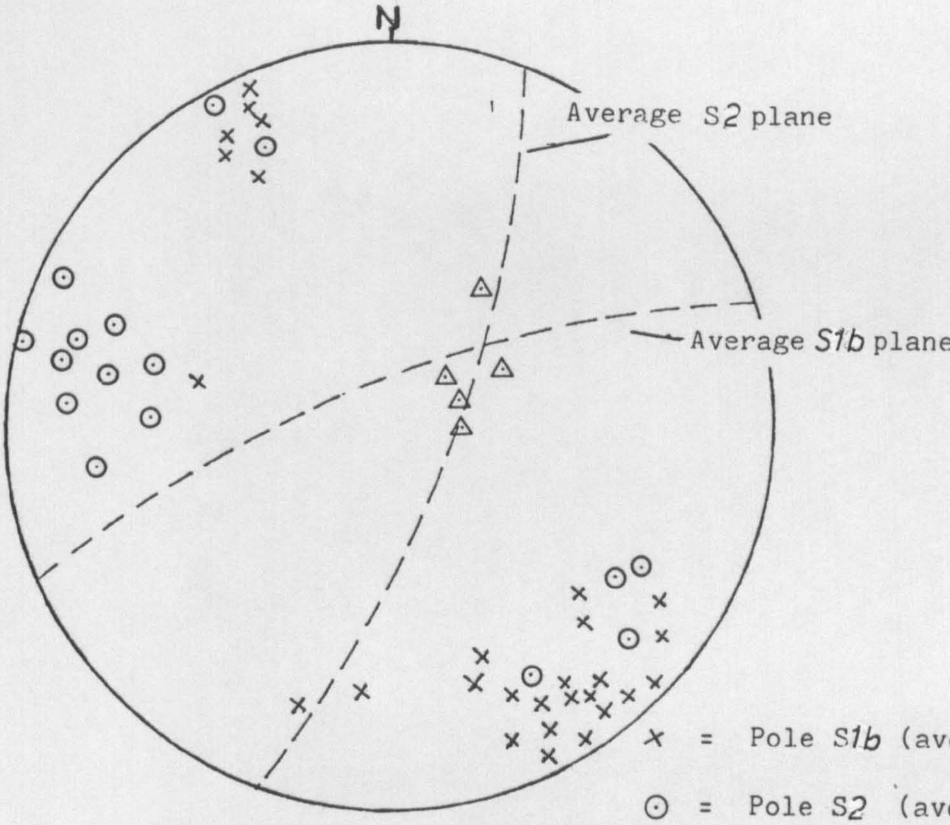
A spaced fracture cleavage, axial planar to these D2 folds, is moderately well-developed in the striped amphibolites and this is parallel to the S2 foliation developed in the granitoid mylonites. The latter, in the Pte. de Séhar region, display a slight warping of the S1b foliation but do not possess the fold structures of the striped amphibolites. The S2 fabric is widely developed in the granitoid mylonites, the fabric is non-pentrative and is best developed in the fine-grained, well-foliated mylonites.

The fabric is defined by a crenulation of the S1b mylonitic fabric, principally of the mica-rich bands. The S2 foliation is developed at 015-030^{o} NNE and the intersection of this foliation with the S1b foliation produces an intersection lineation. In the Locquirec area the two fabrics from an angle of between 15-30^{o}, but in the Pte. de Séhar region due to the E-W trend of the S1b foliation the angle is between c. 30 and 50^{o}. The intersection lineation S1b/S2 plunges at a steep angle (70-80^{o}) to the northeast (Fig. 5:32).

The post-D1 deformed metabasic dykes possess a single schistosity considered to be S2. Fig. 5:33 shows a thin (c. 40 cm) cross-cutting dyke with a well-developed S2 fabric developed at approximately 30^{o} to the S1b mylonite foliation in this area.

A component of flattening is inherent in simple shear deformation and structures within the LSB indicate shortening across the shear belt. Significant shortening across the shear belt is indicated by the presence of apparent flattened clasts within the poudingues and by the extension of the plagioclase grains. It is difficult to give an estimate as to the amount of D1 shortening across the shear belt as the D2 episode also resulted in flattening. This is indicated by, 1) the occurrence of several folded and boudinaged quartz veins (considered to have been

Fig. 5:32 *S1b/S2* relationships LSB; Pte de Sehar.



× = Pole *S1b* (average strike 065/80 SE)

⊙ = Pole *S2* (average strike 018/78 W)

△ = *S1b/S2* intersection lineation (ave. 044/65)

Field photograph of mylonites with two prominent foliations.

S1b is parallel to the mylonitic banding. Scale : Key 45 mm.

Fig. 5:33 Cross-cutting metabasic sheet, Pte. de Séhar

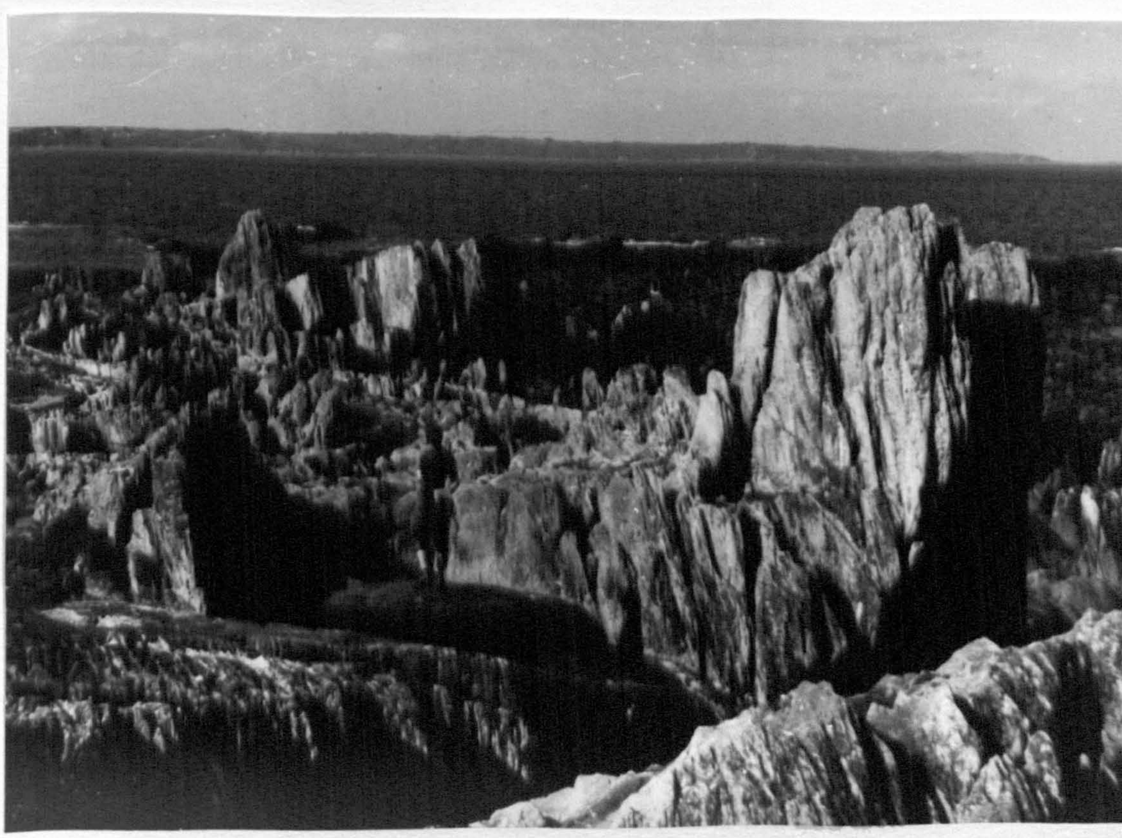
A c. 40 cm thick metabasic sheet truncates the S1b mylonitic banding. The sheet possesses a spaced S2 foliation that is developed at NNE-SSW. Four such metabasic sheets are recognised that truncate the LSB at a high angle.

Scale: Hammer shaft 40 cm

Fig. 5:37 The LSB at Pte. de Séhar looking SW towards Locquirec

General view of the LSB mylonites at Pte. de Séhar looking along strike towards Locquirec. The lithology is dominantly granitic (quartz-feldspar) mylonite. Featured geologist Graham Lees.


mylonites
sheet
S2



emplaced post-D1), 2) the open folding of the post-D1 metabasic dykes that truncate the S1b mylonitic foliation at a high angle and 3) the boudinage of those metabasic dykes lying more parallel to this foliation.

(4) THE D3 EPISODE AND LATE BRITTLE STRUCTURES

Contact metamorphism associated with the Hercynian Granite de Trédrez post-dates the D2 episode. A well-developed metamorphic aureole is associated with this granite, and in the eastern Pte. de Séhar area contact metamorphism has produced a relatively homogeneous amphibole and epidote-rich hornfels. The S1b foliation is destroyed in the immediate contact area near the Pte. du Dourven (Fig. 5:1). Further away from the granite the effect of the contact metamorphism is less marked and the S2 foliation is preserved in the form of relict lithological segregation banding (the striped amphibolites). Amphibole and epidote produced during contact metamorphism overgrow this banding. Corona structure is commonly developed in the granitoid mylonites and striped amphibolites with the nucleation of amphibole on biotite.

The widespread development of kink-bands in the strongly foliated mylonites and the striped amphibolites post-dates the metamorphism associated with the emplacement of the Granite de Trédrez. The kink-bands frequently occur in conjugate sets with one set commonly developed parallel to the S2 foliation. Fig. 5:34 illustrates the nature of the kink-bands in the mylonites of the Locquirec area. Some rather spectacular brittle conjugate structures are developed in the striped amphibolites in the Malabri area (Fig. 5:35). The kink-bands and other brittle structures affect the D3 hornfelsed lithologies and therefore were developed after the emplacement of the Granite de Trédrez.

Fig. 5:34 Ultramylonites, Pte. du Chateau

Well-developed mylonitic segregation banding is developed in fine-grained ultramylonites. These are frequently deformed by D4 kink-bands orientated at NW-SE – NE-SW.

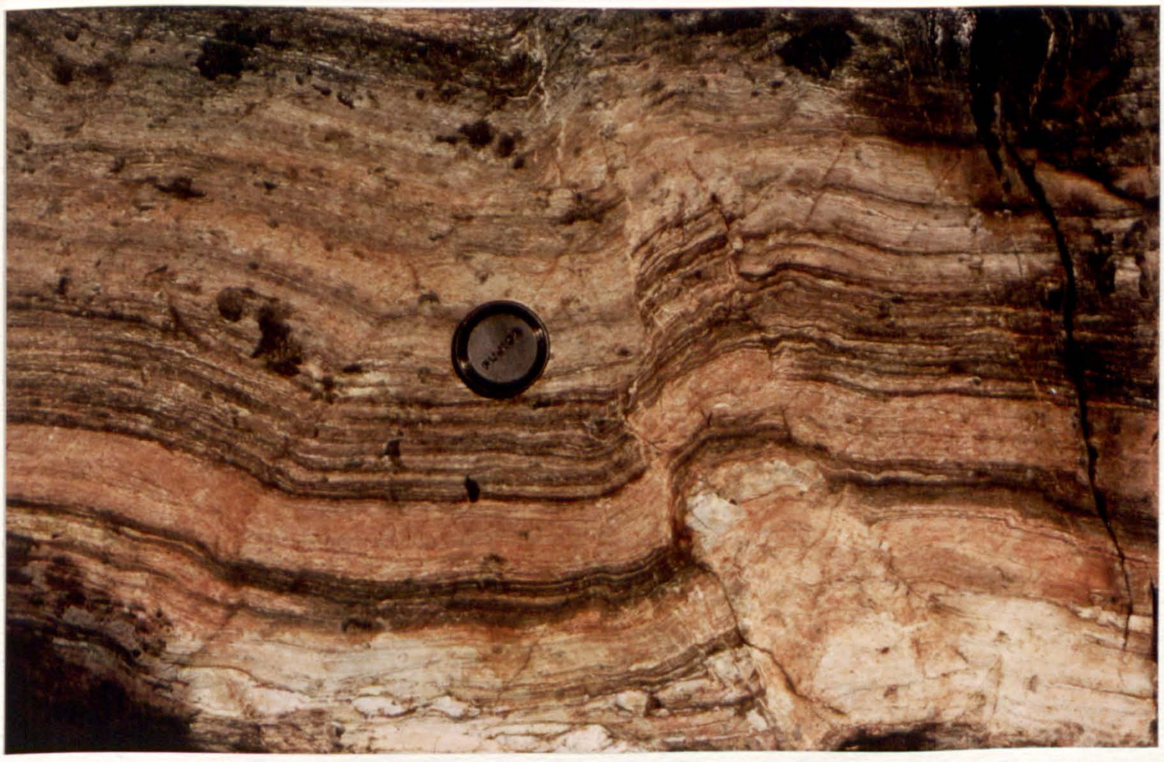
Scale: Lens cap 54 mm

Fig. 5:35 Striped amphibolites, S. Malabri

This lithology shows brittle microstructures such as microfaults and kink-bands which deform the early segregation banding.

Scale: Lens cap 54 mm

N.B. Fig. 5:37 attached to 5:33



(5) SUMMARY

Table 5:1 summarizes the structural and metamorphic events recognised in the LSB. Three distinct foliations are present, termed S1a, S1b and S2. The S1a foliation is a penetrative gneissose fabric, best developed in the orthogneiss complex and in the granitic protomylonites, while S1b is a more continuous closely spaced foliation (schistosity) developed in the shear zones. S1a and S1b are related to the same deformation episode termed D1. A foliation termed S1c is developed in the highest deformed mylonites and is related to the shear zone formation and therefore D1.

Shear zones in the orthogneiss complex, including the LSB, were initiated in localized areas in which several different softening mechanisms were operative. The S1a and S1b foliations were either formed simultaneously during heterogeneous simple shear or the two foliations formed sequentially during progressive heterogeneous simple shearing, so that in effect S1b developed from S1a as a shear-band structure (White et al. 1980). There is not sufficient evidence to state which of the above models occurred.

S2 developed during the later D2 episode, and resulted in a crenulation foliation in the more schistose mylonites and a well-developed foliation in the metabasic dyke suite. D2 folds are present in the striped amphibolites, and open flexures of the same generation are developed in the granitoid mylonites of the Pte. de Séhar area.

Emplacement of the Hercynian Granite de Trédrez (with a biotite K/Ar date of 320 ± 10 m.y. on biotite and a Rb/Sr whole rock date of 300 ± 10 m.y; Leutwein et al. 1968) led to medium grade contact metamorphism of the LSB lithologies in the Pte. de Séhar area.

Late or post D3	Kink-bands and brittle structures, microfaults, etc.
D3	Emplacement of Granite de Trédrez and associated medium-grade contact metamorphism in Pte. de Séhar to Beg Ar Forn area.
D2	Lower-greenschist facies metamorphism (affects the metabasic dyke suite). Foliation S2 developed in metabasic dykes and in finely foliated mylonites. Chevron folds developed in striped amphibolites, open warping of the mylonites (restricted largely to the Pte de Séhar).
	Emplacement of basic dyke suite
D1	Greenschist facies metamorphism, syn-deformation. Assemblage = Qtz + Alb + K-felds + Chl + Musc + Calc + Epi. Development of S1c shear band structure in ultramylonites and highest deformed mylonites. Development of main S1b mylonitic foliation in shear zones and LSB. Microshears or crush zones in granodiorite and other components. Development of S1a gneissose foliation in the Moulin de la Rive Orthogneiss Complex and parts of the LSB. ↑ Progressive or simultaneous development ?

TABLE 5 : 1 - SUMMARY OF DEFORMATION AND METAMORPHIC EPISODES, LSB.

D2 post-dated the emplacement of the basic dyke suite (considered to be of Strunian age, see Chapter 6) and pre-dated the Granite de Trédrez. The D1 episode pre-dated the dyke emplacement, and the deformation must have occurred in the time interval between the emplacement of the late Precambrian igneous rocks, which now form the Moulin de la Rive Orthogneiss Complex (and the Perros-Guirec Granitoid Complex), and the emplacement of the late Devonian-early Carboniferous basic dyke suite. The D1 episode can therefore be considered as related to Cadomian or early Hercynian (Bretonic) earth movements.

(D) COMPARISON OF ROCKS OF THE LOCQUIREC SHEAR BELT WITH THOSE OF OTHER SHEAR BELTS IN THE TRÉGOR

Two major mylonite belts have been recognised in the Trégor (the area between Trébeurden and Paimpol) and both of these appear to be formed of granitoid mylonitic lithologies similar to those of the LSB. These are called in this thesis; 1) the Trégor Shear Belt, which trends E-W and passes close to the towns of Lannion, Tréguier and Paimpol, and 2) The Pte. de Bihit Shear Belt, which extends northeastwards from Pte. de Bihit to Porz Rolland (Fig. 5:36).

The Trégor Shear Belt (TSB) accords approximately to the outcrop of the unit commonly known as the Tufs de Tréguier(Barrois 1908b). This shear belt incorporates granitoid rocks similar to those developed in the LSB and it is proposed that the various granitoid mylonites were derived from a plutonic igneous host, rather than tuffs, as has been envisaged by all previous workers who have described this lithology, from Barrois (op. cit.) to Auvray (1979). In the TSB of the Lézardrieux and Tréguier areas the protomylonites and mylonites appear to have been derived from crystalline rocks varying from granodioritic (sometimes tonalitic) to granitic composition. Relict porphyritic textures (phenocrysts of plagioclase ± quartz and groundmass quartz-feldspar intergrowths are seen, particularly in specimens taken from the northern margin of the shear belt.

Along the southern margin of the Perros-Guirec Granitoid Complex, e.g. at Porz Even near Paimpol, other lithologies have been involved in the development of the TSB, although in this area the degree of deformation is less and notably heterogeneous. These include rocks (supposed pyroclastic ash flows) labelled the Ignimbrites de Lézardrieux, which have yielded an Rb/Sr whole-rock isochron date of 547 ± 12 m.y. (Auvray 1972, 1974, 1979; Auvray and Vidal 1973; Auvray et al. 1976).

The Trégor Shear Belt is developed along the southern margin of the Pe-ros-Guirec Granitoid Complex and is a major tectonic structure. This igneous complex is demonstrably intrusive into the Brioverian metavolcanic and metasedimentary formations in the Lézardrieux area (Roach pers. comm.), and is thus in a similar stratigraphical-structural relationship to the Moulin de la Rive Orthogneiss Complex which intrudes Brioverian metavolcanics in the Baie de Lannion area.

In the Pte. de Bihit area the granodioritic to granitic Gneiss de Trébeurden (Barriere 1976; Auvray 1979) is deformed within a major NE-SW trending shear zone, here called the Pte. de Bihit Shear Belt. Early amphibolite components (possible rafts of basement material) of the Gneiss de Trébeurden are deformed within the shear zone, but the dominant lithology is a highly deformed granitoid mylonite, that passes gradationally from a mylonitic rock into a foliated granite with a variably developed S1a type fabric. The mylonites are also similar in composition and nature to those of the LSB.

Mylonitic rocks crop out along the coast in the Porz Rolland area (Fig. 5:36) and are considered to form the northern extension of the Pte. de Bihit Shear Belt. At this locality intermediate-acidic composition

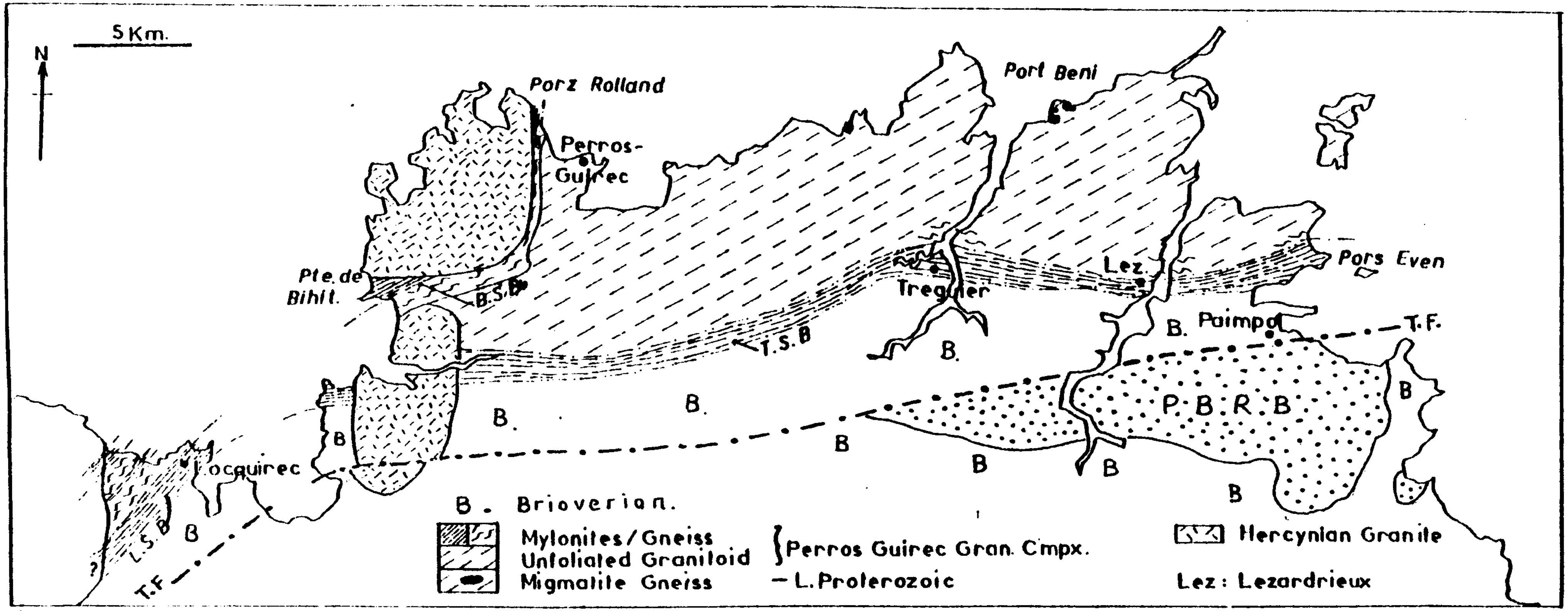


FIG. 5 : 36 MAJOR SHEAR BELTS IN THE TREGOR AND PETIT TREGOR

The LSB rotates from a NE - SW to an E - W trend and forms the western continuation of the major Trégor Shear Belt (TSB). The relationship of the Pte de Bihit Shear Belt (BSB) is not clear, it may be a branch of the LSB - TSB system or related to other large shear zones recognised in the Orthogneiss Complex of Moulin de la Rive. Lower Proterozoic migmatite gneisses enclosed within the Cadomian Perros-Guirec Complex are shown in the Port Beni and Locquirec (Moulin de la Rive) areas. P.B.R.B. = Plurive Bréhec Red Beds. T.F. = Trégorrois Fault mylonites are developed which can be demonstrated to pass gradationally into unfoliated Granite de Perros (the Granite de Port-Blanc of Auvray 1979). The western margin of the shear belt is truncated by the late Hercynian Granite de Ploumanac'h.

Thus there is evidence of large-scale deformation in hitherto largely unrecognised shear zones within and along the margins of the Perros-Guirec Granitoid Complex. The Moulin de la Rive Orthogneiss Complex represents the western extension of this granitoid complex,where it is in a relatively highly,but markedly heterogeneously,deformed state. See also discussion in chapter 4, section (D).

Major shear zones have developed in the Petit Trégor and the Trégor to accommodate large regional strains,and they are all possibly related to the same period of earth-movements. In Chapter 8 it is argued that the NE-SW trending shear zones have developed as splays off the E-W trending North Armoricain Shear Zone and the largest of these, the LSB-TSB system, swings into an east-west trend in response to local geological conditions.

(E) GEOCHEMISTRY OF THE MOULIN DE LA RIVE ORTHOGNEISS COMPLEX AND THE LOCQUIREC SHEAR BELT ROCKS

Twenty-eight rock samples from the Moulin de la Rive Orthogneiss Complex and the Locquirec Shear Belt have been analysed. The localities of these specimens are indicated in Appendix 2 and the resulting analyses tabulated in Appendices 3B and 3C, where both major and trace element data is presented.

Only a brief discussion is given here of the results, as more data is clearly required on the several components of the orthogneiss complex, and it is intended to produce a more detailed synthesis at a later date. However, it is possible with the data available to make some contrasts between the components of the orthogneiss complex and the mylonites of the LSB which, as indicated in this and the previous chapter, form the highly deformed southeastern marginal facies of the Moulin de la Rive Orthogneiss Complex.

Information was given in Chapter 4 on the nature and distribution of the components forming the Moulin de la Rive Orthogneiss Complex. Appendix 3B gives one analysis of the gabbro component, three analyses of the tonalite/quartz diorite component, four analyses of the granite component, and four analyses of the porphyritic microgranite component. The SiO_2 content ranges from approximately 52 to 75%, reflecting the basic through to acidic nature of the complex. Na_2O is always higher than K_2O in the granite and porphyritic microgranite components. Mineralogically, these acidic components could be classified as adamellites. However, in the Streckeisen classification of plutonic rocks (1974) the term adamellite is not used so the acidic components are probably granites lying near the granite-granodiorite boundary.

The overall calc-alkaline nature of the Moulin de la Rive Orthogneiss Complex is supported by the major and trace element data. A distinctive feature of the acidic components, which is apparent even with the limited number of analyses, is their peraluminous nature combined with relatively high Na_2O values (six of the eight specimens analyses have Na_2O>5%), low CaO values (in the range 0.26-0.64%) and a SiO_2 range of 70.46-72.66%. In this respect they resemble the I-type granite series (Chapple and White 1974).

The granite and porphyritic microgranite components dominate the eastern part of the orthogneiss complex adjacent to the LSB (Map 4). At the boundary between the orthogneiss complex and the LSB it is these acidic components that become heterogeneously deformed to protomylonites. These give way to mylonites and ultramylonites within the LSB.

Eleven chemical analyses were made on rocks from the LSB in order to compare the overall geochemical characteristics of the various mylonites with those of eight samples from the granite and porphyritic microgranite components. Table 5:2 gives average values and range of values for the major elements and selected trace elements for the two acidic components of the orthogneiss complex, the LSB mylonitic rocks, and the tonalite/quartz diorite components of the orthogneiss complex.

As it is certain that some degree of metamorphic segregation will have occurred during the development of the mylonitic rocks (this is apparent in the field from the variably banded nature of some of the mylonites), care must be exercised in comparing the three groups of analyses.

TABLE 5:2 - Summary of average values and range of values for major elements and selected trace elements of specimens from the granite and porphyritic microgranite components of the Moulin de la Rive Orthogneiss Complex (8 analyses), LSB mylonites (11 analyses) and the tonalite/quartz-diorite component of the orthogneiss complex (3 analyses).

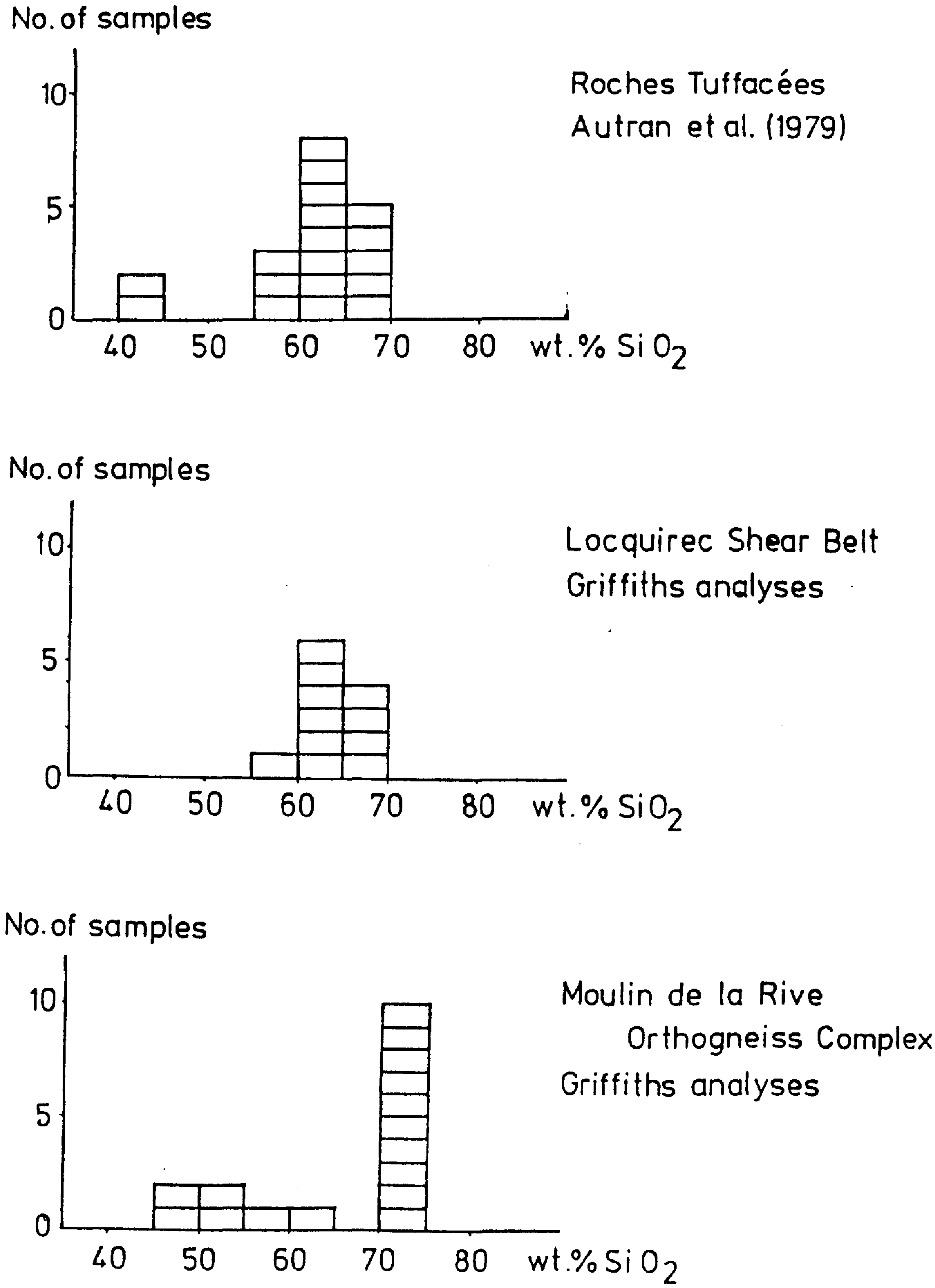
	Granite and porphyritic microgranite component		LSB mylonites		Tonalite-quartz diorite component	
	Av.	Range	Av.	Range	Av.	Range
SiO_2	71.96	(70.46-74.59	63.99	(59.90-68.96)	58.20	(54.18-63.07)
TiO_2	0.23	(0.17-0.26)	0.61	(0.43-1.10)	0.77	(0.61-0.89)
Al_2O_3	14.43	(13.89-14.90)	15.47	(12.37-16.90)	18.58	(17.13-21.01)
Fe_2O_3	1.38	(0.00-2.09)	3.49	(1.16-6.62)	4.36	(3.14-6.30)
FeO	1.47	(0.76-3.76)	1.63	(0.17-3.12)	2.61	(1.61-4.37)
MnO	0.05	(0.02-0.13)	0.10	(0.02-0.13)	0.11	(0.08-0.12)
MgO	0.60	(0.34-0.95)	1.95	(0.82-3.53)	1.94	(1.30-2.13)
CaO	0.48	(0.26-0.64)	2.38	(0.20-3.84)	5.77	(4.65-7.19)
Na_2O	4.92	(3.18-5.56)	4.71	(0.57-7.53)	4.60	(4.17-5.38)
K_2O	3.25	(2.71-3.83)	2.35	(0.77-5.36)	1.74	(1.42-2.37)
P_2O_5	0.05	(0.03-0.07)	0.18	(0.10-0.24)	0.24	(0.21-0.26)
Nb	23	(14-27)	14	(12-17)	18	(17-21)
Y	28	(20-33)	18	(10-31)	26	(18-37)
Zr	231	(116-263)	186	(143-301)	279	(245-345)

It is clear from Table 5:2 that there are sufficient major differences in chemistry between the acidic components of the orthogneiss complex and mylonitic rocks to indicate that the LSB mylonites analysed were not produced by intense ductile deformation of a parent comparable in composition to either the granite or the porphyritic mcirogranite component. The mylonites are poorer in SiO_2, K_2O, Nb, Zr, but richer in TiO_2, total iron (as Fe_2O_3), MnO, MgO, CaO, and P_2O_5 than the two acidic components of the orthogneiss complex.

Some of these differences are even more apparent when the figures are examined closely. For example, seven out of the eight granite and porphyritic microgranite analyses have Zr>230 ppm while nine out of the eleven mylonite analyses have Zr<230 ppm. All the granite and porphyritic microgranite analyses have Y>19 ppm while eight out of eleven mylonite analyses have Y<19 ppm. Another significant difference is in the SiO_2 content, the range for the granite and porphyritic microgranite components (70.46-74.59%) being above and outside the range for the mylonites (59.90-68.96%), even though zones of silica-enrichment and depletion could have been produced during ductile shearing. This difference is also shown on the histograms in Fig. 5:37, where both the present author's data for the granitoid mylonites and those of Autran et al. (1979) for the supposed "Tuffs de Locquirec", form a grouping distinct from the two acidic components of the Moulin de la Rive Orthogneiss Complex.

For the mylonites of the LSB, the range in K_2O and Na_2O values overlap the range of these values in the granite and porphyritic micro-granite components, probably reflecting the mobility of these elements during ductile shearing. CaO also exhibits considerable variation within the mylonites, but when individual figures are examined, ten out of

Histograms of SiO_2 Content



eleven analyses have values >1.92% compared with an average value of 0.60% and a range 0.26-0.64% for the granite and porphyritic microgranite components. It thus seems probable that the parent rock of the mylonites was more calcic than the two acidic components of the orthogneiss complex.

It is more difficult to make a comparison with the tonalite/quartz diorite component of the complex as there are only three analyses available at present. However, from Table 5:2 it does appear that these more intermediate rocks are generally poorer in SiO_2, FeO, Fe_2O_3, K_2O, and Rb, but richer in Al_2O_3, CaO, Y, and Zr than the LSB mylonites.

It may be concluded from this preliminary survey that the LSB mylonites appear to represent, in terms of their major and trace element geochemistry, highly deformed granitoids which lie broadly between the composition of the acidic and intermediate components of the Moulin de la Rive Orthogneiss Complex. The LSB mylonites cannot be directly equated with any component recognized and analysed so far within the orthogneiss complex. It is tentatively suggested from a study of the relict primary mineralogy and the geochemical data, that the parent rocks were mainly either plagioclase or quartz plus plagioclase phenocrystic intrusive rocks of microgranodioritic to quartz micro-monzodiorite composition according to the Streckeisen classification. Unfortunately, no deformed intrusive contacts have been identified between such rocks and the protomylonitic equivalents of the more acid components of the Moulin de la Rive Complex in its boundary zone with the LSB.

(F) GEOCHRONOLOGY

In Chapter 4 geochronological evidence presented for the Perros-Guirec Granitoid Complex and the Moulin de la Rive Orthogneiss Complex indicated a Cadomian age for these two related composite plutons. The LSB is developed in the orthogneiss complex and it appears to be related to the westerly extension of a major ductile shear zone, the Trégor Shear Belt (Fig. 5:36), that accords to the outcrop of the Tufs de Tréguier (Barrois 1908b; Pruvost, Waterlot and Delattre 1966; Auvray 1979). Geochronological data for the LSB is limited, but several authors have published dates for the rocks labelled Tufs de Tréguier and related lithologies along the southern margin of the Perros-Guirec Granitoid Complex. The geochronological information that has been published for relevant lithologies in both the LSB and Trégor Shear Belt is summarized in Table 5:2.

In the Locquirec area, Charlot (in Autran et al. 1979) produced an Rb/Sr whole rock isochron on five acidic dykes (filons ketatophyriques) occurring between the Grève de St. Michel and Pte. de Corbeau. Four of these dykes truncate the Formation de Pte. de l'Armorique while the fifth occurs at the Pte. du Corbeau within the Moulin de la Rive Orthogneiss Complex. The isochron date reached was 586 ± 18 m.y. Unfortunately, no location was given for the dyke cutting the orthogneiss complex, and the isochron could be interpreted as representing either the emplacement age of these acidic dykes or of isotopic disturbance during a metamorphic episode (Cadomian?). A six point Rb/Sr whole rock isochron for the Tufs de Locquirec show a considerable scatter of points between 1170 m.y. and 510 m.y.. Four of the points are aligned at 745 ± 35 m.y. (Table 5:2), but Charlot considers this date to be spurious and not representative of the date of eruption of these rocks. Indeed contamination of the sampled material may have occurred as basement derived fragments (large K-feldspars in the poudingue

AUTHOR	LITHOLOGY	METHOD	Pts.	RATIO	AGE
CHARLOT 1979 (in Autran et al)	TUFS DE LOCQUIREC	87Sr/86Sr WR	6	0.7073	745 ± 35 My
	FILONS KERATOPHYRIQUES	87Sr/86Sr WR	5	0.7035 ± 0.0002	586 ± 18 My
AUVRAY 1979	SPILITES DE PAIMPOL (2 Spees) and TUFS DE TREGUIER (7 Spees)	87Sr/86Sr WR	9	0.7048 ± 0.0003	640 ± 12 My *
"	IGNIMBRITES DE LEZARDRIEUX (5pts)	87Sr/86Sr WR	5	0.7064 ± 0.0012	548 ± 24 My *
VIDAL 1980	TUFS DE TREGUIER (7 spees) SPILITES DE PAIMPOL (3 Spees)	Rb/Sr	10	0.7048 ± 0.0003	618 ± 12 My +
	IGNIMBRITES DE LEZARDRIEUX	Rb/Sr 87-86 Sr	5	0.7064 ± 0.0012	528 ± 12 My +
LEUTWEIN, SONET AND ZIMMERMAN (1969)	TUFS DE TREGUIER (Porz Even)	K/Ar WR			440 ± 30 My
	TUFS DE TREGUIER (Treguier)	Rb/Sr WR			420 ± 40 My
	SCHISTES DE LOCQUIREC "	K/Ar K/Ar			300 ± 10 My 350 ± 10 My
	GNEISS DE LA PTE DE BIHIT	K/Ar			315 ± 10 My *

+ calculated with λ Rb^{87} = 1.47 x 10^{-11} Yr^{-1}
* revised VIDAL data (published 1980 from thesis completed in 1976).

TABLE 5 : 2 - AVAILABLE GEOCHRONOLOGICAL AGES FOR THE ROCKS PREVIOUSLY NAMED THE TUFFS DE TREGUIER AND OTHER RELATED LITHOLOGIES.

horizons) may have been analysed. He concludes that the Tufs de Locquirec are contemporaneous with the Tufs de Tréguier (based on Auvray's 640 ± 12 m.y. age, Table 5:2) and the filons keratophyriques are unconnected with the tuffaceous, acidic volcanism and represent later magmatic activity.

Leutwein et al. (1969) obtained two K/Ar whole-rock dates of 350 ± 10 m.y. and 300 ± 10 m.y. for the Schistes de Locquirec (i.e. mylonitic rocks of the LSB), and a K/Ar whole-rock date of 315 ± 10 m.y. for the Gneiss de la Pointe de Bihit (the Gneiss de Trébeurden of Barriere 1976 and Auvray 1979).

Vidal (1976) produced an Rb/Sr whole-rock isochron date of 618 ± 12 m.y., based on three specimens from the Spilites de Paimpol (the lateral equivalents of the Formation de Pte. de l'Armorique of this thesis) and seven specimens from the Tuffs de Tréguier (considered to be the mylonitized southernmost component of the Perros-Guirec Granitoid Complex). Subsequent to the above publication Auvray (1979) and Vidal et al. (1981) quote the same results with an isochron date of 640 ± 12 m.y., calculated using $\lambda Rb^{87} = 1.42 \times 10^{-11}$ yr^{-1} as against the value $\lambda Rb^{87} = 1.47 \times 10^{-11}$ yr^{-1} originally used by Vidal (op. cit.; Table 5:2).

In Vidal et al. (op.cit.) the 640 ± 12 m.y. date is used as a basis for placing the Spilites de Paimpol and the Tuffs de Tréguier within the Upper Brioverian. However, the grouping together of the Spilites de Paimpol and the Tuffs de Tréguier on the same isochron is considered invalid, as work in progress (Roach and Griffiths) indicates that the Tuffs de Tréguier are not pyroclastic rocks but the heterogeneously deformed marginal component of the Perros-Guirec Granitoid Complex. These form the major part of the Trégor Shear Belt. Removal of the two spilite analyses would have little affect on the position of a seven point isochron for the rocks analysed as the Tuffs de Tréguier. It could be argued that the 640 ± 12 m.y. date represents either the age of emplacement of a segment of the Perros-Guirec Granitoid Complex or signifies an episode of Cadomian metamorphism. It should be noted that the 640 m.y. value is not too distant from the combined whole-rock/mineral Rb/Sr isochron date of 617 ± 15 m.y., that Adams (1967) obtained from foliated granitoid rocks forming the reefs and islands of Ecréhous, Paternosters and Minquiers off southern Jersey. These reefs may form the easternmost observed extension of a major heterogeneously deformed and metamorphosed north Brittany batholith, which is also thought to include the Gneiss Granitique d'Île Callot in the west (Chapter 2), the St. Jean-du-Doigt Gabbro Complex (Chapter 7), the Moulin de la Rive Orthogneiss Complex and its sheared marginal equivalent the LSB (Chapters 4 and 5), the Perros-Guirec Granitoid Complex and its southern marginal facies in the Trégor Shear Belt.

However, part of the Perros-Guirec Granitoid Complex and the TSB appears to contain younger components. The rocks labelled the Ignimbrites de Lézardrieux (Auvray 1974) have yielded a five point Rb/Sr whole rock isochron date of 547 ± 12 m.y. (Auvray 1979). Auvray (1972, 1974, 1979) claims that these ignimbritic rhyolites rest with discordance on the Spilites de Paimpol and the Tuffs de Tréguier, and indicate a period of Cambrian Volcanism. Work in progress (Roach and Griffiths) points to the Ignimbrites de Lézardrieux as being originally high-level intrusive porphyritic rhyolites (with evidence of a frequently glassy groundmass). This date for the 'ignimbrites' accords well with the 554 ± 19 m.y. date that Auvray (1979) quotes for a nine point Rb/Sr whole rock isochron, obtained from specimens of the Granite de Porz Scorff (from the north Trégor coast) and the Microgranites de Loguivy (which lie immediately north of the TSB in the eastern part of the Trégor).

Leutwein et al. (1968) obtained a K/Ar whole-rock date of 440 ± 30 m.y. and a Rb/Sr whole-rock date of 420 ± 20 m.y. for specimens from the Tuffs de Tréguier at Tréguier and Pors Even. It is difficult to interpret Leutwein's dates for these rocks but they could:-

1) Reflect a post-Cadomian but pre-Hercynian metamorphic episode.

2) Represent a spurious mixed age.

(G) CONCLUSIONS

The LSB is the largest of a number of NE-SW trending shear zones that cut the Moulin de la Rive Orthogneiss Complex in the Petit Trégor. The LSB forms part of a large shear zone system which affects the western and southern parts of the major Perros-Guirec Granitoid Complex in the Petit Trégor and the Trégor areas of northern Brittany.

The LSB is composed of a number of different lithological units, collectively termed mylonites, that are variably deformed. The dominant lithologies are granitoid mylonites many of which are derived from a granodioritic porphyry parent lithology. In the Pte. de Séhar area striped amphibolites are an important constituent of the LSB and these are derived from the Brioverian metabasic Formation de Pte. de l'Armorique.

The orthogneiss complex was emplaced into the Brioverian Supergroup and field and geochronological evidence points to a Cadomian age of emplacement for the complex.

The mylonites were formed during an episode labelled D1. Two major foliations were developed during this episode, S1a a gneissose fabric and S1b, a finer-scale and more continuous mylonitic schistose foliation. S1b may have developed simultaneosly or sequentially to the S1a fabric as a shear-band structure.

A series of basic sheets were emplaced post-D1 and these are considered to be the hypabyssal equivalents of the Strunian-lowermost Dinantian, Formation de Barnénez which crops out in the Morlaix Basin (discussed in Chapter 6). The dykes and the mylonitic rocks of the LSB are affected by a D2 episode which resulted in the development of an S2 crenulation fabric and some minor folding. Significant contact metamorphism is associated with the emplacement of the late Hercynian Granite de Trédrez. The D2 episode can be bracketed within the interval post-early Dinantian to pre-late Hercynian. The development of the LSB occurred at some time within the interval late-Cadomian to Bretonic (early Hercynian). This is discussed further in Chapter 8.

CHAPTER SIX

THE PALAEOZOIC FORMATIONS OF THE MORLAIX BASIN AND ST. MICHEL-EN-GRÈVE AREA

CHAPTER SIX

THE PALAEOZOIC FORMATIONS OF THE MORLAIX BASIN AND THE ST. MICHEL-EN-GRÈVE AREA

(A) INTRODUCTION

The Morlaix Basin is the name used in this thesis for the area that lies between the St. Pol-de-Léon Metamorphic Complex and the area known as the Petit Trégor. The term basin is used in a geographical sense and although metasedimentary formations, assigned to the Palaeozoic, are restricted to this area they may not necessarily have been deposited in a single basin as envisaged by Cabanis et al. (1979a). In the St. Michel-en-Grève area metasedimentary lithologies occur that are also attributed to the Palaeozoic but these are isolated from the lithologies of the Morlaix Basin (Maps 1 & 2).

A new stratigraphy is erected for the Morlaix Basin, which is based largely on the relationship recognised between fossiliferous metasediments (the Poudingues de Dourduff) and unfossiliferous metasediments, principally the Schistes Zébrés de Morlaix. This stratigraphy differs considerably from that proposed by Cabanis (1974) and Cabanis et al. (1979a, 1981). Particular attention is given to the nature of the boundary between the Morlaix Basin with the adjacent tectono-metamorphic areas, as these critical boundaries have largely been ignored in the previous literature.

(B) PREVIOUS RESEARCH

The spectacular lithologies that crop out within the Morlaix Basin have been documented by several authors who have assigned different ages to the rocks of the area, with little general agreement. Barrois (1905a and b) first termed the sequence of alternating psammitic or semi-psammitic and pelitic metasediments, which crop out around and to the north of Morlaix, the Schistes Zébrés de Morlaix, to which he attributed a Brioverian age. He considered the overlying Arkose de Kerarmel to be Lower Brioverian and correlated this unit with the Tufs de Brélévenez (i.e. Tufs de Locquirec). Milon (1928) considered the Schistes Zébrés to be Brioverian in age, and the fossiliferous Poudingues et Calcaires de Dourduff (equivalent to the Poudingue de Dourduff Member of the Formation de Dourduff of this thesis) to be Carboniferous. Delattre (1952a) and Delattre et al. (1966) considered the Quartzophyllades de St. Martin-des-Champs, i.e. Schistes Zébrés (the Formation de Morlaix of this thesis) and the Poudingues et Calcaires de Dourduff to be of Lower Devonian (Coblencian) age and of Lower Carboniferous (Dinantian) age respectively, with the deformation being Hercynian.

More recently, Cabanis (1972, 1974, 1975) and Cabanis et al. (1979a, 1981) have considered the formations of the Morlaix area to be a volcano-sedimentary assemblage that has infilled a "unité apatialement circonscrite" - the Morlaix Basin. It is marked, in the southern half of the basin, by a basal formation (the Schistes et Grès Feldspathiques of Upper Devonian age) followed by the Formation de Dourduff, which is in turn overlain by the Schistes Zébrés. These authors cite the Strunian age, obtained by Coquel and Deunff (1977), for the dark pelites interbedded with the Poudingues de Dourduff which, together with the enclosing sequence (the Schistes Ardoisiers), comprise the Formation de Dourduff (sensu Cabanis et al. 1979a). The overlying Schistes Zébrés are assigned to the Tournaisian.

Cabanis et al. (op. cit. 1979a) consider the Devono-Carboniferous formations to overlie predominantly Brioverian lithologies along the eastern part of the Morlaix Basin. In the northeast part of the basin they consider metadolerites amphibolitiques (the Formation de Barnénez of this thesis) to be overlain by the Strunian-dated metasediments. They also consider the metabasic rocks to be of Upper Devonian age and the extrusive equivalents of the nearby Gabbro de St. Jean du Doigt (the St. Jean-du-Doigt Gabbro Complex of this thesis).

The structural sequence has been described by Cabanis (op. cit. 1974) and Cabanis et al. (1979a, 1981), and all deformation and metamorphism is considered by them to be Hercynian. Cabanis (1982) has described the geochemical characteristics of some of the metasedimentary formations within the Morlaix Basin and in adjacent units. Of note are the Micaschistes de Penzé which have different geochemical characteristics to the Brioverian rocks of the Petit Trégor.

Geochronological work in the area is limited, Leutwein et al. (1969) have given a 540 ± 30 m.y. K/Ar whole-rock date for the metabasic Formation de Barnénez. This, they point out, is compatible with the conclusion drawn earlier by Barrois that these rocks belonged to the Lower Brioverian. They also note the resemblance of these metabasic rocks to those in the Paimpol area, and conclude that the Formation de Barnénez is not Palaeozoic in age as suggested by Delattre et al. (1966).

In the Michel-en-Grève area, meta-quartzites that form the c. 85 m high Grand Rocher (also called Roch Hirglas) and the NE-SW trending hills in this area have traditionally been attributed to the Palaeozoic. Barrois (1980c) correlated these quartzites with the Grès de Toulgoat, which crops out in the area south of Morlaix, and to which he assigned a Lower Ordovician age (the Grès Armoricain). Delattre (1952a) and Delattre et al. (1958) placed the quartzites within the Lower Devonian and he considered these to be faulted against Brioverian rocks in the area west of the town of St. Michel-en-Grève. Delattre et al. (1966) considered the Grand Rocher to be an isolated quartz outcrop and the main belt of quartzites, which he labelled the Quartzites de St. Michel-en-Grève ($d2^b$), to be of Lower Devonian (Upper Sieginian) age.

Verdier (1968) considered the quartzites and associated pelites and semi-pelites that crop out in St. Michel-en-Grève area to be Lower Ordovician in age. He also described the structure of the lithologies in the Grève-de-St. Michel area. Verdier (op. cit.) termed the quartzites, the Gres Quartzites de Roc'h Hirglas, and the interbedded finer grained metasediments the Schistes à Chiastolites (the chiastolite being a product of late Hercynian contact metamorphism).

(C) THE PALAEOZOIC ROCKS OT THE ST. MICHEL-EN-GRÈVE AREA

Two metasedimentary formations considered to be of Palaeozoic age in this thesis crop out in the St. Michel-en-Grève area of the Petit Trégor (Map 2). The most extensive formation is the distinctive Quartzites de Grand Rocher, mainly composed of massive quartzites with some interbanded semi-pelites. The second formation recognised, the Schistes à Chiastolites de St. Michel-en-Grève, has an outcrop limited to the foreshore at St. Michel-en-Grève (this is broadly the equivalent of the Schists Noirs d'Izela, considered by Delattre et al. (1966) to be of Middle Sieginian age).

The Quartzites de Grand Rocher are in faulted contact with the Brioverian Formation de Plestin (Map 2) and, in the area between the boundary and the town of St. Michel, the formation is composed of interbedded quartzites, semi-pelites and semi-psammites. The quartzite beds range in thickness from 6-30 cm, with thinner semi-pelitic beds 2-10 cm thick and occasional semi-psammite beds up to 40 cm thick. The lithologies are strongly folded (Fig. 6:1).

A common sedimentary structure developed in the semi-pelitic beds are worm-tubes (Fig. 6:2). These are sub-vertical, c. 5 mm in diameter, rod-like structures composed of semi-psammitic material. The tubes provide strain-markers and are variable deformed in folded beds.

Fig. 6:1 Quartzites de Grand Rocher; W. St. Michel-en-Grève

Interbanded psammites and semi-psammites dominate the Quartzites de Grand Rocher in the area west of St. Michel. Upright F2 folds are well-developed with an associated crenulation cleavage. Rod-like structures, considered to be sub-horizontal worm tubes are common within the semi-psammite beds. Bedding in thinner psammite beds is often laterally discontinuous.

Scale: Coin 29 mm

Fig. 6:2 Quartzites de Grand Rocher; W. St. Michel-en-Grève

Probable deformed worm tubes in interbedded semi-psammites and semi-pelites. The structures are rod-like and are variably deformed adjacent the F2 fold hinges.

Scale: Width of field of view approximately 1 m

In the St. Michel-Grand Rocher area the quartzites are usually more massive, with beds 0.5-2 m thick (commonly c. 1 m). Thin, less than 5 mm thick laminie of pelitic material (dominantly composed of white mica) occurs between the massive quartzite beds. The quartzites are totally recrystallized and no primary sedimentary structures have been found. Bedding is often difficult to establish as the lithology is strongly jointed.

At St. Michel-en-Grève a series of dark pelites and semi-psammites crop-out on the foreshore at GR 1650 1258 under the church. This formation termed the Schistes d'Izela by Delattre et al. (1966) is here termed the Schistes à Chiastolites de St. Michel-en-Grève. This formation is not observed in contact with the Quartzites de Grand Rocher, but structural studies suggest that it underlies the Quartzites de Grand Rocher and occupies the core of an anticline. Verdier (1968) considered the two formations to be in faulted contact.

The semi-psammites are rich in quartz + white mica ± albite while the pelitic beds are composed of very fine-grained assemblage of quartz + biotite + white mica. Chiastolite is developed throughout the formation and is a product of contact metamorphism by the late Hercynian Granite de Trédrez and/or Granite de Plouaret.

The structure of the Palaeozoic rocks in the St. Michel-en-Grève area is similar to that in the adjacent Brioverian metasedimentary lithologies. Early tight to open F1 recumbent folds are recognised which face north-westwards (Fig. 6:1). These are commonly modified by low angle thrusts. A second fold phase F2 refolds the recumbent phase. These later folds are characterised by steep limbs with flat hinge zones. At St. Michel (GR 1659 1259) a single large-scale fold, height c. 40 cm, is observed in the massive quartzites that is similar in style to that of the smaller scale folds within the interbedded lithologies near the boundary of the formation.

An S1 fabric, developed axial-planar to the F1 folds, is defined by the alignment of the deformed worm tubes and phyllosilicate minerals. This fabric is generally sub-parallel to the bedding. A set of thin quartz veins (less than 1 mm) is also developed parallel to the S1 fabric.

A well-developed crenulation cleavage S2 is associated with the upright F2 structures and is orientated 050/80SE. This cleavage is non-penetrative and is restricted to the semi-pelitic and semi-psammitic lithologies. A pressure-solution lithological striping is developed parallel to the S2 crenulation fabric in some pelitic beds,and silica-rich worm-tubes are in part modified by this cleavage. In the quartzite beds an S2 fracture cleavage is commonly developed (Fig. 6:1). Joint sets orientated 040/60 SE and 060/90 are well-developed in the massive quartzites. Kink-bands orientated 060-080/90 are developed in some finer-grained laminated beds.

Contact metamorphism associated with the Hercynian Granite de Plouaret (Delattre et al. 1966) has resulted in complete recrystallization of the quartzites in the Grand Rocher area and in the development of biotite and chiastolite in the pelites. To the south of the Quartzites de Grand Rocher an extensive sequence of highly metamorphosed sediments occur that have been labelled the Migmatites de Tréduder in this thesis. The injection migmatite sequence is composed of meta-quartzites interbanded with more pelitic bands rich in biotite + silliminite + cordierite and injected by sheets of homogenous leucogranite that are considered to be related to the Granite de Plouaret. The metasediments are folded and small isoclines are occasionally recognised that pre-date the high temperature metamorphism. The Migmatites de Tréduder are adjacent to the Palaeozoic Quartzites de Grand Rocher but not enough work has been carried out to establish their exact relationship to other units.

However, the general quartz-rich psammitic nature of the sequence does suggest a Palaeozoic rather than a Precambrian age for these rocks.

The quartzites in the Grand Rocher area are crossed by a series of NW-SE trending faults that slightly offset the formation along the valleys of the Rivers Yar and Roscoat and in the region west of Grand Rocher (GR 1628 1247).

(D) THE RELATIONSHIP OF THE LITHOLOGIES OF THE MORLAIX BASIN TO THOSE OF THE ST. POL-DE-LÉON METAMORPHIC COMPLEX AND THE PETIT TRÉGOR

There are fundamental differences between the lithologies that comprise the Morlaix Basin and those in adjacent tectono-metamorphic units. Within the St. Pol-de-Léon Metamorphic Complex (discussed in Chapter 2) amphibolite facies rocks are encountered, and the lithologies are considered to be largely Brioverian supracrustals and Cadomian intrusives cut by extensive Hercynian granites. In the Morlaix Basin the supracrustal rocks are within the greenschist facies, the lithologies are considered to be of Palaeozoic age and Hercynian granite plutonism is less extensive.

A major structural feature, termed the Carantec Shear Belt (CSB), is recognised that forms the boundary between the two tectono-metamorphic units; the St. Pol-de-Léon Metamorphic Complex to the west and the Morlaix Basin to the east. The CSB is a major ductile shear zone within which mylonite rocks (now blastomylonites) of two possible parent types, psammites and granitoids, are present. Movement along this shear zone has resulted in the juxtaposition of the two contrasting tectono-metamorphic units.

The mylonites of the CSB are well exposed to the southeast of Carantec along the west side of the Morlaix Estuary at (GR 1400 1243) between Ty Nôd and the Plage du Clouët (GR 1412 1253). Inland exposure is poor, but mylonitic rocks can be traced south-southeast to Lavollot (GR 1428 1200) and towards St. Sève which lies to the southwest of Morlaix (GR 1415 1147).

The eastern boundary of the Morlaix Basin with the Petit Trégor lithologies is very poorly understood. It appears faulted in some areas and is possibly marked by an unconformity in other areas. In the north-east part of the basin the Palaeozoic lithologies are in faulted contact with the St. Jean-du-Doigt Gabbro Complex. The present author has not been able to locate a junction between Brioverian and Palaeozoic rocks along the eastern margin of the Basin. Cabanis et al. (1979a) interpret the Palaeozoic formations to unconformably overlie the Brioverian formations of the Petit Trégor. This interpretation is based upon the Upper Devonian-Strurian age proposed for conformable units they call the Schistes et Grès Feldspathiques Grauwackes à Elements Volcaniques and the Schistes Ardosiers.

The units of Cabanis et al. (op. cit.) cited above are equated with a pelite-dominated sequence with occasional psammites and heterolithic conglomerates which form the Formation de Dourduff of this thesis. At one locality, Dormeur (GR 1488 1219) close to the boundary, similar lithologies occur which are also assigned to the Formation de Dourduff. These appear to young to the east (opposite to the direction required by the map given in Cabanis et al. 1979a, Fig. 1), and are therefore considered to be in some form of highly discordant contact with the Brioverian. If the contact (which cannot be directly observed) is an unconformity then the stratigraphy of the Morlaix Basin sequence requires that the Formation de Dourduff has overstepped lower formations along the present eastern boundary of the basin. Alternatively, the junction could also possibly be a thrust contact.

(E) THE LITHOLOGIES AND STRATIGRAPHY OF THE MORLAIX BASIN

(1) INTRODUCTION

The stratigraphy of the Morlaix Basin is difficult to interpret as the lithologies have been strongly deformed and exposure at critical boundaries is often lacking. The most thorough account of the lithologies that comprise the Morlaix Basin and their stratigraphy is that of Cabanis et al. (1979a, p. 273) who propose the following:-

1.	Schistes zébrés de Morlaix		L. Tournaisian
2.	Conglomérat volcanique	Formation de Dourduff	* Strunian
3.	Schistes ardoisiers	Formation de Dourduff	* Strunian
4.	Schistes et grès feldspathiques		U. Devonian
			-.-.-.-.-.-.
5.	Schistes carburés		L. Devonian
6.	Grès de Plouezoc'h		* Gedinnian
7.	Grès à Platyorthis		
8.	Schistes et quartzites		Siluro-Devonian
9.	Micaschistes de la Penzé		Brioverian and/or Palaeozoic

Note: * dated by palaeontology or palynology

-.-. probable stratigraphic break

In this thesis a completely different stratigraphy is erected to that proposed above. The new stratigraphy is based on the interpretation of sedimentary and tectonic structures, from both along the margins and from within the Morlaix Basin, together with the correlation of several debris-flow horizons which are assigned to the Formation de Dourduff. These debris flows, the Poudingues du Dourduff of Barrois (1905b), have yielded Strunian spores from the matrix of the lowermost debris flows

(Coquel and Deunff 1977) and Dinantian macrofossils and foraminifera (Barrois 1927, Milon 1928, Delattre 1952a). Whilst agreement exists as to the age of some units there is a fundamental difference of opinion as to the age of major lithological units, principally the extensive Schistes Zébrés which occupy most of the central part of the basin. The following stratigraphy is proposed in this thesis:-

5. Grès de Plouézoc'h
4. Formation de Barnénez
3. Formation de Dourduff; including the Arkose de Kerarmel and the Poudingue de Dourduff Members.
2. Formation de Morlaix (or Schistes Zébrés de Morlaix)
1. Formation de Kerolzec

- Lithologies (dominantly blastomylonites) of the CSB -

As previously indicated the basin is bounded to the west by the CSB, beyond which occurs the Micaschistes de Penzé of the St. Pol-de-Léon Metamorphic Complex (see Chapter 2). To the south and southwest of the Basin are the Schistes Carburés of Siegenian age,and the Grès de Landevennec (also called the Grès à Platyorthis) of Gedinnian age,upon which the Morlaix Basin sequence rests with slight discordance (Cabanis et al. 1979a, 1981). To the east of the basin there is the ENE-WSW trending Brioverian succession and the southwesterly extension of the Moulin de la Rive Orthogneiss Complex and the Locquirec Shear Belt mylonites (Chapters 4 and 5). To the northeast of the basin lies the St. Jean-du-Doigt Gabbro Complex and to the north the Hercynian Primel-Carantec Granite (Chapter 7).

(2) THE LITHOLOGIES OF THE CARANTEC SHEAR BELT

The rocks that comprise the LSB in the Plage du Clouët-Ty Nôd area are dominantly blastomylonites (sensu Higgins 1971, Sibson's 1977 nomenclature cannot strictly be applied here), with granitoid mylonites occurring in part.

(a) Blastomylonites

The blastomylonites are banded quartz-rich or quartzo-feldspathic rocks that are strongly folded and foliated (Fig. 6:3). Individual bands vary from 1-8 cm thick, with quartz-rich bands alternating with thinner bands rich in phyllosilicate minerals. Quartz is totally recrystallized with a granoblastic texture and an even c. 0.3 mm grain size. The quartz forms up to 85-90% of the quartz-rich bands. Other minerals in these quartz-rich bands vary in importance,as does the composition of the phyllosilicate-rich bands,and it is possible to recognise two types of blastomylonite; a pale-coloured lithology which is rich in white mica and occurs in the northern part of the section at Le Clouët and in the Lavallot area (GR 1428 1200), and a darker coloured lithology which is rich in biotite and chlorite and occurs in the southern part of the section at Le Clouët. A common feature is the development of quartz veins parallel to the banding. The mylonitic banding, micaceous foliae and quartz veins have been subsequently folded. The late recrystallization of quartz postdates this folding,as does the growth of rare pale to medium brown biotite grains (Table 6:1).

(b) Foliated granitoids

Several meta-granitoid bodies have been mapped within and on the margins of the LSB. At Plage de Clouët one small isolated outcrop of foliated granitoid occurs (Fig. 6:5; GR 1407 1250). The lithology is foliated,with a crude banding developed parallel to the well-developed

Fig. 6:3 Blastomylonites, LSB; Plage du Clouët

Folded blastomylonites showing the nature of the S1 segregation banding. The prominent F2 folds are overturned to the northwest and plunge at a moderate angle (c. 45^{0}) to the northeast. A well-developed crenulation cleavage S2 is preferentially developed in the thin phyllosilicate rich bands (Table 6:1).

Scale: Hammer shaft 36 cm

Fig. 6:6 Formation de Morlaix; S. Le Dourduff-en-Mer

At this locality well-developed segregation banding S1 (orientated E-W on photo) is developed obliquely to lithological bedding, S0, defined by the grey (c. 2 cm thick) psammite beds (orientated NE-SW on photo). Transposition by pressure-solution leads to dark phyllosilicate-rich pelitic bands and thin (c. 5 mm thick) quartz-rich bands. An upright crenulation cleavage, S2, associated with upright F2 folds modifies the earlier S1 fabric.

Scale: Pencil head is c. 1 cm

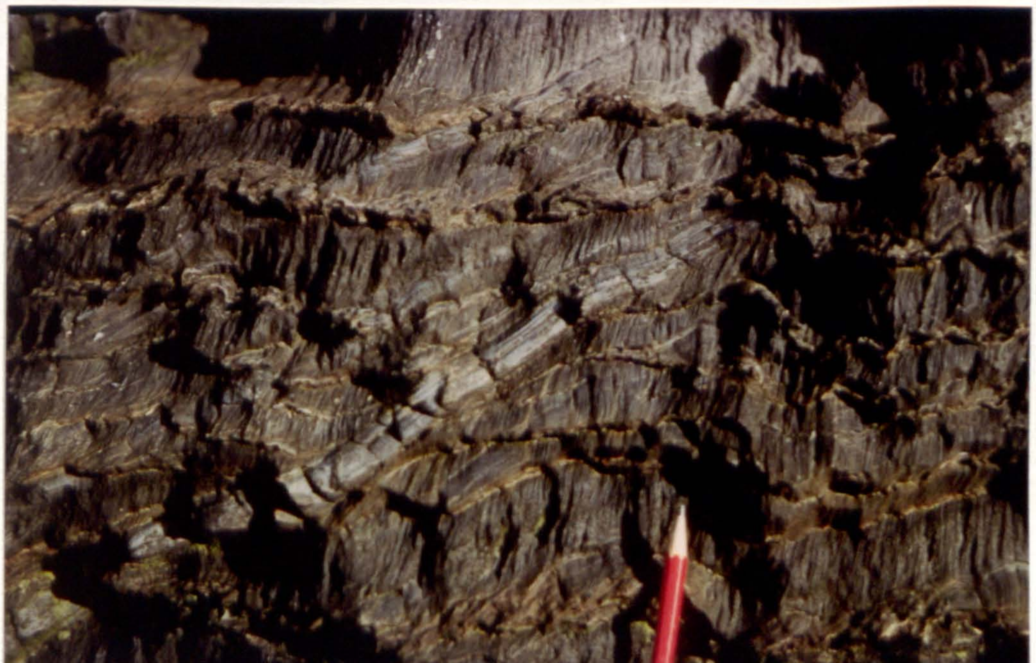


Fig. 6:4 Formation de Morlaix; S.W. Baie de Morlaix

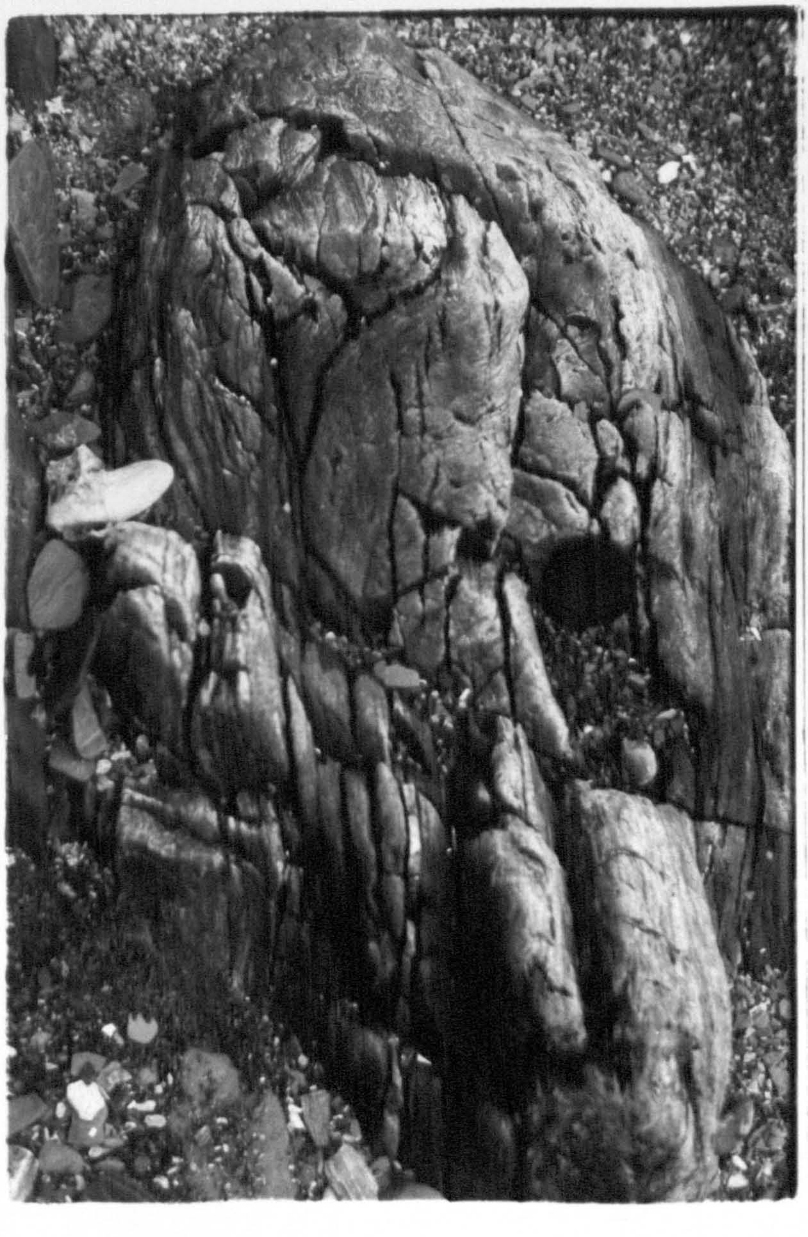
Primary lithological banding in the Formation de Morlaix. A psammitic bed is comspicuous in the centre of the photograph which is interbedded with dark pelites and thinly laminated semi-pelites. The psammite bed depicts a recumbent F1 fold which has been gently re-folded by upright F2 folds. S2 crenulates S1 in the pelitic bands

Scale: Hammer shaft 36 cm

Fig. 6:5 Foliated granitoid mylonites, LSB; Plage du Clouët

A segregated and foliated mylonite of granitoid aspect crops out at Plage du Clouët. The S1 banding is depicted by thin quartzo-feldspathic-rich bands and phyllosilicate-rich bands. The S1 segregation banding has been folded by F2 folds.

Scale: Lens cap 54 mm



S2 strain-slip cleavage of the adjacent blastomylonites at 042/82 SE. This foliation is more variable in attitude than in other foliated granitoids recorded. The mineralogy of this lithology in the Plage du Clouët section approximates to a granite, with an assemblage quartz + K-feldspar (perthite) + plagioclase + white mica + biotite + chlorite + epidote. The quartz grains occur as elongate aggregates (showing evidence for dynamic recrystallization). They are parallel to the foliation which is depicted by the alignment of the micaceous minerals. The K-feldspar and plagioclase is altered and forms 1-2 mm porphyroclasts. Chlorite has formed at the expense of biotite.

(c) Foliated metabasic dykes

Two metabasic (now amphibolite) dykes occur within the CSB at Plage du Clouët. These dykes, which trend NE-SW, contain a greenschist facies assemblage and are variably foliated. The dykes carry two fabrics, a dominant steeply dipping foliation orientated 054^{o} and a later, less well-defined fabric aligned 020^{o}.

The dykes are composed chiefly of pale green to pale bluish green amphibole with minor clinozoisite or epidote, ore and sphene. The original plagioclase has been almost completely recrystallized into fine-grained aggregates of sodic plagioclase which may vaguely outline the original laths. The amphiboles may occur as aligned elongated aggregates, but often with random orientation of individual grains within the aggregates. Some aggregates are composed of sub-hedral grains, each slightly out of optical continuity with each other (i.e. as sub-grains). Amphibole growth continued after the early, main deformation event and in some instances this mineral is seen to enclose ore and sphene trails. Small prismatic amphiboles also grow with random orientation in the recrystallized plagioclase-rich areas.

These dykes are correlated with other greenstone dykes (at lower grade) in the Morlaix Basin sequence further south along the banks of the Morlaix Estuary, where they cut the metasediments of the Formation de Morlaix. They are also equated with the concordant and penecontemporaneous metabasic sheets which are abundant within the dark pelites of the Formation de Barnénez along the east side of the Morlaix Estuary.

(d) The extent of the CSB

The blastomylonites can be traced for some distance inland, where they are dominated by the quartz + white mica variety. Unfortunately, no contacts between the foliated granitoids and the blastomylonites have been encountered. The recognition of meta-granite within the CSB suggests that the banded quartz-rich micaceous blastomylonites could be of sedimentary parentage. The age of such sediments involved in the CSB are considered as probably Palaeozoic, as quartz-rich orthoquartzites or protoquartzites are very rare in the Brioverian but common in the Palaeozoic successions.

Blastomylonites of similar appearance to those of the CSB occur within the St. Pol-de-Léon Metamorphic Complex in the area of Pont de la Corde (GR 1387 1240). These are considered to have formed within a belt parallel to the main CSB, and could possibly represent one of a series of minor shear zones present along the eastern margin of the complex that are related to and parallel with the CSB.

In the northern part of the CSB the blastomylonites are in fault contact with the metasediments of the Formation de Kerolzec (Map 1). Both of these units are truncated at their northern limits by the Hercynian Primel-Carantec Granite. Further south, to the west of Morlaix, the CSB is difficult to trace, and the mapping showing its extension is partly based on the recognition of the Micaschistes de Penzé being in close proximity to lower grade metasediments of the Formation de Kerolzec.

(3) THE FORMATION DE KEROLZEC

The Formation de Kerolzec comprises the sequence of metasediments which underlie the distinctive Schistes Zébrés de Morlaix (the Formation de Morlaix of this thesis) and form the western flank of the Morlaix Basin, where they are in contact with the mylonitic rocks of the CSB. The formation is composed of interbedded meta-quartzites, semi-psammites, semi-pelites and monotonous pelites that vary in abundance throughout the outcrop of the formation. The Formation de Kerolzec is easily distinguished from the extensive metasedimentary Micaschistes de Penzé of the St. Pol-de-Léon Metamorphic Complex, cropping out to the west of the CSB,which are mainly monotonous, segregated semi-pelitic and pelitic schists. The Formation de Kerolzec is of lower metamorphic grade and the pelitic horizons are black in colour.

In its northern outcrop the Formation de Kerolzec, in the area between la Phare de la Lande (GR 1425 1234) and Locquenolé, consists of semi-pelites and semi-psammites with some meta-quartzite beds. The siliceous beds are recrystallized. The pelitic beds are graphite-rich and are dark with a distinctive waxy feel and shiny lustre. The whole succession in this area is strongly deformed and their proximity to the lithologies of the CSB is of importance. The meta-quartzites increase in importance southwards and they are well-exposed in the area of Lannigou, southwest of Locquenolé,and further south near Kerolzec (GR 1418 1158), where the meta-quartzites are quarried for roadstone.

In the central part of the Formation de Kerolzec, around Kerolzec itself, there is a sequential development of lithologies. The meta-quartzites are the dominant lithology and form the basal part of the formation. These are overlain by a sequence of interbedded semi-psammites and semi-pelites which are, in turn, overlain by monotonous dark pelites. This fining-upward sequence is not as well-developed elsewhere.

In the area south of Morlaix the Formation de Kerolzec is largely contact metamorphosed. This late metamorphism post-dates the low-grade regional Hercynian metamorphism and is related to the presence of small granite bodies, which may be related to a more extensive pluton at depth. Interbedded lithologies occur, with meta-quartzites dominant (up to 2 m thick) in the Berlingar area (GR 1472 1166). A gradation towards dark semi-pelites and pelites from dominant meta-quartzites has been observed in part of the formation. The Formation de Kerolzec shows the same structural and metamorphic history as the adjacent Formation de Morlaix and blastomylonites of the CSB.

The main, early developed foliation S1 within the pelites and semi-pelites was subsequently reorientated and modified by pressure-solution segregation during D2, which produced lithological striping parallel to S2 (a crenulation cleavage) (Table 6:1). In the Plage du Clöuet area, immediately adjacent to the CSB, the growth of garnet porphyroblasts (up to 1 cm diameter) and chloritoid prisms post-dates the development of the S1 foliation. These minerals were rotated during D2. Muscovite and chlorite foliae defining S1 may be bent around F2 fold hinges but may also show mimetic growth around these. Quartz is largely recrystallized with a polygonal fabric and this recrystallization may have occurred during regional or contact metamorphism associated with the emplacement of numerous Hercynian granites (see part G).

The age of the Formation de Kerolzec and its relationship to the overlying Formation de Morlaix is somewhat problematical, due largely to the lack of fossils and poor inland exposure. Cabanis et al. (1974) have described Lower Devonian spores from the Schistes Carburés (broadly equivalent to the upper part of the Formation de Kerolzec of this thesis) approximately 1km southwest of Morlaix. Cabanis et al. (op. cit.) also consider the Grès à Platyorthis to be of Lower Devonian (Gedinnian) age, this formation underlies the Schistes Carburés, and together they constitute the Formation de Kerolzec (sensu this thesis).

Fossil evidence indicates that Lower Devonian lithologies crop out along the southern side of the Morlaix Basin. The continuation northwestwards of the Formation de Kerolzec is based on lithological mapping and no fossils have been recorded by this author in this area. An important stratigraphical break is recognised between the broadly parallel Formation de Kerolzec and the overlying Formation de Morlaix. The age of the Formation de Morlaix is discussed again later.

(4) THE FORMATION DE MORLAIX

The Formation de Morlaix occupies the central part of the Morlaix Basin. Its extensive outcrop can be examined in many excellent exposures in the valley of the Riviere de Morlaix and in and around the town of Morlaix. The formation is characterized by a distinctive lithologically striped sequence which Barrois (1905b) termed the Schistes Zébrés de Morlaix. The striped character of the Schistes Zébrés is due to the presence of both a primary sedimentological bedding and metamorphic segregation banding. Light coloured quartz-rich bands alternate with dark pelitic bands of similar or greater thickness on a millimetric to centimetric scale. The Formation de Morlaix is strongly deformed and two generations of folds are recognised. Upright F2 folds with a well-developed crenulation cleavage are ubiquitously formed and deform an earlier isoclinal F1 fold phase. Strong deformation and associated metamorphic segregation related to these two fold phases are in part responsible for the banding that occurs. Three types of banding are recognised:-

1) Primary lithological bedding, whereby psammitic beds composed of quartz (80-85%) + albite (c. 10%) with very minor amounts of white mica and chlorite alternate with pelite beds that are composed of very fine-grained quartz + white mica + chlorite. Bedding is usually regular 0.5-4 cm, but more massive psammite units up to 80 cm may occur with some internal fabric preserved such as graded-bedding (Figs. 6:4, 6:6 and 6:8).

2) Transposed beds, in which thin (less than 5 mm thick) quartz-rich bands (recrystallized and with regular grain size) alternate with thicker pelite bands. These are considered to form by solution transfer mechanisms during the D1/M1 (or possibly earlier) episode (Figs. 6:6 and 6:7).

3) Quartz vein banding. Monomineralic veins of variable thickness alternate with dark pelites. This type of banding may co-exist with type (1) banding and could be the product of transposition by a pressure solution mechanism, or by metasomatic processes associated with granite intrusion known to exist in the region (Figs. 6:7 and 6:8). Figs. 6:4 and 6:6-8 illustrate the different types of banding recognised here and also present in the Formation de Dourduff.

The Schistes Zébrés are not necessarily rhythmic sediments as considered by Cabanis et al. (1979a) or Delattre (1952a), although it must be emphasised that the primary banding is the most common type recognised. The transposition of quartz-rich bands by pressure solution is, however, considered an important mechanism in the development of a secondary fabric in the Schistes Zébrés. The bands are developed parallel to the S1 cleavage, associated with the F1 folds (Fig. 6:6) (Table 6:1).

Fig. 6:7 Formation de Dourduff; N. La Palud de Kerarmel

S1 segregation banding (orientated E-W on photo) is folded and crenulated by dominantly upright F2 folds. A fracture cleavage is considered to offset the prominent S2 crenulation cleavage (bottom left).

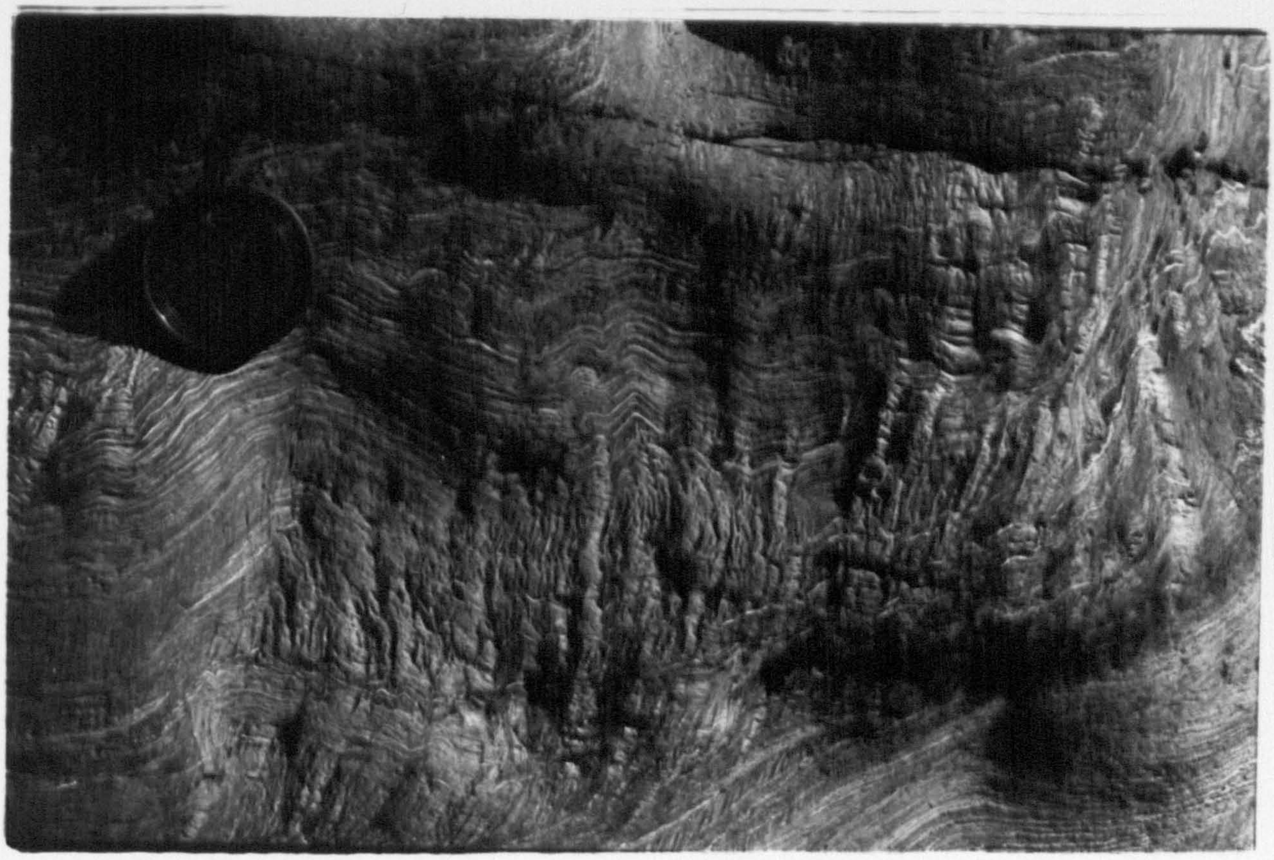
Scale: Lens cap 54 mm

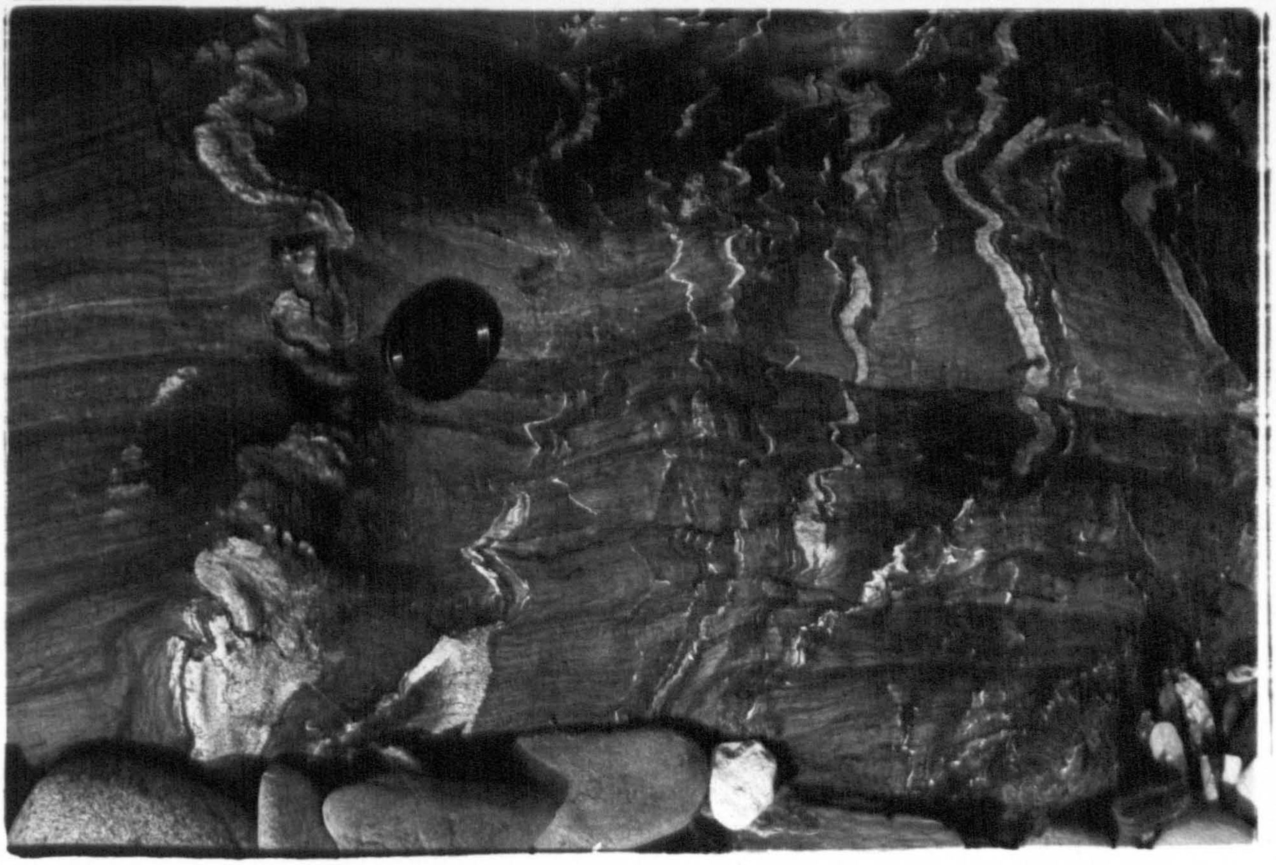
Fig. 6:8 Formation de Dourduff; N. La Palud de Kerarmel

Primary lithological banding S0 (orientated N-S on photo) passes laterally in some beds into quartz-rich segregation banding S1. Both S0 and S1 are folded by small-scale F2 folds with an associated upright crenulation cleavage/pressure solution cleavage S2 (east-west on photo). The S2 pressure-solution striping is therefore a secondary segregation fabric.

Scale: Lens cap 54 mm

N.B. Fig. 6:6 attached to 6:3





Sedimentary structures within the primary sedimentological psammite (arkose) and pelitic (shale) interbedded succession are rarely preserved, and this limits the information that can be gained as to the primary nature of the Schistes Zébrés and to the younging directions. Graded-bedding is sometimes preserved in the thicker psammitic beds and this can be verified by grading in adjacent conglomeratic units of the Formation de Dourduff. Rippled-tops are occasionally preserved, but no internal bed organization consistent with the bed-top have been found. Pseudo cross-bedding is a common phenomenon that results from the intersection of the S2 cleavage and S0 lithological banding in some areas. Occasionally, loading is observed at the base of psammitic beds.

Primary sedimentological structures are preserved occasionally and, although the formation has been highly deformed and metamorphosed by Hercynian earth-movements, there is sufficient evidence to broadly indicate the sedimentary environment. The dark pelites are considered to reflect slow accumulation of mud in a somewhat restricted basin. These quiet conditions were frequently interrupted by the influx of sediment gravity flows, principally turbidites, which resulted in the deposition of usually relatively thin quartz sandstones of arkosic or sub-arkosic aspect.

(5) THE FORMATION DE DOURDUFF

The Formation de Dourduff overlies the Formation de Morlaix and crops out along the east side of the Morlaix Basin. It is best exposed along the east side of the Morlaix Estuary between la Palud de Kerarmel (GR 1439 1237) and Pte de Barnénez (GR 1432 1261) and also along the north banks of the Riviere de Dourduff. The formation is composed mainly of a sequence of dark pelites, the continuity of which is interrupted by the presence of several horizons of sediment gravity flow deposits (both debris flows and turbidite flows). The two thickest

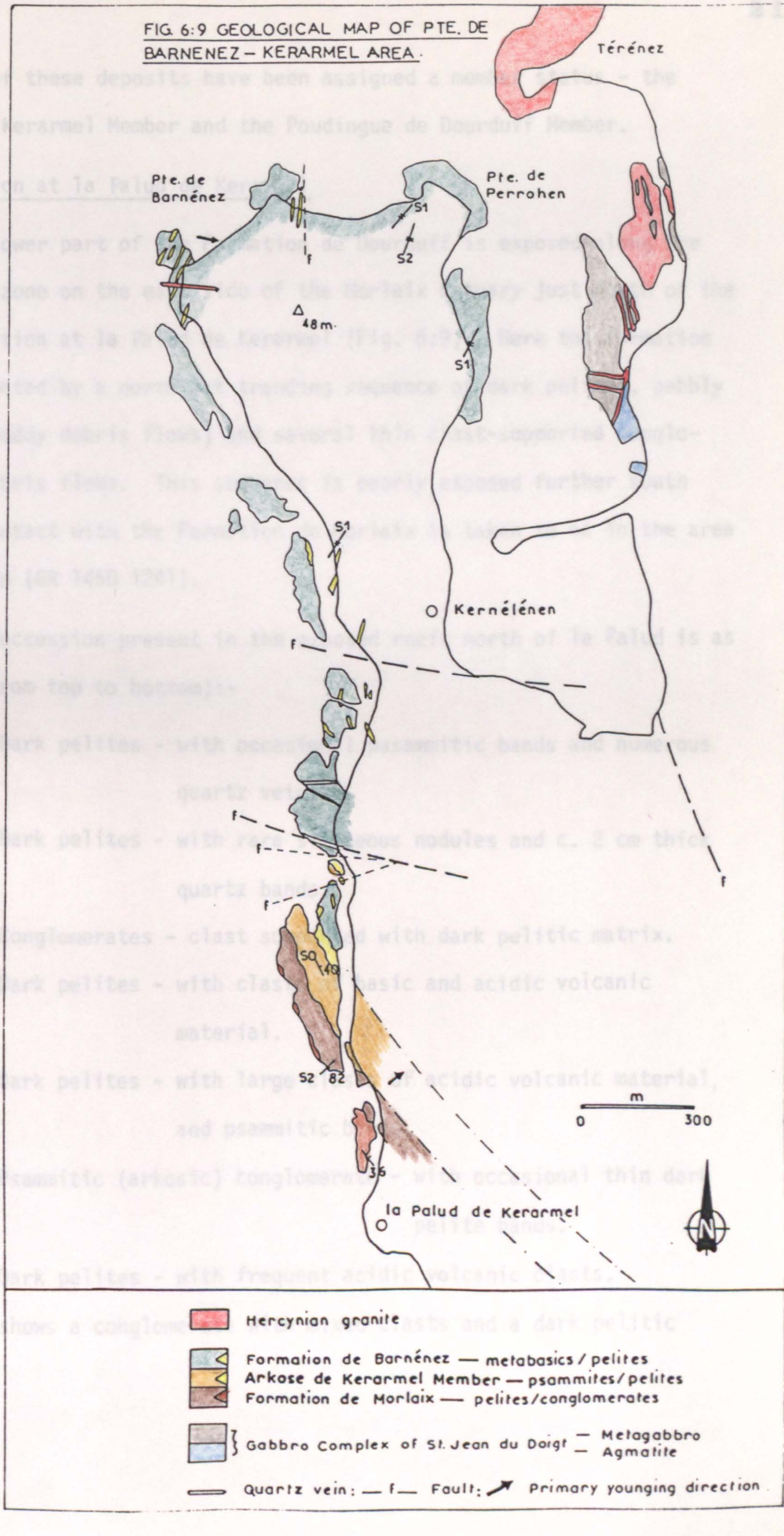


FIG. 6:9 GEOLOGICAL MAP OF PTE. DE BARNENEZ – KERARMEL AREA.

horizons of these deposits have been assigned a member status - the Arkose de Kerarmel Member and the Poudingue de Dourduff Member.

(a) Section at la Palud de Kerarmel

The lower part of the Formation de Dourduff is exposed along the inertidal zone on the east side of the Morlaix Estuary just north of the oyster station at la Palud de Kerarmel (Fig. 6:9). Here the formation is represented by a northwest trending sequence of dark pelites, pebbly pelites (muddy debris flows) and several thin clast-supported conglomeratic debris flows. This sequence is poorly exposed further south but its contact with the Formation de Morlaix is taken to be in the area of Trodibon (GR 1450 1241).

The succession present in the exposed reefs north of le Palud is as follows (from top to bottom):-

7. Dark pelites - with occasional pasammitic bands and numerous quartz veins.
6. Dark pelites - with rare siliceous nodules and c. 2 cm thick quartz bands.
5. Conglomerates - clast supported with dark pelitic matrix.
4. Dark pelites - with clasts of basic and acidic volcanic material.
3. Dark pelites - with large clasts of acidic volcanic material, and psammitic bands.
2. Psammitic (arkosic) conglomerate - with occasional thin dark pelite bands.
1. Dark pelites - with frequent acidic volcanic clasts.

Fig. 6:10 shows a conglomerate with mixed clasts and a dark pelitic matrix.

Fig. 6:10 Formation de Dourduff; La Palud de Kerarmel

Matrix supported pelitic conglomerates contain clasts of acidic (fine-grained) and basic (fine-grained) material. The matrix is dark pelitic- semi pelitic material.

At this locality D1 flattened clasts have been folded into a tight, almost recumbent, northward facing fold, e.g. deformed clast just above hammer handle in centre of photograph.

Scale: Hammer handle 36 cm

Two contrasting types of clast dominate this lower part of the formation; firstly acidic clasts of quartz + white mica + albite, fine-grained and of probable volcanic origin; and secondly basic greenstone clasts of chlorite + epidote + albite ± quartz, fine-grained and of extrusive or high-level intrusive origin. The thin psammitic (arkosic) bands increase in importance towards the top of the sequence north of la Palud de Kerarmel and form a thin transitional zone into the Arkose de Kerarmel Member.

The deformation fabric is similar to that in the underlying Formation de Morlaix, with a well-developed pressure-solution cleavage associated with both the D1 and D2 deformation episodes. Occasional grading in the psammitic beds towards the top of this lower part of the Formation de Dourduff indicate that it is succeeded by the Arkose de Kerarmel Member in la Palud de Kerarmel section.

(b) Arkose de Kerarmel Member

In la Palud de Kerarmel section the pelite and pebbly pelites of the lower part of the Formation de Dourduff pass rapidly upwards, through the incoming of thin psammitic beds, into a sequence of more thickly-bedded psammites, which Delattre (1952a) termed the Arkose de Kerarmel. Delattre (op. cit.) assigned the Schistes Zébrés (which he termed the Quartzophyllades de Morlaix) to the Lower Devonian (middle to upper Sieginian). Included in this sequence was the pelite-dominated lower part of the Formation de Dourduff described in the last section. The Arkose de Kerarmel, together with the Poudingue de Dourduff, was assigned to the Dinantian, and Delattre considered the arkoses to lie disconformably upon the pelite and drew a section at la Palud de Kerarmel showing this relationship (Delattre, op. cit. Fig. 7). This conclusion is not verified by the present author, who postulates a rapid transition from a pelite to psammite-dominated conformable sequence (Fig. 6:11).

In the present work, the Arkose de Kerarmel is given a member status, and in the section north of la Palud de Kerarmel the top of this member is taken as marking the boundary between the Formation de Dourduff and the overlying Formation de Barnénez as follows:-

9.	Metabasic sheets	Formation de Barnénez
8.	Dark pelites with irregular bodies of metabasic material.	
7.	Metabasic sheets	.-.-.-.-.-.-.-
6.	Dark pelites with several conglomerate beds	
5.	Psammites (arkosic) with conglomerate lenses	Arkose de Kerarmel Member of the Formation de Dourduff
4.	Dark pelites	
3.	Dark pelites with irregular bodies of metabasic material	
2.	Dark pelites	
1.	Psammites (arkosic) with conglomerates lenses + thin pelites	

The thickest of the psammitic beds (up to 1 m) occur towards the base of the member where they may be pebbly (Figs. 6:11, 6:12 and 6:13). The psammites are composed mainly of quartz + albite + muscovite with minor chlorite and ore. They are generally medium to coarse-grained and weather to a white or cream colour, standing out markedly from the adjacent dark pelites. The psammites are well bedded and may show grading, with a pebbly psammite base passing up through a massive psammite into a laminated finer psammite/semi-pelite top (Figs. 6:14 and 6:15). At one locality, the base of a graded bed was observed to cut slightly obliquely across the laminated top of the underlying graded bed.

Fig. 6:11 Formation de Dourduff; N. la Palud de Kerarmel

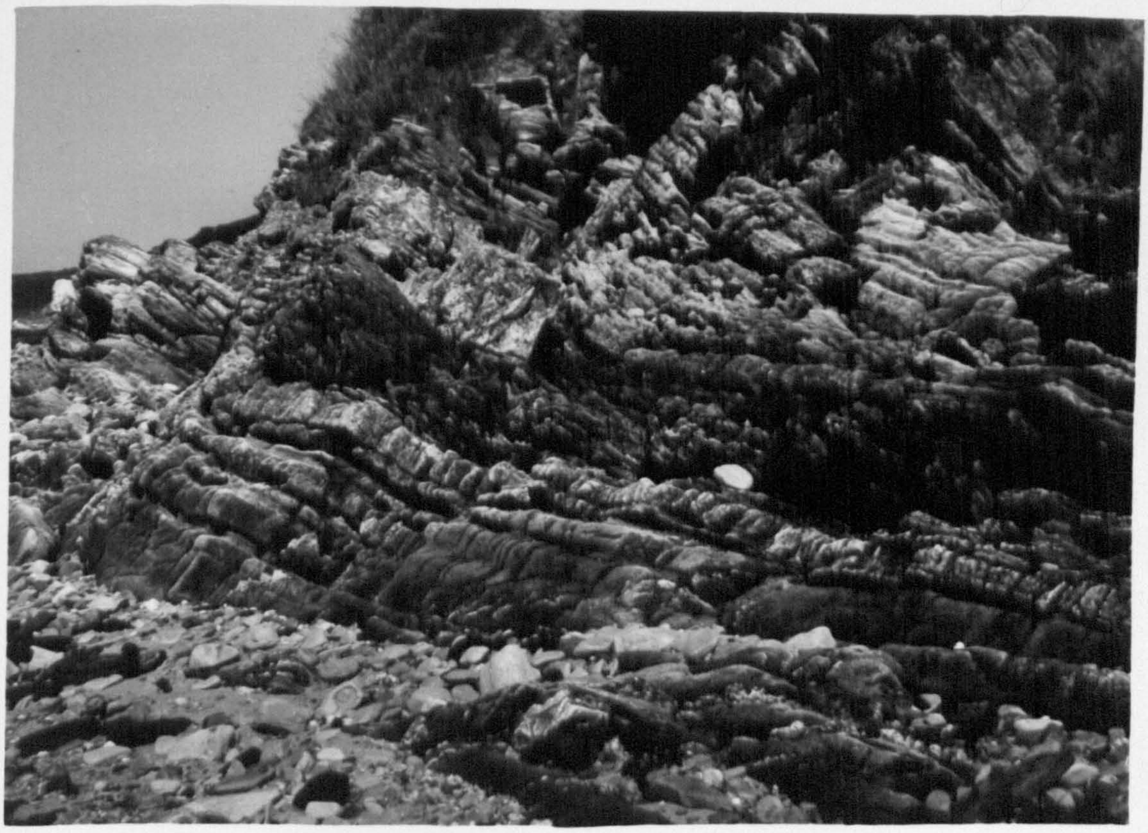
Bedded psammites of the Arkose de Kerarmel Member of the Formation de Dourduff. These conformably overlie dark pelites of this formation, seen in the foreground. Sedimentoligical criteria such as pebbly bases, normal grading and discordant bedding indicate that the psammite beds are the right way-up and young to the east.

Scale: Lowermost psammite bed is 1.6 m thick

Fig. 6 12 Formation de Dourduff; N. la Palud de Kerarmel

Laminated semi-psammites and semi-pelites of the Arkose de Kerarmel Member. Primary bedding is seen to be deformed into a small-scale F1 recumbent isocline just above the coin on the left of the photograph. The lithological banding and the S1 foliation has been deformed by northward verging F2 folds with a well-developed crenulation cleavage (S2) on the right of the photograph.

Scale: One franc coin 23 mm



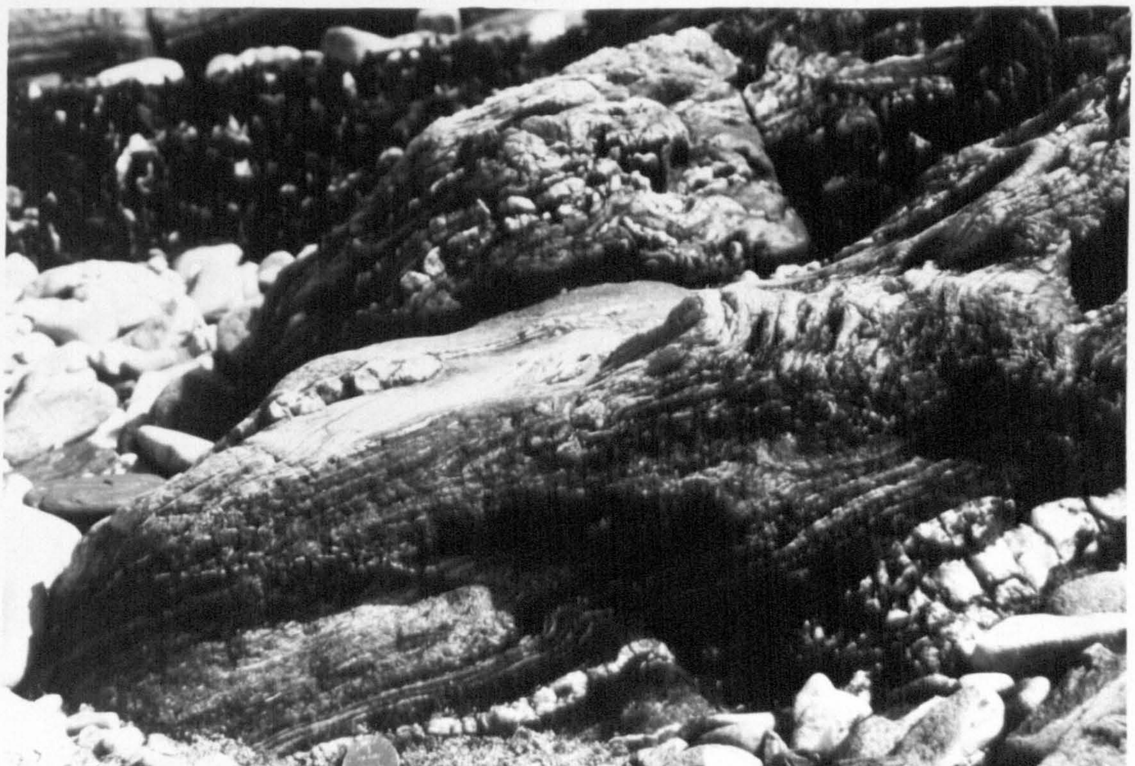


Fig. 6:13 Formation de Dourduff; N. la Palud de Kerarmel

Base of a psammitic conglomerate unit, Arkose de Kerarmel Member. Two clast types are present, pebble size fine-grained acidic types of probable volcanic origin and dark pelitic possible rip-up clasts.

The pelitic clasts show preferential flattening parallel to S1 (often oblique to S0) and development of the S2 crenulation cleavage

Scale: Lens cap 54 mm

Fig. 6:16 Formation de Dourduff; N. la Palud de Kerarmel

Conglomerate unit towards the top of the Arkose de Kerarmel Member. Clasts are dominantly fine-grained acid volcanics with minor basaltic (now greenstone) types. Clasts may be angular-rounded.

Scale: Hammer 36 cm

Fig. 6:14 Formation de Dourduff; N. la Palud de Kerarmel

Primary psammite/arkosic bedding S0 (orientated N-S in photo) is interbedded with semi-pelite. The psammites may pass laterally into quartz veins orientated parallel to S1. S1 is sub parallel to the prominent bedding at this loclaity. A well-developed crenulation-cleavage and associated pressure-solution cleavage (orientated E-W on photo) has led to the transposition and micro-folding of the quartz-rich material.

Scale: Hammer head 18 cm

Fig. 6:15 Formation de Dourduff; N. La Palud de Kerarmel

Deformed contact between a graded psammite unit and underlying pelites and semi-pelites. The psammite unit also displays load structures.

S2 is preferentially developed in the finer-grained pelitic material and noticeably in the upper part of the graded psammite.

Scale: Width of scale of view approximately 55 cm

In la Palud de Kerarmel section these bedded psammites dip at approximately 30^0 to the east-northeast and are the right way-up. This is an important observation, as Cabanis (1974, Fig. 2) and Cabanis et al. (1979a) have this succession as inverted,with the Schistes Zébrés stratigraphically above but structurally below the Arkose de Kerarmel and Poudingue de Dourduff.

Within the Arkose de Kerarmel Member there are several conglomerate horizons. These occur as lenticular, wedge-shaped or more continuous sheet-like bodies in association with both the psammites and pelites. The conglomerate lenses within the psammite sequence are characterized by both quartz-rich and pelite clasts, generally matrix supported (Fig. 6:13). The matrix here is similar to that of the constituents of the psammites. Conglomerates within the pelites have quartz-rich and quartzo-feldspathic clasts suspended in an abundant pelitic matrix (Fig. 6:16). The laterally discontinuous conglomerate lenses within the psammites thin out laterally over c. 5 m to be replaced by (pebbly) psammite.

The conglomerates are interpreted as being the result of a series of debris flows, in which lithoclasts and rip-up mudstone clasts were transported and deposited in high-energy conditions, while the graded psammites retain some of the characteristics of turbidite flows. Bedding is laterally discontinuous and the resultant wedge-form is evident on two scales; single beds of conglomerate die out rapidly, while on a larger scale the Arkose de Kerarmel Member is laterally impersistent as the psammites and conglomerates are replaced by dark pelites (there is no trace of the member inland).

Clasts within the conlgomerates have been deformed, with the mudstone clasts preferentially flattened and arranged parallel to the S1 fabric. Grading in the psammites indicates a northeasterly younging direction. This is consistent with the structural younging direction (based on the asymmetry of folds) discussed in part (F), and with younging directions interpreted elsewhere within the Formation de Dourduff.

Several dark pelite beds occur within the dominantly psammitic succession and occasionally the psammites load down into the underlying mudstones (Fig. 6:15). Thin psammite beds may exist within these pelites and may also wedge-out in the same sense as the conglomerate horizons. Overlying the psammites and conglomerates is a sequence of monotonous dark pelites intruded by penecontemporaneous basic sheets and more irregular basic masses. This sequence constitutes the Formation de Barnénez.

(c) Poudingue de Dourduff Member

To the south of la Palud de Kerarmel section there is exposed along the north bank of the eastern end of the estuary of the Riviere de la Dourduff, between Kerrivoalen (GR 1461 1217) and Melin Vor (GR 1472 1215), a spectacular sequence of closely related conglomerates which has attracted considerable attention because of the fossils it has yielded. The conglomerates appear to form a lenticular outcrop pattern which can be traced for at least 2 km along strike and appears to reach its maximum thickness at Melin Vor (also termed in the literature Dourdu-en-Terre). The conglomerates have a WNW-ESE strike and dip at a low and moderate angle to the north-northeast.

The conglomerates were first mentioned by E. de Billy in 1830 and the first fossils (crinoids) identified by a Morlaix medical practitioner, le Hir, in 1843. Barrois (1905b, 1908c) placed the conglomerates within the Schistes et Tuffs Volcaniques de Brélévenez and assigned them to the Brioverian, along with the other sediments of the Morlaix Basin, although he had previously (1886) placed the same rocks within the Carboniferous.

Barrois (1927) identified brachiopods initially collected by a Morlaix barrister, M. du Laurens de la Barre, and commented upon by Bézier in 1923. These fossils were obtained from the limestone pebbles and boulders which form an important clast components of the conglomerates. This is the reason why the unit has sometimes been referred to as the Poudingues et Calcaires du Dourdu (Barrois, op. cit.). In spite of their poor state of preservation Barrois identified the brachiopods Martina glabara (Mast.), Seminula voisin de Seminula ficoides (Vaugh.), Spirifer voisoin de Spirifer trigonalis (Mart.). Barrois assigned not only the Poudingue de Dourduff but also the remainder of the Morlaix Basin sequence to the Dinantian. A year later Milon (1928) described, from thin section study of the limestone clasts, foraminifera (Endothyra, Valvulina and Archaeodiscus), radiolaria, crinoid ossicles, and bryozoa.

Delattre (1952a, Fig. 15) broadly equated the Poudingue de Dourduff with the Arkose de Kerarmel and portrayed both as Dinantian sediments resting with slight discordance upon the Quartzophyllades de Morlaix (Schistes Zébrés) which were assigned to the Lower Devonian. The discordance was related to the Bretonic earth movements. On the other hand Cabanis in his thesis (1972) depicts a continuous (albeit now inverted) passage between the Schistes Zébrés de Morlaix and the Poudingue de Dourduff (which was assigned a formation status). Cabanis placed all the rocks of the Morlaix Basin within the Dinantian.

Pelhate (1973) in her examination of Milons preparations confirmed the presence of crinoids, radiolaria and foraminifera. In particular, she identified the species Koninckopora inflata (De Kon.) and concluded that the minimum age of the Poudingue du Dourduff was middle Visean.

The most recent paper is that of Coquel and Deunff (1977), who in their palynological study, identified twenty species of spores collected from the dark pelitic matrix in the lower part of the conglomerate outcrop at Dourduff-en-Terre. This microflora was assigned a Strunian age (i.e. at the Devonian-Carboniferous boundary).

Mapping by the present author has shown that the member is composed of a number of isolated lenticular bodies separated by dark pelites or psammite beds. The conglomerates are markedly polymictic, with clasts of variable size held within a sandy or muddy matrix. The lens-like bed form of the conglomerates is probably a primary sedimentological feature, although repetition of beds due to the strong D1 episode was also considered. The member is variable in aspect along its strike, and two localities are briefly described that show the differences in size and composition of clasts within the lenses.

Locality 1 Fig. 6:17. Cliff face on north bank of Riviere de la Dourduff near Kerrivoalen (GR 1462 1228). Here the conglomerate, which is well-exposed on a c. 30 m high cliff face, is composed of clasts showing considerable variation in size and composition. Clast sizes range from one large sub-angular orthoquartzite boulder, which reaches 4 x 3 m, down through smaller boulder-size to cobble size and pebble size. Most clasts commonly have their longest axis in the range 0.5-2 m. Clasts vary from sub-angular to highly rounded. The largest clasts tend to be formed of bedded orthoquartzites. Other clast lithologies present are arkosic or sub-arkosic sandstone, limestone (occasionally showing macro-fossils, mainly crinoid fragments), acidic igneous rocks (of both coarse-granite granitoid and fine grained volcanic aspect) and basic igneous clasts (now greenstones or greenschists). The clasts are set, at this locality, within a gritty quartz-rich, occasionally also calcareous, matrix. The matrix is variably foliated according to the abundance of chlorite

Fig. 6:17 Formation de Dourduff; Nr. Kerivoalen, Riviere de Dourduff

Large (c. 30 m high) debris flow unit, Poudingue de Douduff Member. Clasts (up to large boulder size) include orthoquartzites (which may be bedded), arkosic to sub-arkosic sandstone, limestone, acidic igneous rocks (intrusive and extrusive) and basic igneous.

A single large Neptunean dyke is present at this locality composed of medium-grained sandstone and interpreted as a dewatering structure.

Scale: Geologist c. 1.90 m

Fig. 6:18 Formation de Dourduff; Nr. Melin Vor, Riviere de Dourduff

Debris flow unit, Poudingue de Dourduff Member, composed of pebble-cobble-small boulder size clasts. The clasts are moderately well-rounded and at this locality show major D1 flattening. The clast-types in order of importance are acid igneous (intrusive and extrusive), metabasic greenstones, arkosic to sub-arkosic sandstone,s occasional limestones and orthoquartzites. The matrix material is variable from gritty pelitic to gritty psammitic and may show preferential development of the S1 and S2 cleavage.

Scale: Hammer 36 xm

N.B. Fig. 6:16 attached to 6:13

and/or muscovite. When the latter minerals are common the matrix is well-foliated and more pelitic in aspect.

A single large neptunean dyke is present at this locality. The dyke is of a medium-grained sandstone and is interpreted as a dewatering structure reflecting rapid deposition of this deposit (Potter and Pettijon 1977).

Locality 2, Fig. 6:18 North bank of the Riviere de la Dourduff between (GR 1466 1215) and Melin Vor (GR 1471 1215). Here the Poudingue de Dourduff Member is exposed in small, largely isolated, outcrops along the river bank. In this area the member is composed of small clasts of more limited size range and a different abundance of clast types. The relative abundance of clast types at this locality is:- acid igneous (some coarse-grained granitoid clasts but mainly fine-grained volcanic material), metabasic greenstones and greenschists, arkosic to sub-arkosic sandstone, limestones and orthoquartzites (least abundant). The composition of the matrix material is again variable, ranging from gritty psammite to gritty pelite or semi-pelite.

Along the north bank of the Riviere de la Dourduff between localities 1 and 2 there is a continual variation in the relative abundance of clast types in the several outcrops of the conglomerate member. Occasionally, some crude form of grading is observed and lenses on more continuous sheet-like bodies of psammite may occur. Younging directions are consistent and indicate the sequence is younging to the north-northeast.

The Poudingue de Dourduff Member is therefore formed of compositionally variable conglomerates, probably deposited as a series of lenticular beds separated either by pelites or psammite beds. Each conglomerate is considered to represent a debris flow, reflecting a period of considerable instability along the margin of the Morlaix Basin. Here,bimodal volcanism and erosion of granitoid basement led to acid and basic igneous clasts being incorporated within a shallow-water environment where limestones, and psammites? locally accumulated. This material was then carried by mass flow into deeper water where black mud sedimentation was dominant.

(d) Exposures in the Dourmeur and Kerozar Areas

The Formation de Dourduff has been traced southeastwards to the area around Dourmeur and Kerozar east of Morlaix. Here exposures are poor, but the areas are critical as the formation appears to be in contact with the Brioverian along the east margin of the Morlaix Basin.

The dominant lithology is dark pelite with smaller amounts of thin interbedded psammite and conglomerate. The conglomerates are characterized by clasts of acid igneous material and psammite similar to those encountered in the Poudingue de Dourduff Member and other conglomerates seen in the Palud de Kerarmel section. These lithologies can be examined in roadside cuttings at Dourmeur (GR 1488 1219) and near Kerozar (GR 1483 1189). At Kerozar the conglomerates are not well-developed, but the dark pelites here may be represented by muddy debris flows,as they contain occasional pebbles. The younging direction established in these exposures is consistant with that established elsewhere within the formation, i.e. to the northeast.

Cabanis et al. (1979a) and Cabanis et al. (1981) portray a unit, labelled the Schistes et Grès Feldspathiques,as lying discordantly upon the Brioverian in the area around Kerozar. These are assigned to a possible Upper Devonian age and are shown as being succeeded conformably westwards by younger sediments of Strunian age,labelled the Schistes Ardoisiers. The direction of younging implied here is opposite to that deduced by the present author.

The Schistes et Grès Feldspathiques are shown by Cabanis et al. (1979a) to crop out both along the west and east side of the Morlaix Basin in its southern part. This is in keeping with their regional stratigraphy which has the Schistes Zébrés de Morlaix (the Formation de Morlaix of this thesis) as the youngest stratigraphic unit. In order to account of the northeasterly dip of the beds in the northeast and east side of the basin Cabanis et al. (1972, Fig. 2) have depicted these beds as being inverted.

As the strike of the adjacent Brioverian is NE-SW, varying ENE-WSW, there must be a major discordant contact between the Formation de Dourduff and these older rocks. In order to account for the current outcrop pattern it is tentatively suggested that the Formation de Dourduff is in thrust contact with the Brioverian, although there is no exposure where the contact can be observed. Possibly, this thrust contact developed during the D1 episode, and its somewhat sinuous outcrop trend is due to the effect of D2 folding.

(6) THE FORMATION DE BARNÉNEZ

The dominantly metabasic Formation de Barnénez is a c. 1 km thick unit that is restricted to the east side of the Morlaix Basin. Two major outcrops of this formation are recognised, the largest comprises the Presqu'ile de Barnénez in the northeast of the basin, the second outcrop occurs in the southeast corner of the basin near Morlaix. Excellent exposure is afforded across the strike of the succession in the Presqu'ile de Barnénez (Map 1).

Various authors have attached different names and ages to the formation, which is generally recognised as a strongly deformed and metamorphosed basic volcanic and/or intrusive pile. The presence of occasional metasedimentary horizons has been cited as evidence of an extrusive origin for the encompassing metabasic rocks. Barrois (1908b) labelled these rocks the Schistes Cristallins et Epidiorites de Lannion and assigned them to the Brioverian. Delattre (1952a) and Delattre et al. (1966) attributed the Étage Doleritique de Barnénez to the Dinantian, while Leutwein et al. (1969) dated a single whole-rock (K/Ar) specimen from the Pte. de Perrohen (Fig. 6:9) at 540 ± 30 m.y.. Sandrea (1958) placed the Dolérites de Barnénez as post-Coblencian and Pre-Dinantian. Cabanis et al. (1979a) assign the Metadolérites Amphibolitiques (de Barnénez) to the Upper Devonian and have described these rocks as tholeiitic in character. They consider the metabasic rocks to be intrusive in part, and regard the extrusive part to be equivalent to the nearby St. Jean-du-Doigt Gabbro Complex.

The base of the Formation de Barnénez has been briefly described in the previous section (5) dealing with the Formation de Dourduff, where the metabasic lithologies are in contact with the Formation de Dourduff at the north end of la Palud de Kerarmel section. At the boundary a c. 8 m thick band of metabasic material occurs which overlies dark pelites (of the Arkose de Kerarmel Member) and this, in turn, is overlain by a series of psammitic conglomerates and black pelites.

Within the basal metabasic unit are several thin dark pelite bands and throughout much of the lower part of the formation the two lithologies are intimately intermixed (Fig. 6:9). The metasediments occur in two modes :-

1. As distinct, c. 1-2.5 m thick laminated horizons arranged parallel to the strike of the outcrop and the schistosity. In these horizons the dominant lithology is dark pelite, but inter-bedded 2-6 cm thick semi-psammitic layers may occur (Fig. 6:19).

2. As irregular-shaped masses of metasediment within the metabasic lithology. The edges of these masses are commonly lobate and frequently small lobes or pillows of the basic material occur

Fig. 6:19 Formation de Barnénez; Pte. de Barnénez

Metasedimentary screen within the dominantly metabasic Formation de Barnénez. The lighter coloured bands are highly deformed metabasic pods or lenses that are streaked out or sheared parallel to the S1 fabric in the enclosing amphibolites. The dark pelitic material may show both S1 and S2 cleavage fabrics.

Scale: Hammer 36 cm

Fig. 6:20 Formation de Barnénez; S. Pte. de Barnénez

Dark pelite and lighter coloured metabasic relationships near to the base of the Formation de Barnénez. Lobes and small pillows of metabasic material and flames of pelite suggest a fluidized primary relationship between the two materials. This is interpreted as a pepperitic fabric, in which basic magma was injected into unconsolidated sediment.

Scale: Hammer shaft 36 cm

isolated within the dark pelitic metasediments (Fig. 6:20).

The distinct, sheet-like metasedimentary horizons occur more frequently to the north in the Pte. de Barnénez area whilst the more intimately mixed lithologies occur towards the base of the formation. The sheet-like horizons of laminated metasediments are interpreted as water-lain deposits. Preserved vesicles in the meta-basics (particularly frequent in the Pte. de Perrohen area) point to an extrusive origin for the metabasic rocks. The second, lobate type of intermixing is interpreted as a pepperitic fabric (Kokelaar 1982) in which basic magma has been injected into fine-grained, unconsolidated (water-saturated) muds at a shallow depth below the sediment-water interface. This accounts for the delicate intermixing and structures preserved at the contact of the two contrasting lithologies.

In the lower part of the Formation de Barnénez, along the north end of la Palud de Keraramel section, the metabasic rocks are light to medium green in colour and generally massive to slightly foliated. Irregular, lobate fine-grained margins are common. These rocks here are greenstones of doleritic aspect with a relict sub-ophitic texture. The primary pyroxenes have been replaced by large colourless to pale green amphibole forming sub-prismatic plates up to 10 mm in length. Original plagioclase lath-shapes are now preserved as sodic plagioclase (An_{12}) peppered with small epidote and sphene grains. Randomly orientated chlorite aggregates and zoned epidotes are prominent between the amphibole and plagioclase. Altered ilmenite is often surrounded by sphene.

Northwards, along the east side of the Morlaix Estuary towards Pte. de Barnénez the metabasic rocks become dark in colour and more amphibolitic in aspect. A foliation, S1, defined by the alignment of elongated amphibole-rich aggregates separating lighter coloured areas rich in plagioclase plus minor epidote and quartz, is frequently present.

The ratio of metabasic rock to metasediment increases and the latter has taken the bulk strain to a greater degree than the former. The result is that the pepperitic mixture of basic blobs set within a muddy matrix becomes strongly deformed with the irregular basic blobs pulled-apart and streaked out into lenses to produce a rock resembling a deformed matrix-supported conglomerate (Fig. 6:19).

The darker colour of the metabasic rocks northwards reflects an increase in metamorphic grade, whereby chlorite and epidote decrease in importance and may be absent, while the original sub-ophitic texture is lost and the assemblage becomes one principally of amphibole and plagioclase. The amphibole occurs in two forms; as plates up to 1.5 cm across of colourless amphibole intergrown with and frequently fringed by a pale to medium-green amphibole; and as randomly orientated smaller prisms of green amphibole together with sodic plagioclase aggregates between the large amphiboles. The plagioclase (An_{12}) is in an advanced to totally recrystallized state, and may be associated with small amounts of quartz. Minor biotite, ore, sphene are also recorded.

Although the amphibolites are frequently foliated it can be established that amphibole growth (and therefore the peak of metamorphism) largely post-dates the D1 event as 1) individual grains within the aligned amphibole aggregates are randomly orientated and 2) the smaller individual amphibole prisms associated with the plagioclase are also randomly orientated (Fig. 6:21).

Whereas the D2 event produces a spaced crenulation cleavage which deforms S1 in the metasediments its effect on the foliated amphibolites is less apparent. The amphibolites are crossed by narrow shear zones which deform S1 (Fig. 6:22). Within the shear zones which are usually <40 cm wide, a more closely spaced foliation is present, the orientation of which gives a dextral sense of displacement. Here amphibole is absent,

Fig. 6:21 Formation de Barnénez; Pte. de Perrohen

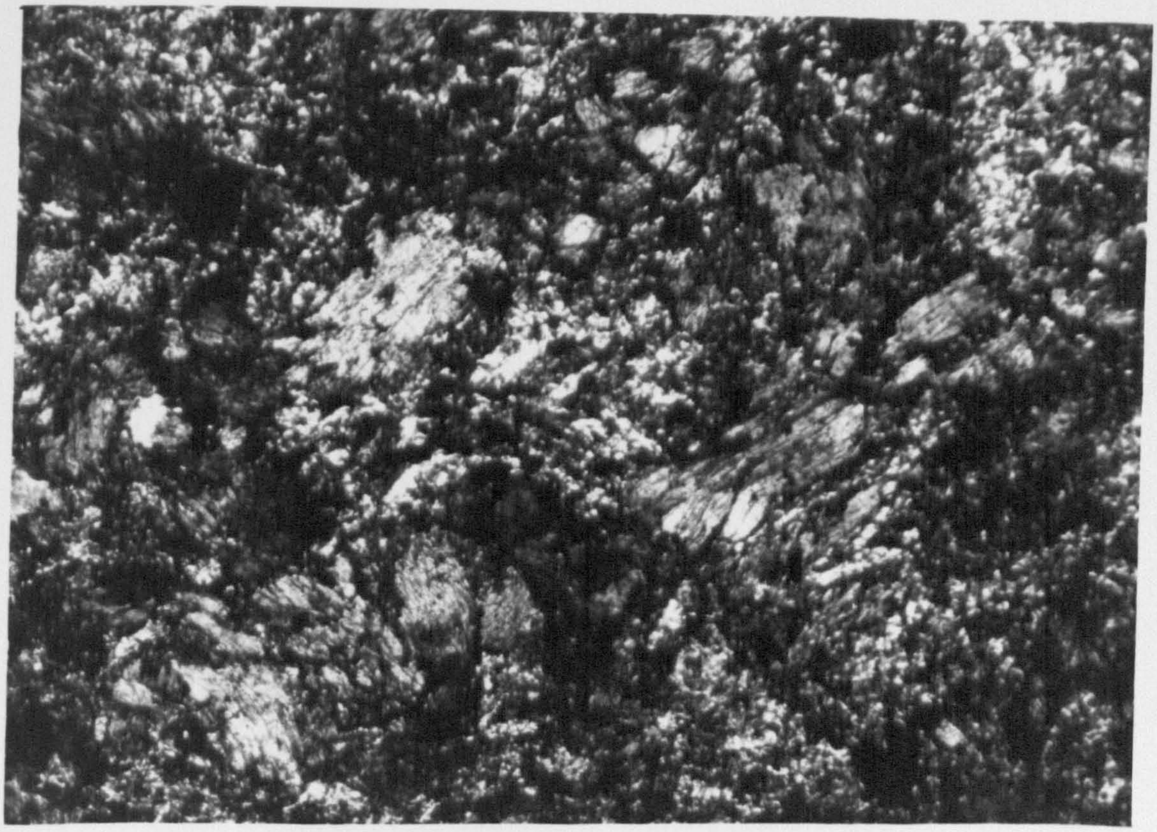
Amphibole within the plane of the S1 foliation showing random orientation. This indicates that the peak metamorphism was achieved post-D1 but pre-D2,as D2 structures modify the amphibole grains.

Scale: x15 XPL

Fig. 6:22 Formation de Barnénez; Pte. de Perrohen

Micro-shear zone in the amphibolites. In this example narrow shear zones truncate and offset a large amphibole grain. Epidote + chlorite + sphene are developed and define the S2 schistosity. The amphibole displays kinking and chlorite rimming.

Scale: x15 XPL



having been replaced by chlorite and minor epidote, as the main mafic phases, with plagioclase and quartz.

On the north side of Pte. de Barnénez the metabasic rocks are darker and somewhat finer grained rocks. Thin sections reveal randomly orientated pale to medium green amphibole prisms up to 3 mm in length and equigranular plagioclase with some quartz, biotite, ore and sphene. These rocks are hornfelsic in aspect, due to contact metamorphism by the nearby late Hercynian Primel-Carantec Granite which forms the Ile Stérec, some 300 m north of Pte de Barnénez (Map 1).

(7) THE GRÈS DE PLOUÉZOCH

The Grès de Plouézoch crops out along the northeast side of the Morlaix Basin between the Formation de Barnénez (along its southwest boundary) and the St.Jean-du-Doigt Gabbro Complex (along its northeast boundary; Map 1). However, because of a severe lack of inland exposure the relationship of the Grès de Plouézoch to the surrounding rocks is difficult to establish and its stratigraphical position is uncertain.

Le Hir (1871) recorded Scolithus linearis from these quartz-rich rocks and compared them with the Lower Ordovician Grès Armoricain. Barrois, likewise, during an excursion of the Geological Society of France in 1886 drew a similar comparison. However, in the first edition of the 1:80,000 Lannion map Barrois 1909) labelled these rocks the Quartzites Sericitiques and placed them within the Brioverian. Delattre (1952a) labelled these rocks the Gres de Plouézoch and equated them with the Schistes et Grès de Plougastel of Lower Devonian (Gedinnian) age. In the second edition of the Lannion map Delattre et al. (1966) have labelled these rocks the Quartzites de Plouézoch (of Gedinnian age). Cabanis et al. (1979a) agree with Delattre (op. cit.) and place the Grès de Plouézoch as Lower Devonian, although they show (Cabanis et al. op. cit. Fig. 1) the unit surrounded by metabasic rocks equivalent to the Formation de

Barnénez of this thesis. Most of these previous authors have commented on the similarity of the orthoquartzite clasts in the Poudingue de Dourduff to the main lithologies in the Grès de Plouézoch.

The Grès de Plouézoch sensu this thesis and Cabanis et al. (1979a) comprises a NW-SE trending sequence of bedded meta-quartzites and massive conglomeratic meta-quartzites. Figure 6:23 shows the nature of the coarsely fragmented clast-supported conglomerates in which sub-angular to rounded orthoquartzitic and protoquartzitic clasts up to 30 cm diameter are set within a matrix rich in quartz but also with prominent white mica. The bedded quartzitic lithofacies consists of beds up to 60 cm thick interbedded with thin c. 1-2 mm thick pelitic laminae. The relationships between the bedded quartzites and the massive conglomeratic units cannot be established because of the lack of exposure. However, the latter tend to dominate the possibly stratigraphically lower, southern half of the outcrop.

The following possibilities can be considered concerning the nature and age of the Grès de Plouézoch.

1. They immediately post-date the Formation de Barnénez,and the massive oligomictic quartzitic conglomerates represent one or more mass flow deposites that reflect an unstable tectonic environment,which also characterized the deposition of the Formation de Dourduff.

2. They immediately pre-date the Formation de Barnénez and are therefore part of the Formation de Dourduff. This would require major dip-slip faulting along the southwest boundary of the unit, or a major reversal in the direction of dip,for which there is little evidence.

Fig. 6:23 Grès de Plouézoch; N. St. Antoine

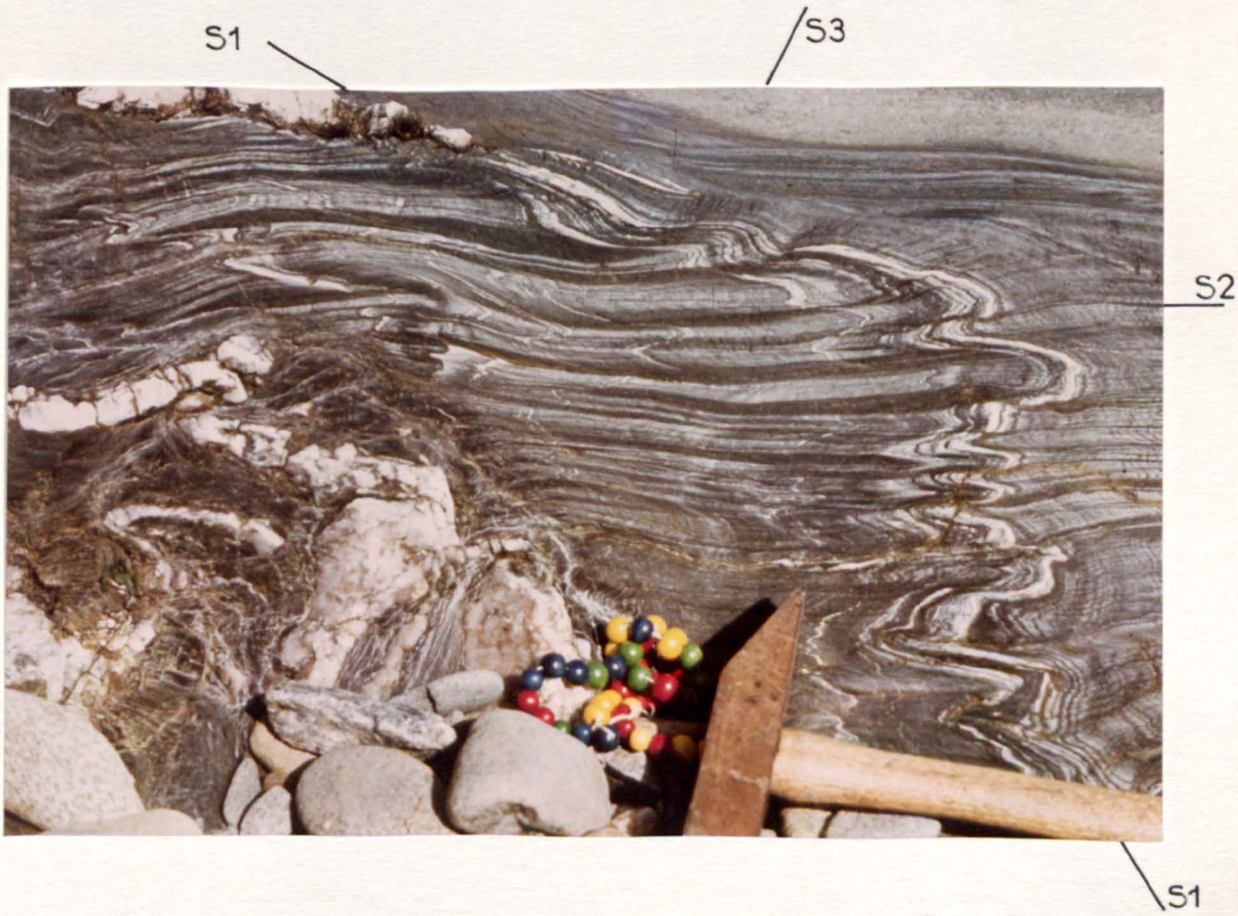
Coarsely fragmented, clast-supported conglomerates of the Grès de Plouézoch. The clasts are sub-angular to rounded and largely orthoquartzitic, the matrix is quartz + muscovite-rich. The conglomerates dominate the southern (possibly lower) part of the succession.

Scale: Hammer shaft 36 cm

Fig. 6:25 Formation de Dourduff, la Palud de Kerarmel

S0, S1, S2, S3 relationships in dark pelites, Formation de Dourduff. Primary lithological banding, S0, is preserved (top right) and is sub-parallel to the lithological segregation banding and parallel quartz veins, S1. The S0/S1 banding is deformed by D2/F2 structures and S2 is a marked crenulation/pressure-solution cleavage (with a well-developed segregation banding, E-W on photo). S3 is a fracture cleavage developed in restricted areas and lithologies.

Scale: Hammer head 18 cm


S1
S3
S2
S1

3. They are of pre-Carboniferous age - possibly equivalent to the Lower Ordovician Grès Armoricain (as suggested by Le Hir 1871 and Barrois 1886 and 1908c) or of Lower Devonian age - equivalent to the Grès de Plougastel (as suggested by Delattre 1952a and Cabanis et al. 1979c).

In view of the general northeasterly younging direction present in the northern part of the Morlaix Basin sequence the first possibility is considered the most likely, although firm proof for this is lacking.

(8) SUMMARY

The Morlaix Basin is comprised of a series of metasedimentary and metabasic lithologies. All of the lithologies are considered to be of Palaeozoic age as:-

1. Palaeozoic fossils have been recorded in the Poudingue de Dourduff Member of the Formation de Dourduff (Barrois 1927; Milon 1928; Delattre 1952a; Coquel and Deunff 1977) to which a Strunian age is assigned and adjacent formations are conformable. The Formation de Kerolzec has yielded Lower Devonian fossils (Cabanis et al. 1974; the Schistes Carburés and Grès à Platyorthis sensu Cabanis et al.; op. cit).

2. The metasedimentary formations are significantly different in character to the adjacent Brioverian successions. The Palaeozoic metasediments are dominated by quartzites, black carbonaceous pelites and debris-flow conglomeratic horizons (with abundant limestone clasts in the Poudingue de Dourduff Member).

The meta-quartzite and pelitic formations of the St. Michel-en-Grève region are isolated from the Morlaix Basin. No fossil evidence has been found and their age could be Lower Ordovician (Grès Armoricain) or Lower Devonian (c.f. Plougastel Formation of Renouf, 1965).

The oldest formation present within the Morlaix Basin is the extensive Formation de Kerolzec which is assigned to the Lower Devonian (Gedinnian). This is overlain, with an important stratigraphical break, by the Formation de Morlaix (characterized by the Schistes Zébrés) which is considered to be of Upper Devonian (or possibly lowermost Carboniferous) age. Both formations contain metamorphosed basic and acid dykes. Because of the absence of fossils and its highly deformed character the Schistes Zébrés have previously been assigned to the Brioverian (e.g. Barrois 1905b, 1908b). However the Schistes Zébrés (Formation de Morlaix) is assigned to the Upper Devonian (or lowermost Carboniferous) as they pass conformably upwards into the Formation de Dourduff.

The Formation de Dourduff consists of a sequence of pelites with minor psammites and local conglomerate lenses. There are also two thicker, coarser clastic sequences given member status, termed here the Arkose de Kerarmel Member and the Poudingue de Dourduff Member. Both members appear to occur in the upper part of the formation. The various conglomerates are of particular importance as they are interpreted as mass-flow deposits, and probably reflect unstable tectonic conditions (rapid subsidence of the basin?) associated with largely basaltic volcanism (and minor acidic volcanism), which reaches its maximum intensity in the Formation de Barnénez that conformably overlies the Formation de Dourduff. The Formation de Barnénez, in its upper part, is almost entirely composed of metabasalt and metadolerite sheets which can have pepperitic contacts with the enclosing pelites, indicating injection of basic magma into unconsolidated mud. The metabasic lithologies of the Formation de Barnénez are demonstrably penecontemporaneous with the dark pelites that pass down without a break into the Strunian dated Formation de Dourduff. Thus the Strunian or lowermost Carboniferous age for the Formation de Barnénez is firmly established. The age of the Grès de Plouézoch remains problematical and the various possibilities concerning its age have been cited,of which a post-Formation de Barnénez (lowermost Carboniferous) age is preferred.

In the northern part of the Chateaulin Basin a similar association of Devono-Carboniferous conglomerates, acid and basic volcanic rocks have been reported (Conquéré 1966; Conquéré and Ovtracht 1963; Sagon 1966; Cabanis and Sagon 1973; Rolet and Thonon 1979; Cabanis et al. 1982). Rolet and Thonon (op. cit.) have concluded that three 'groups' occur in the Plouyé-Heulgoat area, some 24 km due south of Morlaix, in which volcanism has occurred,and are in many respects similar to the association present within the Morlaix Basin.

Rolet and Thonon:-

1) Quenec'h Group = Lower and Middle Devonian (tuffogenic conglomerates, tuffaceous sandstones and shells)
2) Kermerrier Group = Strunian and (?) Tournaisian (conglomerates and tuffs)
3) Kerroc'h Group = Lower or Middle Viséan (conglomerates, basic lavas, breccias and tuffs)

Major tholeiitic volcanism occurs within the Kerroc'h Group and the metabasic volcanics are underlain by a series of conglomerates. Cabanis and Sagon (op. cit.) have correlated formations in the Chateaulin Basin with those in the Morlaix Basin and attribute the major volcanism to the Dinantian.

(F) RELATIONSHIP OF BASIC ROCKS OF THE MORLAIX BASIN TO BASIC DYKES OF ADJACENT REGIONS

Metabasic dykes are recognised throughout the area of study and truncate the three tectono-metamorphic areas described in this thesis. In the St. Pol-de-Léon Metamorphic Complex amphibolite dykes are particularly frequent within the Gneiss Granitique d'Île Callot (see chapter 2). Greenschist facies metabasic dykes occur within the Morlaix Basin sequence (principally within the Formation de Morlaix) and they are frequent within the Moulin de la Rive Orthogneiss Complex and the Locquirec Shear Belt (see Chapters 4 and 5).

The Gneiss Granitique d'Île Callot and the Moulin de la Rive Orthogneiss Complex are considered to be of Cadomian age and possibly related to the Perros-Guirec Granitoid Complex of the Trégor. All three complexes are therefore truncated by a suite of metabasic dykes, in different metamorphic and structural states, that appear to be related to the same phase of magmatic activity and pre-date the peak metamorphic episode.

Auvray (1979) has given four K/Ar whole rock ages for dolerite dykes from the Trégor. Two metadolerites from the Gouffre-Castel Meur (north of Plougrescant, central Trégor) gave dates of 435 m.y. and 445 m.y.. In this area metamorphic amphibole has completely replaced pyroxene in the majority of the metadolerites (Roach, pers. comm.). The other two samples were from the eastern Trégor (near the Sillon de Talbert). Here, the dolerites have experienced only very low grade metamorphism (prehnite and pumpellyite assemblages are recorded but primary pyroxene is fresh Both dykes yield a 350 m.y. date, which may be close to the time of emplacement.

Leutwein et al. (1972) have given whole-rock K/Ar dates on basic dykes from three areas in the northern Armoricain Massif which give three different sets of dates. Their results are as follows; 1) Mancellian (Cogné 1974) dykes from the Dinard-Erquy area are 350 ± 10 to 379 ± 10 m.y.; 2) Two dykes from the Trégor region give 250 ± 10 and 285 ± 10 m.y., and; 3) Four dykes from Finistère and the Douarnenez-Le Conquet area give a range 205 ± 10 to 195 ± 10 m.y.. These dates indicate either different emission periods or a re-setting of the K/Ar whole-rock age. Leutwein et al. (op. cit.) have been criticized (Roper 1980) as the K/Ar pair is susceptible to thermal resetting during subsequent tectono-metamorphic episodes. In areas, such as the northern part of Mancellia (Dinard-Erquy), the Hercynian metamorphism was of very low-grade and the 350 and 379 m.y. dates may reflect the approximate age of emplacement of these dykes. In Finistère field evidence supports a Permo-Triassic age for a series of NW-SE trending dykes (Roper 1980; Chauris et al. 1980). The Trégor dykes may have been subjected to Hercynian metamorphism (no petrographic details are available in the Leutwein et al. op. cit. account), but the ages given may reflect the true emplacement age.

In the area of study the Formation de Barnénez is recognised as a metabasic, dominantly extrusive volcanic unit of tholeiitic affinity (Cabanis et al. 1979a). The Formation de Barnénez conformably overlies the Strunian Formation de Dourduff and is also considered to be of Strunian or Lower Dinantian age. It can be argued that the basic dyke suite present across the area of study represents the hypabyssal equivalent of the extrusive Formation de Barnénez. The metabasic dykes truncate Upper Devonian-Strunian metasedimentary formations in the Morlaix Basin, and the c. 350 m.y. geochronological date obtained by Leutwein et al. (op. cit.) and Auvray (op. cit.) is broadly equivalent to a Strunian (end Devonian-early Carboniferous) age (Odin 1982; Harland et al. 1964).

However, the Formation de Barnénez and the basic dykes have been subjected to peak metamorphism which must have occurred (if the c. 350 m.y. date is valid) during post-early Carboniferous times. Thus in Stille's original terminology the peak metamorphism in the Morlaix Basin and adjacent areas is considered as Bretonic. This has important implications with regard to the timing of deformation in the area of study and in neighbouring areas and is discussed further in Chapter 8.

(G) THE STRUCTURE AND METAMORPHISM OF THE FORMATIONS OF THE MORLAIX BASIN

(1) INTRODUCTION

The lithologies of the Morlaix Basin, the Carantec Shear Belt and the Palaeozoic lithologies of the Grève-de-St. Michel are deformed and metamorphosed to varying degrees (summarized in Table 6:1). Structures in the dominantly orthoquartzitic lithologies in the St. Michel-en-Grève and Grand Rocher area have been described (part C) and these are broadly similar to those recorded in the Morlaix Basin.

The Morlaix Basin is an important area in establishing the age and sequence of the deformation and metamorphic episodes in the northwest of the Massif Armoricain. The Palaeozoic sedimentary and volcanic rocks (and basic dykes) were deformed prior to the emplacement of Hercynian granites, and with this knowledge the relative importance of the Cadomian Orogeny in the adjacent St. Pol-de-Léon Metamorphic Complex and the Petit Trégor area can be examined. The structures and metamorphic textures of the lithologies comprising the CSB are described first, then the dominantly metasedimentary formations, and finally the dominantly metabasic Formation de Barnénez, as all three units exhibit contrasting structural styles.

EVENT	CARANTEC SHEAR BELT	THE MORLAIX BASIN		
		WEST OF RIV. DE MORLAIX	SOUTH OF RIV. PENNELE	EAST OF RIV. DE MORLAIX
M3	Contact metamorphism, retrogression of biotite to chlorite, quartz recrystallized.	Contact metamorphism, development of biotite in metasediments.	Extensive contact metamorphism; biotite and andalusite in the Formation de Kerolzec.	Contact metamorphism of Formation de Barnénez.
D3	Minor kinking and spaced fracture cleavage in restricted bands.	N.R.	N.R.	Spaced fracture-cleavage and kink-bands in pelitic lithologies.
M2	Growth of biotite and large muscovite plates. Part mimic and part overgrow F2 folds.	Lower Greenschist Facies, much quartz mobility in some lithologies.	Lower Greenschist Facies ?	Retrogression of amphibole to epidote + chlorite + ilmenite + sphene.
S2	Well-developed crenulation cleavage	Crenulation-cleavage, rotation of almandine.	Well-developed crenulation cleavage and pressure solution in some lithologies.	Well-developed crenulation cleavage and partial schistosity in metabasics.
D2	Upright-overturned N.E. plunging folds.	Upright folds re-fold earlier structures.	Large and small-scale upright folds.	Large and small-scale folds. Shearing ? of metabasic lithologies.
M1	Growth of muscovite	Post-D1 static growth of almandine and chloritoid.	Lower Greenschist Facies, development of quartz-rich segregation bands.	Late D1 growth of amphibole within S1 schistosity in metabasics. Segregation in metasediments.
S1	Parallel alignment of phyllosilicate minerals.	Well-developed fabric.	Well-developed fabric.	S1 foliation in metabasics. Strong alignment of minerals and pressure-solution in metasediments.
D1	Mylonitic segregation banding.	Isoclinal folding of lithological bedding.	Small-scale isoclines recognised.	Isoclinal folding and flattening of pebbles.

TABLE 6 : 1 - THE MAJOR DEFORMATION AND METAMORPHIC EVENTS IN THE MORLAIX BASIN AREA. (N.R. Not recognised)

*Mylonitic

(2) THE STRUCTURE AND METAMORPHISM OF THE CARANTEC SHEAR BELT

The structure of the lithologies comprising the CSB is different to that of the formations of the Morlaix Basin. Structures are best examined at the Plage de la Clouët section, where blastomylonites consisting of alternating quartz-rich bands and phyllosilicate-rich bands occur, together with a foliated granitoid lithology and two foliated greenstone dykes.

The following deformational and metamorphic history is recognised in the CSB; D1 resulted in the mylonitization of either a granitoid and/or quartz-rich metasedimentary parent to give the characteristic banded lithology (Fig. 6:3), in which S1 is a well-developed segregation banding. The S1 segregation banding strikes NNW-SSE (340^{o}-160^{o}) and this early fabric has been re-orientated by later deformation, principally during D2. Metamorphic conditions during the D1/M1 episode are difficult to establish due to the late growth of major mineral phases (to give the blastomylonites), but it may be argued that D1 mylonitization was associated with a low-grade (greenschist facies?) metamorphism as there is no evidence now for an early higher grade metamorphism. Present phyllosilicate minerals, principally muscovite, frequently mimic an early fabric that is parallel to the segregation banding. The muscovite growth, attributed to D2/M2, largely mimics the S1 fabric.

The major effect of the D2 episode in the blastomylonite sequence has been to produce often spectacular folds. F2 folds are open-tight, with an associated variably-devleoped axial-planar crenulation cleavage which crenulates the S1 foliation. Large-scale F2 folds can be mapped out and their general profile is modified by a series of smaller-scale, Z-, S- and M-shaped congruous F2 folds as shown in Fig. 6:3. The folds are characterised by upright-overturned limbs with hinge areas that may be angular or rounded.

The shape of the hinge area appears to be determined by the frequency and thickness of the quartz-rich bands relative to the interbanded phyllosilicate-rich layers. Thicker quartz-rich bands (>8-10 cm) tend to form rounded hinge areas and thinnerbands with interbanded layers tend to form angular hinge areas. In a single fold,therefore, an angular core may pass into a more rounded hinge if the banding changes in character.

F2 folds plunge northeast at a moderate angle of 45^{0}. The S2 crenulation cleavage is developed in the phyllosilicate layers,and passes into a fracture cleavage in the quartz-rich bands or a spaced crenulation cleavage,depending upon the band thickness. A well-developed banding/ cleavage intersection lineation can be determined which is approximately parallel to the plunge of the F2 fold axes. Quartz rodding is apparent in some thin quartz-rich bands, the extension direction indicated by these structures being NE-SW parallel to the S1/S2 banding/cleavage intersection lineation.

The overall asymmetry of the dominantly northwest verging folds in the blastomylonites of the CSB indicates a structural younging direction to the south-southwest (towards the Formation de Morlaix).

The blastomylonites are in faulted contact with the Formation de Kerolzec in the Plage de la Clouët section (Map 1).

M2 index minerals (biotite and muscovite) in the CSB lithologies point to the continuation of greenschist facies metamorphism. Petrographic studies show that the metamorphism occurred late-post F2 folding as frequently, but not always, muscovite grains have grown mimectically around the F2 fold hinges and are rarely deformed themselves. In addition, occasional large biotite plates (restricted to the southern end of the Plage de la Clouët section) overgrow the F2 minor folds. Quartz grains are largely unstrained and are often polygonal in shape (even in hinge areas of tight folds) and therefore have recrystallized post-F2.

Thus there is evidence that the M2 episode post-dates the F2 folding. This metamorphic episode is characterised by the growth of quartz, muscovite and biotite under static conditions.

The gneissose fabric developed in the granitoid lithologies and the metabasic sheets within the CSB is generally orientated 045^{o}/vertical, and therefore oblique,to the S1 mylonitic banding developed in the blastomylonites. The granitic gneiss fabric is considered to be S1, which has been re-orientated in the Plage du Clouët area, as elsewhere it is sub-parallel to the early segregation banding (e.g. near Taulé GR 1411 1182). The dominant foliation in the metabasic sheets is S1, and this is modified to some extent by a non-penetrative S2 fabric. The basic dyke suite is associated with the Formation de Barnénez. A discussion as to the age of emplacement and deformation of the Morlaix Basin formations and adjacent units is given in part (F) of this chapter and in chapter 8.

Later structures and minor metamorphic retrogression are recognised. There is a small-scale D3 kinking of the S2 fabric in some phyllosilicate-rich layers. The granitic gneiss shows an open-flexuring of the S1 fabric which may be a D2 or D3 structure. Some biotite grains have gone to chlorite and some quartz grains show slight undulose extinction which may be a D3/M3 effect. Major NE-SW faulting has dislocated the CSB in the Baie de Morlaix area (Map 1).

(3) THE STRUCTURE AND METAMORPHISM OF THE METASEDIMENTARY FORMATIONS OF THE MORLAIX BASIN

The metasedimentary formations of the Morlaix Basin have undergone the following deformation sequence:-

D1. Isoclinal folding with an associated well-developed axial planar cleavage and/or segregation banding.

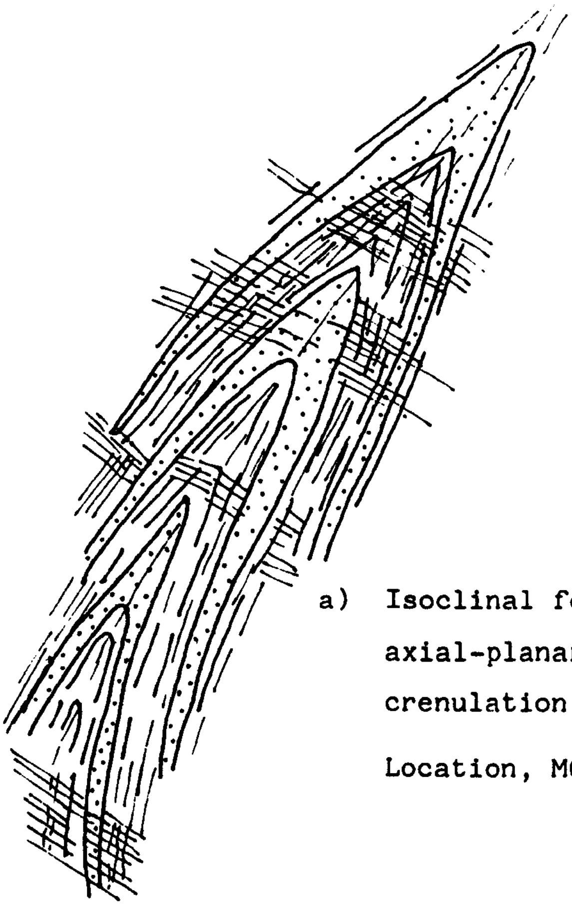
D2. Tight, usually upright northeast plunging folds with a ubiquitously developed crenulation and/or pressure solution cleavage.

D3. A spaced cleavage is recognised in some areas in restricted lithologies (Table 6:1).

The D1 folds are relatively uncommon, and where observed are always modified by later structures. The isoclines may be small-scale folds (Fig. 6:12) or larger-scale structures (Fig. 6:4). Within the Formation de Morlaix small-scale isoclinal F1 folds are relatively frequent. Fig. 6:24 illustrates such structures which are characterised by marked hinge thickening and frequent limb-thrust micro-faults. The larger scale folds that have been recognised are recumbent structures which have an associated penetrative axial-planar cleavage and thickened hinge zones.

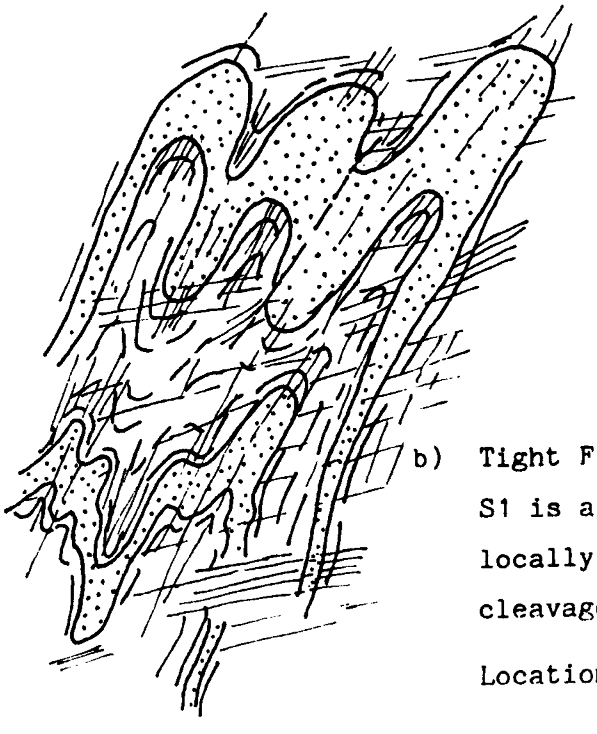
In the Formation de Dourduff flattened clasts occur with their long and intermediate axes orientated parallel to the S1 fabric. This fabric may be markedly oblique (up to 25^{o}) to the primary lithological banding. Figs. 6:13 and 6:24 illustrate this relationship. Clasts present in the conglomeratic horizons indicate preferential flattening of pelitic as compared with acid igneous material. Measured clasts show that the pelitic clasts are elongated 10:1 (length/width ratio) in the X:Y plane, whilst the more competent quartz-rich acid fragments are flattened with a 3:1 ratio (Fig. 6:13).

FIG. 6 : 24 SMALL-SCALE F1 STRUCTURES ; FORMATION DE MORLAIX



a) Isoclinal fold in primary lithological bedding, SO, with axial-planar cleavage S1 and oblique, non-penetrative, crenulation cleavage S2.

Location, MORLAIX (GR 1452 1170)



b) Tight F1 folds in possible hinge of a larger F1 structure. S1 is axial-planar to the folds which is crenulated by a locally low-angle S2 crenulation / pressure-solution cleavage. A small limb-thrust fault is developed.

Location, MORLAIX (GR 1454 1166)

Note : a larger scale F1 structure, also within the Formation de Morlaix is shown in Fig. 6 : 4

Within the Formation de Morlaix a quartz-rich segregation banding is developed that is considered to be associated with the D1/M1 episode. Fig. 6:6 shows the nature of this banded lithology, which is formed by the transposition of quartz-rich and phyllosilicate rich layers from an original sedimentary rock of broadly similar compositional variation. The original bedding is partly preserved and is, at this locality, a quartz-rich metasiltstone. The more conspicuous quartz-rich layers (S1 banding) are composed of quartz with some albite while the dark pelitic horizons vary in their composition, depending upon the quartz content, from semi-pelites to pelites. These horizons are strongly deformed by the S2 cleavage fabric,and significant pressure-solution is associated with the formation of the upright F2 folds. True lithological bedding is recognised elsewhere.

Within the dark pelite-dominated lower part of the Formation de Dourduff a similar and related low-grade metamorphic process has occurred. A set of quartz veins in la Palud de Keramel section is developed parallel to the S1 foliation. These are sub-parallel to the preserved c. $\geq$5 cm psammitic beds (Fig. 6:25). The quartz veins are considered to form at the expense of the psammites. At the boundary with the overlying Arkose de Keramel Member a series of thick (<8 cm) quartz veins occur that are apparently truncated by the basal psammite units. As indicated in part (E) this boundary has been referred to as a disconformity (Delattre 1952a) but this is not considered to be the case as S1 parallel quartz veins are in contact with the S0 primary psammite beds.

Metamorphic conditions during the D1/M1 episode allowed the mobility of quartz and this is considered to have been achieved largely through a solution transfer mechanism, principally pressure-solution associated with the S1 cleavage formation. In the eastern sector of the Morlaix Basin,lower greenschist facies metamorphism has occurred,that has allowed the extensive movement of quartz. The mineral assemblage of dominantly quartz + albite + chlorite is evidence of this. The development of a segregation banding is to a large degree governed by the lithology, so that the striping and segregation that occurred during D1/M1 and D2/M2 is restricted to the pelitic assemblages, principally in the Formation de Morlaix and the Formation de Dourduff.

In the western sector of the Morlaix Basin at Plage du Clouët, garnets (up to 5 mm diameter) present within the Formation de Kerolzec contain relatively straight inclusion trails considered to be parallel to S1. The garnet growth is post-D1 but pre-D2 as the S2 foliation wraps around the garnets (Fig. 6:26).

The D2 episode is characterised by the development of major dominantly upright folds developed throughout the metasedimentary formations of the Morlaix Basin. An associated axial-planar cleavage is very well-developed and varies in intensity within the basin. The F2 folds refold the F1 structures and the S1 fabric, the folds are orientated at 050^{o} NE-SW and plunge at a moderate angle of 042^{o} towards the NE (eg. Fig. 6:27).

Congruous small-scale folds are developed on the limbs and in the hinge areas of larger-scale F2 folds. The smaller folds can be disharmonic around the trace of the larger folds, and whilst the S2 cleavage is dominantly upright it can rotate towards a sub-horizontal angle.

F2 folds within the Formation de Morlaix are shown in Fig. 6:28. Common features of the folds are thickened hinge zones and squeezed-out and boudinaged limbs. F2 folds within the Formation de Dourduff along the Palud de Kerarmel section are illustrated in Figs. 6:10 and 6:27. Apparent opposed facing-directions occur within these formations, as F2 folds overturned to the north, face F1 folds (of similar style in the

Fig. 6:26 Formation de Kerolzec; Plage du Clouët

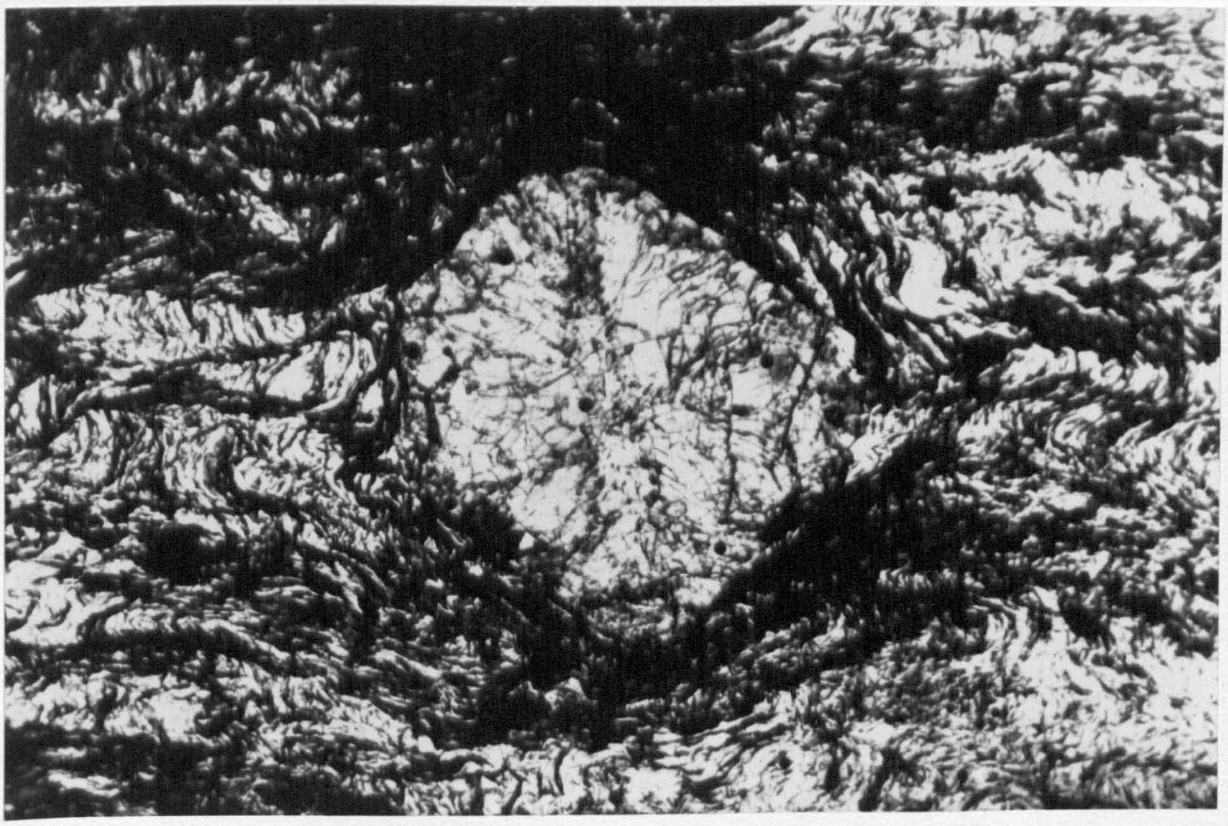
Post D1/M1-pre D2/M2 garnet in the Formation de Kerolzec (pelite band), Plage du Clouët. In this example, the garnet exhibits a form of sectional growth. The prominent S2 crenulation cleavage (seen overprinting S1) is wrapped around the garnet.

Scale: x20 PPL

Fig. 6:27 F2 fold Formation de Dourduff; la Palud der Kerarmel

F2 similar fold in psammite bed immediately below the Arkose de Kerarmel Member at la Palud der Kerarmel. S1 quartz veins are developed sub-parallel to the folded bed. A well-developed S1 crenulation/pressure-solution cleavage is axial-planar to the fold. This medium-scale fold reflects the larger fold style observed in the Palud de Kerarmel section.

Scale: Compass-clinometer 10 cm



figured example; Fig. 6:28) which face south. Fig. 6:27 shows a medium-scale fold in a psammite bed and here the similar fold style reflects the larger fold style developed in the Arkose de Keramel Member.

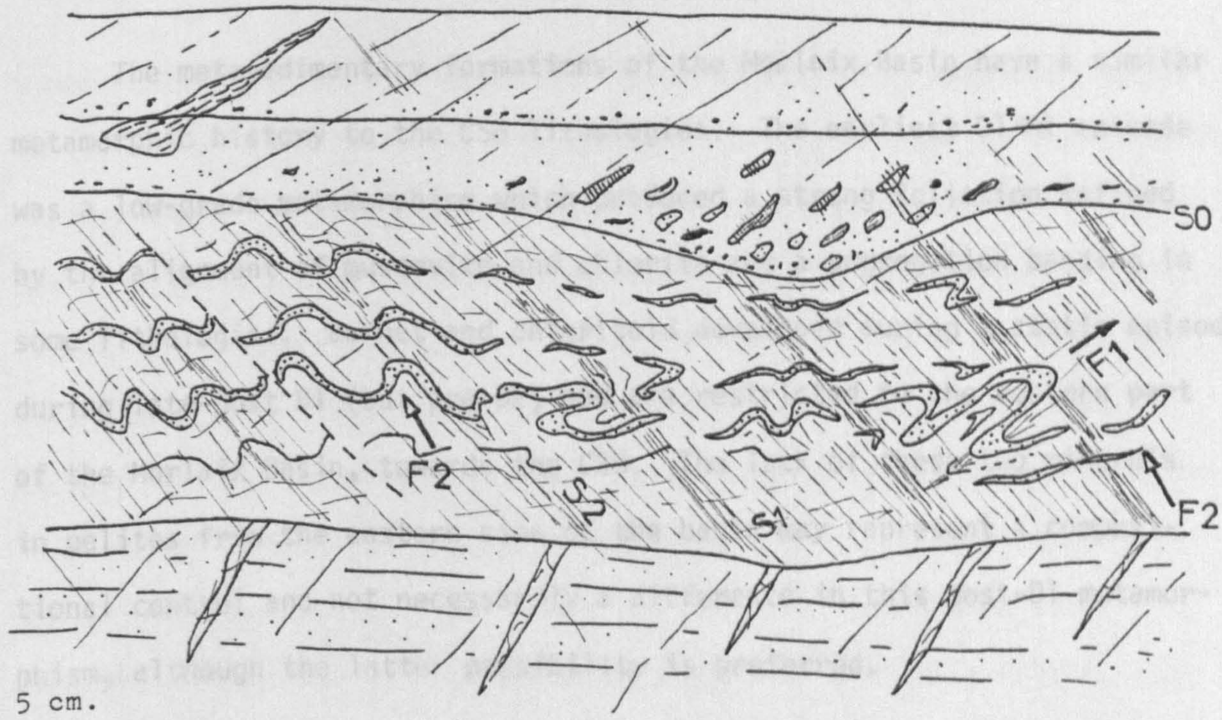
The S2 cleavage is variable,in that it crenulates an earlier S1 fabric and in some lithologies develops a pressure-solution striping. In the pelite dominated assemblages the S2 cleavage is well-developed with an 050^{o}/vertical orientated, spaced crenulation cleavage fabric. In some areas there is a striping developed parallel to the cleavage. This striping is considered to be a pressure-solution cleavage in which some degree of mineral segregation and recrystallization has occurred. Fig. 6:25 illustrates the maximum development of this cleavage fabric. The S2 cleavage striping is commonly developed in the same lithologies that are affected by the S1 segregation banding where the two fabrics are developed perpendicular or oblique to each other.

The S1 quartz-rich bands can be transposed into the S2 stripes (Fig. 6:25). The dark bands are characterised by the assemblage quartz (very fine-grained) + chlorite + white mica and the lighter coloured bands by the same mineralogy, but with increased white mica and a slightly coarser quartz grain-size. The development of the S2 pressure solution cleavage appears to be dependent upon the lithology rather than the degree of deformation or metamorphism.

A D3 fracture-cleavage (S3) is formed in pelitic lithologies of the Palud de Kerarmel section (Fig. 6:7 and 6:25). Kink-bands also occur in this area and these are considered to have formed during a relatively minor episode of deformation. Both of these structures are orientated E-W at $80\text{-}100^{o}/80^{o}$ S.

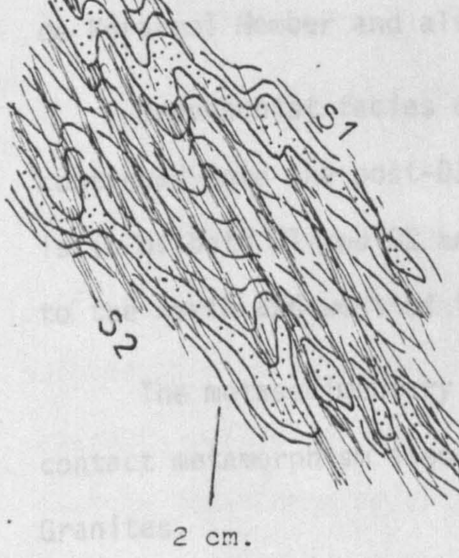
FIG. 6 : 28 SMALL-SCALE F2 STRUCTURES ; MORLAIX BASIN

(a)



(a) Small F2 folds may refold early recumbent F1 structures to give apparent oppositely facing folds. Grading is common in the arkose beds which may also load down into the more pelitic beds. Quartz veins are frequently developed in the arkose beds and are conjugate to the S2 cleavage.

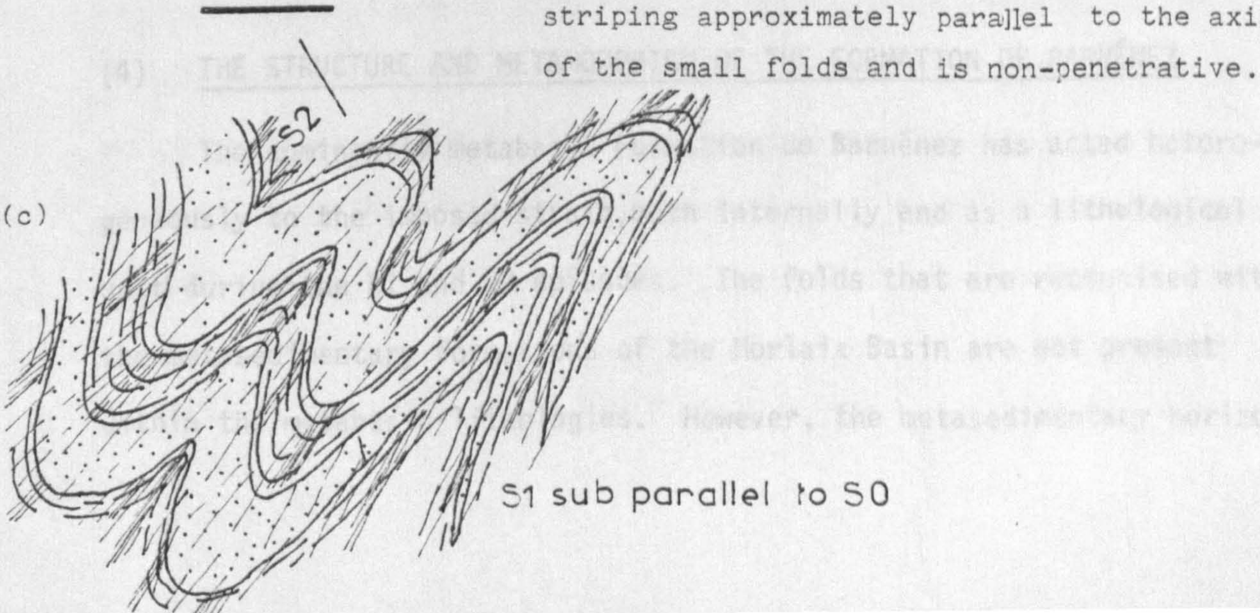
(b)



(b) and (c)

Small-scale fold style and cleavage relationships. Folds are commonly tight with thickened hinge zones. The S2 crenulation cleavage and related pressure-solution cleavage is marked by a lithological striping approximately parallel to the axial planes of the small folds and is non-penetrative.

(c)



The metasedimentary formations of the Morlaix Basin have a similar metamorphic history to the CSB lithologies. The earliest D1/M1 episode was a low-grade metamorphism which produced a strong foliation defined by the alignment of muscovite and chlorite and a segregation banding in some lithologies. Garnet and chloritoid developed during a static episode during late-post D1 (but pre-D2) and are restricted to the western part of the Morlaix Basin, towards the CSB. The lack of these two minerals in pelites from the eastern side of the basin may represent a compositional control and not necessarily a difference in this post-D1 metamorphism, although the latter possibility is preferred.

A post-F2 event resulted in the recrystallization of quartz and the growth of large muscovite plates. Quartz is largely polygonal and unstrained, and muscovite mimics the F2 hinge traces in phyllosilicate-rich bands. Biotite is developed in the coarser rocks of the Arkose de Kerarmel Member and also post-dates the F2 folds.

Greenschist facies conditions possibly commenced during D1 and continued into the post-D2 interval. Segregation banding is characteristic of both D1 and D2 and an increase in metamorphic grade is apparent to the north and west of the Morlaix Basin.

The metasedimentary formations are affected in localized areas by contact metamorphism associated with the emplacement of Hercynian Granites.

(4) THE STRUCTURE AND METAMORPHISM OF THE FORMATION DE BARNÉNEZ

The dominantly metabasic Formation de Barnénez has acted heterogeneously to the imposed strain, both internally and as a lithological unit during the D1 and D2 episodes. The folds that are recognised within the metasedimentary formations of the Morlaix Basin are not present within the metabasic lithologies. However, the metasedimentary horizons within the formation are internally deformed with well-developed intrafolial folds. The folds are isoclinal and highly non-cylindrical, plunging at a moderate angle to both northeast and southwest within the plane of the schistosity. The folds may have formed 1) by the deformation of an initially irregular surface, 2) by the stretching and rotation of the fold axis within the schistosity as described by Sanderson (1973), 3) by refolding the fold axis. A single cleavage is associated with the folds, which is axial-planar and parallel to the foliation developed in the adjacent metabasic lithologies. In pelitic interbands a later crenulation cleavage is present, which cross-cuts the early fabric. The folds are assigned to D1 and the associated axial planar foliation is S1. The later spaced crenulation cleavage is assigned to the D2 episode. It is interesting to note the similarity of these folds to those developed within the metasedimentary horizons of the Lower Brioverian Formation de Pte de l'Armorique.

A description of the principal S1 fabric present within the variably foliated metabasic sheets and more irregular masses has been given in section (E). With increase in metamorphic grade northwards along the east side of the Morlaix Estuary the metabasic rocks change from greenstones to amphibolites. The climax of this metamorphism, as indicated earlier, post-dates the initial development of S1. Evidence for this is seen in the random orientation of amphiboles which comprise the elongated aggregates and alternate with more plagioclase-rich areas to define S1. The plagioclase occurs as largely recrystallized aggregates, within which are set smaller randomly orientated amphiboles. The D2 episode may be represented by the narrow (c. 40 cm wide) shear zones which occasionally cut across the NW-SE trending metabasic sheets at a high angle.

(5) A SUMMARY OF DEFORMATION IN THE MORLAIX BASIN

During D1/M1 the onset of deformation led to the development of segregation banding and a foliation with associated low-grade metamorphism. The climax of the M1 episode was post-D1, as garnet and chloritoid growth at Plage du Clouët,and amphibole in metabasic lithologies at Le Clouët and in the Kerarmel-Pte. de Barnénez area,shows static post-D1 pre-D2 growth. There is some evidence for metamorphic grade increasing towards the north and northwest of the Morlaix Basin.

The D2/M2 episode resulted in significant folding of the metasedimentary formations and shearing of metabasic lithologies. A second metamorphism, M2 (which may possibly be a continuation of M1),led to segregation banding and late mineral growth. The M2 episode climaxed post-F2 (growth of biotite over F2 fold hinges) but prior to local contact metamorphism.

(H) SUMMARY

The sediments and volcanics of the Morlaix Basin sequence have been strongly deformed. An early deformation (D1) produced a strong penetrative cleavage and an associated pressure-solution banding either parallel to or slightly oblique to the primary bedding fabric. This S1 foliation is parallel to the NNW alignment of the basin except in areas of intense D2 folding. The F1 folds are usually recumbent and on a small scale. The second deformation produced more upright minor folds with an associated strain-slip foliation and a pressure-solution banding. The F2 axial traces trend E-W or ENE-WSW, frequently with a plunge to the E or ENE. The S2 foliation varies from a penetrative to a spaced cleavage. A third cleavage, is a variably developed crenulation foliation. These rocks were metamorphosed within the greenschist facies; the principal mineral growth was post-D1 but pre-D2.

The Morlaix basin is separated from the high grade Hercynian terrain to the west (the St. Pol-de-Léon Metamorphic Complex) by a NNW-SSE trending ductile shear zone, the CSB, composed largely of blastomylonites derived both from basement granitoids and arenaceous sediments (the relationship of the latter to the basin sediments is not clear). These mylonites dip eastwards and show the S1 foliation and the upright F2 folds. Along the western and southern margins of the basin the sequence rests on Lower Devonian carbonaceous pelites and metaquartzites (Formation de Kerolzec).

The eastern margin of the basin is ill-defined since exposure is very poor, but may be largely fault-bounded. Along its northern boundary the basin is cut discordantly by the late Hercynian Carantec granite, which also transects the ductile shear zone of the west margin.

The assemblage of mudstones with thin turbiditic sandstones and the incoming of debris flows, followed by return to black mud sedimentation with penecontemporaneous basaltic volcanism reflects the unstable geotectonic regime in which the basin fill accummulated. The basin was initiated by subsidence along a NNW-SSE lineament in late Devonian times. This movement may relate to an early stage of the Bretonic earth movements, which further south in the Chateaulin Basin were responsible for the folding and cleavage development in Upper Devonian and older rocks and for the hiatus between these and the overlying Chateaulin Slates of the late Tournasian to Visean age.

Progressive uplift of adjacent terrains with their Palaeozoic cover contributed detritus to the basin. The high degree of rounding of clasts within the debris flows points to derivation from littoral environments. The return to black mud sedimentation accompanied by basaltic volcanism possibly reflects a period of crustal extension seen elsewhere in northern Brittany. By the time the D2 event was taking place, the

St. Pol de Léon Metamorphic Complex had been juxtaposed with the Morlaix Basin as a result of movements along the ductile shear zone.

Thus there is evidence during the evolution of the basin for both major vertical and compressive movements occurring during the Hercynian orogeny. The timing of the main deformation and metamorphism is post-early Dinantian. This applies not only to the basinal sequence but also to the adjacent metamorphic terrains of northern Brittany.

CHAPTER SEVEN

THE ST. JEAN-DU-DOIGT GABBRO COMPLEX, THE HERCYNIAN GRANITES AND THE MIXED METASEDIMENTS AND AMPHIBOLITES OF THE BAIE DE MORLAIX

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THE ST. JEAN-DU-DOIGT GABBRO COMPLEX, THE HERCYNIAN GRANITES AND THE MIXED METASEDIMENTS AND AMPHIBOLITES OF THE BAIE DE MORLAIX

(A) PRELIMINARY STATEMENT

The St. Jean-du-Doigt Gabbro Complex and the Hercynian granites cropping out within the area covered by this thesis have been examined principally to establish their relationship to surrounding lithological units. Both the gabbro complex and the adjacent granites (e.g. the Granite de Primel-Carantec and the Granite de Beg An Fry) have been assigned to the Hercynian Orogeny (Cabanis et al. 1979a; Autran et al. 1979). Cabanis et al. (op. cit.) considered the emplacement of the St. Jean-du-Doigt Gabbro Complex to be late Devonian. However, the possibility is discussed here that the gabbro complex could be older and may represent a relatively low-strain segment of the Moulin de la Rive Orthogneiss Complex. It can be established that the St. Jean-du-Doigt Gabbro Complex was metamorphosed and heterogeneously deformed prior to the emplacement of the Hercynian granites. These granites are volumetrically important, and it is possible to distinguish both an early and a late group of Hercynian plutons, broadly equivalent to the Older Variscan Granites and Younger Variscan Granites of Adams (1967).

Along the northwest side of the Baie de Morlaix a lithological group, collectively termed the Mixed Metasediments and Amphibolites of the Baie de Morlaix, occurs as inclusions within the Hercynian granites. Although petrographically similar to some of the metasediments present within the St. Pol-de-Léon Metamorphic Complex and in the Morlaix Basin sequence their age is still problematical. The Mixed Metasediments and Amphibolites of the Baie de Morlaix are discussed in part (C) where some indication as to their possible age is given.

(B) THE ST. JEAN-DU-DOIGT GABBRO COMPLEX

(1) INTRODUCTION

The St. Jean-du-Doigt Gabbro Complex occupies a large area in the central part of the region studied (Maps 1 and 2). The complex crops out between Primel-Trégastel and Pors Rodou in the north, where it is bounded by the sea, while its southern limit approximates to a line drawn between near Plouézoc'h (GR 1472 1227) and Lanmeur.

The complex is composed largely of gabbros which have been truncated by a number of different igneous phases, principally Hercynian granites. The complex has been subjected to one main heterogeneous deformation and metamorphosed within the greenschist facies prior to the emplacement of the late or post-tectonic Hercynian granites.

The relationship of the gabbro complex to the surrounding lithological units is examined in this part, and particular emphasis is placed on its relationship to the adjacent Moulin de la Rive Orthogneiss Complex, which is in part composed of metagabbro. There has been some description of the lithologies present within the gabbro complex (e.g. Lelubre 1938; Sandréa 1958), but various authors have assigned the complex to different ages.

Barrois (1908c) considered the gabbro complex, which he termed the Epidiorites de St. Jean-du-Doigt, to be of later Precambrian (Brioverian) age. Milon (1936) and Lelubre (1938) gave brief descriptions of the gabbros and the latter author also described the agmatites which occur within the complex. Both authors considered that the acidic fraction of the agmatite was genetically related to the emplacement of the adjacent Granite de Primel, as also did Delattre et al. (1951).

Perrin and Roubault (1938) interpreted the modifications seen in the basic phase of the agmatites in the Gabbro de St. Jean-du-Doigt to solid-state reactions thus reviving the granitization hypothesis first put forward some fifty years earlier by Barrois (1888).

Sandrea (op. cit.), Delattre (1952a)and Delattre et al. (1966) considered the gabbro complex to be pre-Dinantian. Delattre noted the presence of altered gabbro (which he termed epidiorite) clasts within the Dinantian Poudingue de Dourduff. These basic clasts were equated with lithologies in the gabbro complex, therefore establishing the pre-Carboniferous age.

Verdier (1968) considered the Gabbro de St. Jean-du-Doigt to be intrusive into the Moulin de la Rive Orthogneiss Complex (sensu this thesis) and he recognised several "masses gabbroiques oblongues" that truncated the granitic orthogneisses in the Pte. du Corbeau area. These gabbroic masses have been mapped during the current work and it is equally possible that they predate the granitic components (see later discussion). Cabanis et al. (1979a) and Autran et al. (1979) considered the Formation de Barnénez to be the extrusive equivalent of the gabbro complex.

(2) RELATIONSHIP OF THE GABBRO COMPLEX TO ADJACENT LITHOLOGICAL UNITS

The exact relationship of the gabbro complex to adjacent lithological units is difficult to determine because of lack of rock exposure at all the boundaries. The western margin of the complex is considered to be a major fault, whereby the gabbros and the Hercynian Granite de Kerprigent (Leutwein et al. 1969) are in contact with the metabasic

Formation de Barnénez and possibly the meta-quartzite unit, the Grès de Plouézoc'h (discussed in Chapter 6). All previous maps of this area (Barrois 1909; Delattre 1952a; Delattre et al. 1966; Cabanis et al. 1979a) indicate a fault along this western margin.

To the south, the gabbro complex is thought to truncate the Brioverian metavolcanic and metasedimentary formations, although there is no direct evidence for this. A mylonitized granite occurs in this area, discussed p 260, and is considered to truncate the gabbro complex.

The relationship of the gabbro complex to the Moulin de la Rive Orthogneiss Complex is of importance in establishing the age of the gabbro complex and in correlating deformational and metamorphic events across the area. In the critical eastern area there is no direct contact exposed between the adjacent meta-igneous complexes. In the area of Pors Rodou (GR 1570 1283) the typical lithology of the gabbro complex is a homogenous and unfoliated gabbro. This is truncated by the Hercynian Granite de Beg An Fry and related sheets.

To the east of the gabbro outcrop there is an approximate 120 m break in exposure, east of which the Pors Rodou Breccias of the Moulin de la Rive Orthogneiss Complex crop out. These breccias are truncated by granite sheets, but are not seen in contact with other components of the orthogneiss complex. The breccias are bounded to the east by beach sand. The next exposures in the centre of the bay at Pors Rodou are banded schistose mylonites which form a c. 280 m wide NE-SW trending shear zone (Map 3). Along the eastern boundary of the shear zone the mylonites are seen to be developed from components of the Moulin de la Rive Orthogneiss Complex. These are principally the gabbro component and the younger granite component.

Two possible satellitic intrusions from the St. Jean-du-Doigt Gabbro Complex occur within the orthogneiss complex at Pte. du Corbeau and Roc'h Ledan. At Pte. du Corbeau a narrow (c. 25 m wide) NE-SW trending sheet of gabbro exists, bounded by the granite and porphyritic micro-granite components cut by several post-complex basic sheets (Fig. 4:11). Age relationships between the gabbro and other components are difficult to establish as the contacts are zones of high strain, along which the gabbro has been converted to greenschist. A similar problem exists at the second locality, Roc'h Ledan. An alternative explanation for these two gabbro occurrences is that they represent the early-formed gabbro component of the Moulin de la Rive Orthogneiss Complex caught up as rafts within the younger granitic components of the orthogneiss complex.

The gabbro component of the orthogneiss complex often posesses a well-developed penetrative S1 foliation whereas the gabbros of the St. Jean-du-Doigt Gabbro Complex frequently preserve primary igneous textures and are only foliated within localized high-strain zones. The following possibilities may account for the relationships seen:-

1) The St. Jean-du-Doigt Gabbro Complex and the gabbro component of the orthogneiss complex may have been emplaced during a single episode and subjected to the same heterogeneous deformation (the D1 episode, chapter 4) and metamorphism, but strained to different degrees.

2) The gabbro complex and the gabbro component of the orthogneiss complex may have been emplaced at different times, but both have experienced the same deformation history.

3) The gabbro complex and the gabbro component of the orthogneiss complex may have been emplaced at different times and have undergone separate deformational histories whereby the St. Jean-du-Doigt Gabbro Complex has escaped the penetrative (D1/M1)

episode. It may have been subjected to the D2/M2 episode as identified within the orthogneiss complex.

Further discussion as to the age of the gabbro complex is given later in this chapter.

(3) THE PRINCIPAL COMPONENTS OF THE GABBRO COMPLEX

A number of different components are recognised within the St. Jean-du-Doigt Gabbro Complex. The most important component volumetrically is a medium-coarse grained gabbro, other components recognised are pegmatitic gabbros and agmatites which are often truncated by late Hercynian intrusive phases.

(a) The gabbro component

The gabbro component dominates the complex and is variable in aspect according to the degree of metamorphism it exhibits. In the Pors Rodou area, at the northeastern margin of the complex, the gabbro is holocrystalline with a hydiomorphic texture. Here it is composed of aggregates of mafic minerals - hornblende, actinolite and epidote together with light-coloured minerals - principally plagioclase (An_{25}) and sometimes minor quartz. The aggregates may be up to 6 mm in diameter, but 2-4 mm is more typical (Figs. 7:1 and 7:2).

Actinolite has developed at the expense of hornblende, and epidote may have formed with the breakdown of original labradorite to a sodic placioclase. Minor amounts of quartz may be present between larger grains. Biotite, iron oxide and sphene (frequently as mantles around the ore) are accessory minerals. Single poikioblastic green hornblende plates or aggregates of subidioblastic grains frequently pseudomorph primary pyroxenes and outline a sub-ophitic texture. A pale green actin-olitic amphibole may fringe the green hornblende and is the common amphibole in zones of high-strain, where it is associated with aggregates of recrystallized sodic plagioclase. The larger non-recrystallized plagioclase prisms are peppered with epidote or clinozoisite and small actinolite prisms.

In the St. Jean-du-Doigt area (GR 1518 1303) relict clinopyroxene is present. Here it is preserved in areas of low strain and little agmatization. The clinopyroxene in these areas is commonly amphibolitized and small sub-grains of hornblende overgrow and replace the pale-coloured clinopyroxene (Fig. 7:1). In the least altered specimens the preserved clinopyroxene is commonly mantled by a narrow fringe of amphibole. Plagioclase of composition labradorite (An_{50-55}) may be preserved.

In zones of higher strain the gabbros become flazer gabbros (foliated protomylonites) and sometimes mylonite schists. The foliation is defined by elongated aggregates of amphibole and minor epidote with biotite and/or chlorite. These aggregates are separated by zones rich in recrystallized plagioclase with minor prismatic amphibole, epidote and chlorite (Fig. 7:2). Along discreet slip surfaces chlorite becomes the dominant mafic mineral.

(b) The gabbro pegmatites

Spectacular gabbroic pegmatites are developed within limited areas of the complex. They occur most frequently in the northwest of the complex and are well-exposed along the beach section west of Primel-Tregastel (GR 1493 1295). The pegmatites occur in large zones up to 5 m across. Some of the smaller (<30 cm diameter) pegmatites appear as broadly spherical masses that are held within a medium-coarse grained gabbro host. Boundaries between the two components are sharp or gradational across several centimetres.

The pegmatites are composed of large (up to 12 cm) aggregates of prismatic green hornblende and plagioclase (composition not determined).

Fig. 7:1 St. Jean-du-Doigt Gabbro Complex, Gabbro Component

Preserved igneous texture in the gabbro component. The large grain (right hand side) is of clinopyroxene which has partly been replaced by sub-grains of amphibole along the grain rim.

Scale: x15 XPL

Fig. 7:2 St. Jean-du-Doigt Gabbro Complex, Gabbro Component

Amphibole appears to have pseudomorphed a large clinopyroxene grain in this moderately deformed gabbro lithology. A crude foliation is developed at this locality with recrystallized plagioclase dominant in bands (together with some amph. + epi. + chl.) separated from amph. + epi. + bio. + chl. rich bands.

Scale: x15 XPL

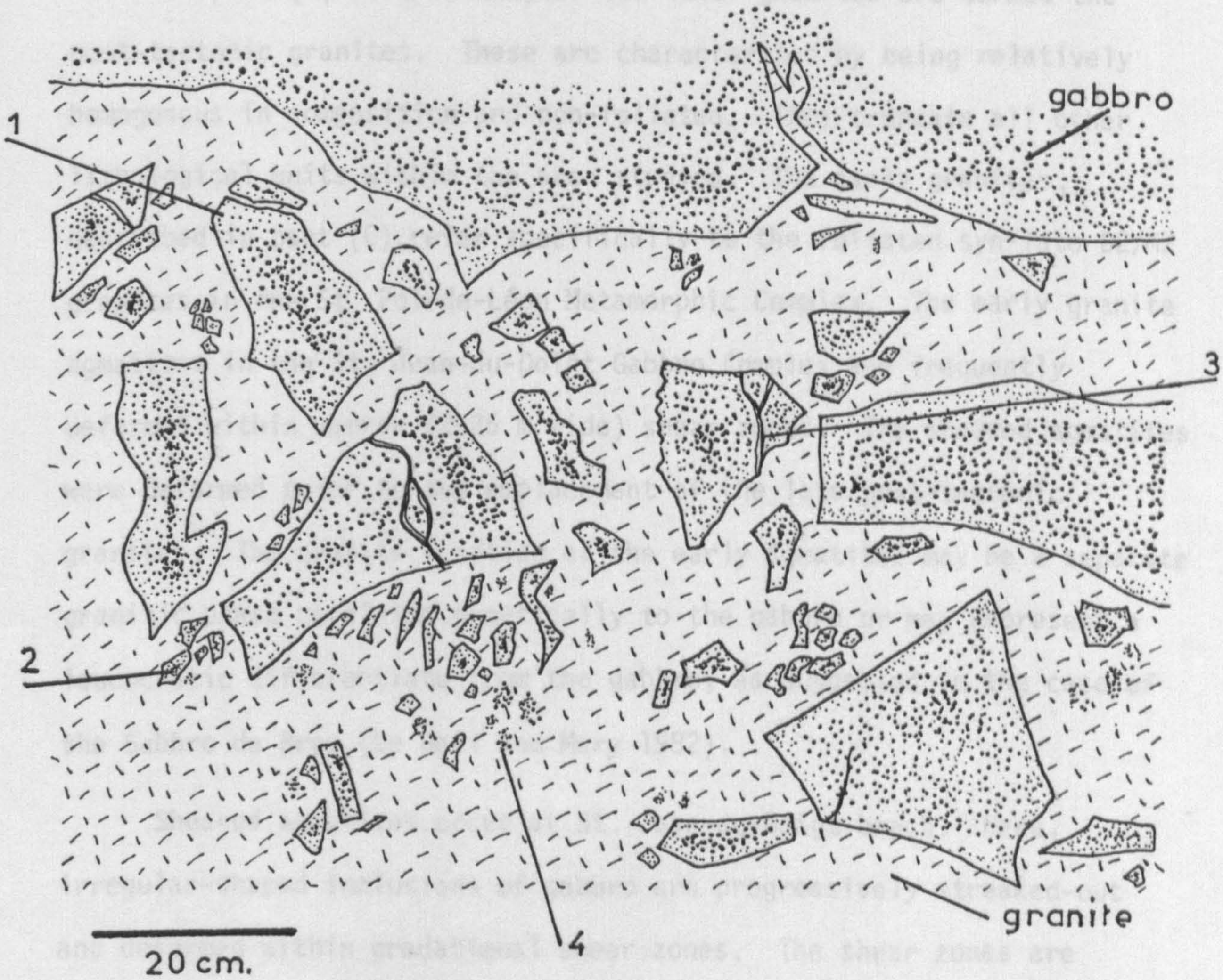
The pegmatites are considered to be either the product of metasomatic reaction of the host gabbro with granite driven hydrothermal fluids or were simply formed from the crystallization of bodies of volatile-enriched basic magma.

(c) The agmatite component

Agmatites are defined here as a mixture of two or more igneous rock types in which the individual rock-types have largely maintained their primary compositional differences. In the St. Jean-du-Doigt Gabbro Complex the common agmatite association is that of granite and gabbro. These have been mapped by Delattre et al. (1966) as "facies de métasomatose alcaline". The previous suggestions offered for the origin of the agmatites have already been outlined in the introduction (i.e. Barrois 1888; Milon 1936; Lelubre 1938; Perrin and Roubault 1938; Sandréa 1958).

In detail two granitic phases, the products of separate injection episodes, can be recognised. An early phase is composed of a light-coloured leucogranite which is restricted in outcrop to the beach area at St. Jean-du-Doigt (GR 1495 1297). This granite forms agmatite in which irregular-shaped, lobate and angular blocks of gabbro are injected by and enclosed within the granite host (Fig. 7:3). A later phase, composed of a pink-coloured coarser-grained granite, truncates the earlier agmatites and also forms an agmatitic facies where it invades the gabbro host and occasionally the early granite. The later granite phase forms large irregular-shaped boss-like masses mapped out by Barrois (1909) and Delattre et al. (1966), e.g. the Granite de Beg an Fry (Table 7:1).

Fig. 7 : 3 AGMATITE, St-JEAN-DU-DOIGT GABBRO COMPLEX



Typical early agmatite lithology showing relationship between host gabbro and injected granite. The granite may be a late magma phase or early related differentiate of the gabbro complex. Characteristic features of the early agmatites are :

(1) metasomatic haloes around the gabbro clasts ;

(2) angular to sub-angular clasts (the smaller fragments tend to be rounded) ;

(3) internal veining of the clasts ;

(4) ghost clasts.

The gabbro appears to have been forcefully injected and large gabbro blocks have broken down to smaller disaggregated clasts.

In part (C) of this Chapter the later granites are termed the post-tectonic granites. These are characterized by being relatively homogenous in composition and non-foliated. They truncate all other lithological units within the area studied. The early granites, described in part (C),refer specifically to the foliated syn-late D2/M2 granites in the St. Pol-de-Léon Metamorphic Complex. The early granite agmatites in the St. Jean-du-Doigt Gabbro Complex are frequently deformed within narrow (2-25 m wide) shear zones. The sheared agmatites were deformed prior to the emplacement of the late post-tectonic granites. The granite fraction of the early agmatites may be a separate granitic phase unrelated genetically to the gabbro or may represent a leucocratic differentiate from the gabbro, as suggested in the case of the Gabbro de Brée (Le Gall and Mary 1982).

Sheared agmatites occur at St. Jean-du-Doigt beach. Here, irregular-shaped inclusions of gabbro are progressively streaked-out and deformed within gradational shear zones. The shear zones are generally orientated N-S and dip vertical-060^{o} W. The shear zones are localized almost entirely within the agmatite zones and only one example of a shear zone has been encountered which lies solely within gabbro.

In thin-section the mixed nature of the parent rock is marked by streaky or lenticular patches resembling a crudely developed segregation banding. The dark elongate mafic lenses and bands are composed of hornblende + actinolite + epidote, which are anastomosed by zones rich in felsic minerals - quartz,plagioclase (An_{16}), biotite ± chlorite. The hornblende forms large grains with actinolite developed at grain margins. Plagioclase grains may be fractured and are usually cloudy due to presence of small epidotes. Quartz may he highly strained or recrystallized. Pools of strained quartz are common. Epidote also occurs as a separate xenoblastic fine-grained phase (Figs. 7:4 and 7:5).

Fig. 7:4 St. Jean-du-Doigt Gabbro Complex, Agmatite Component

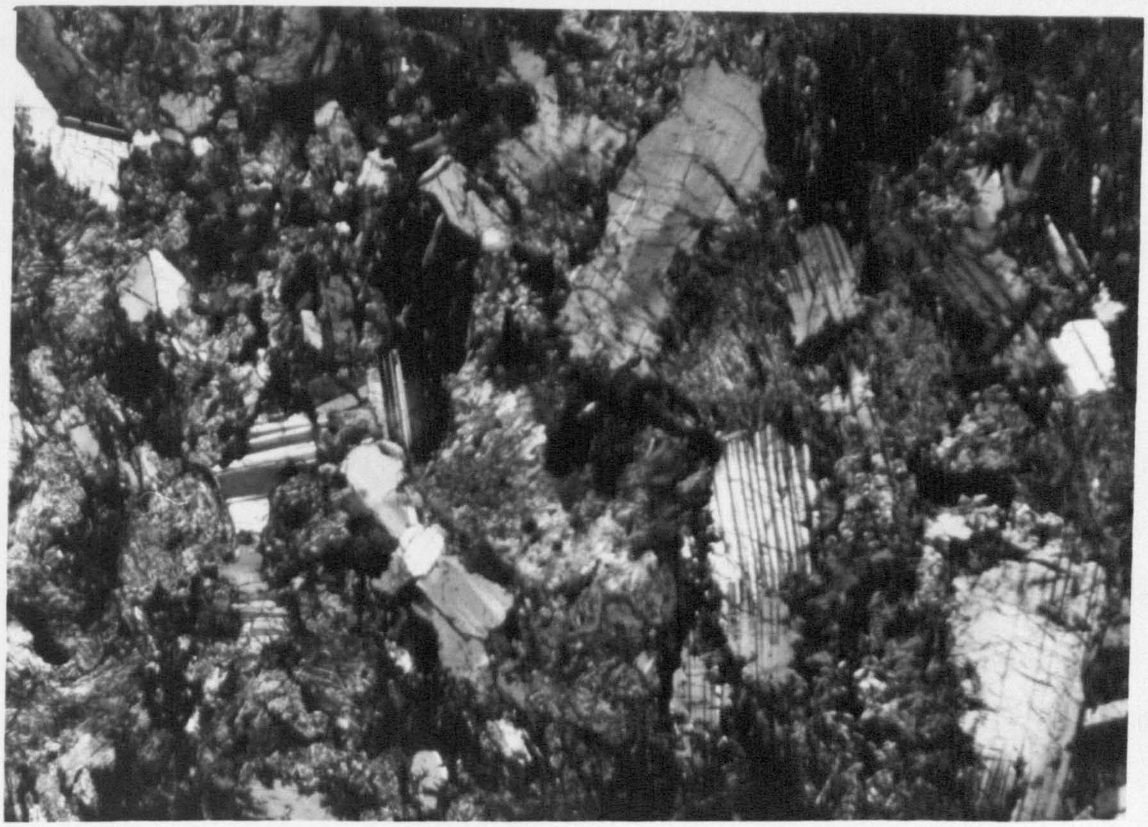
In this low-moderately strained agmatite, plagioclase (An_{16}) and amphibole occur in streaky, poorly segregated lenticular patches. Dark mafic pitches are composed largely of amphibole + epidote which are anastomosed by zones rich in plagioclase + quartz.

Scale: x15 XPL

Fig. 7:5 St. Jean-du-Doigt Gabbro Complex, Agmatite Component

Large amphibole in moderately-highly strained agmatite. The amphibole is pale green-coloureless (actinolite?) and is itself partly overgrown by chlorite. Epidote occurs as a xenoblastic phase largely at the expense of plagioclase.

Scale: x15 XPL



The agmatites produced by the injection of the later granite phase are not seen to be sheared and field evidence indicates that the shearing and metamorphism occurred post the emplacement of the early granite phase but predates the later granite phase. The post tectonic granites are considered to have been emplaced between 290-303 ± 15 m.y. (Barriere et al. 1983), but no firm dates can be given for the early granites of the Petit Trégor-Morlaix region covered by this thesis.

In the area west of Pors Rodou (GR 1567 1287) igneous relationships are possibly indicative of emplacement of granite into gabbro which may have been only partly consolidated. Here, contacts between the two rock types are characterized by intimate lobate margins, pipes (Blake et al. 1965; Topley et al. 1982) and dark margins (Bishop 1963). The intimate lobate margins are characterized by small flames of granite within the gabbro and an irregular interface between the two rock types. The pipes are rare and are c. 20-50 cm long by 1-6 cm tubes of granite within the gabbro. The pipes may be bulbous or irregular in cross-section. Dark (c. 1 cm wide) margins at the rims of the gabbro component occur occasionally at the interface of granite and gabbro. Likewise, light-coloured margins are recorded elsewhere in the complex where a c. 1 cm rim of light-coloured material envelopes the gabbro inclusions within the agmatites. This is possibly the result of metasomatic reaction within the injected granite phase, and related to this may be occasional small ghost xenoliths of mafic (gabbroic) material which have undergone alteration (Fig. 7:3).

There are also, at the Pors Rodou locality, granite sheets and bosses (of similar composition to the pipe material) that sharply truncate the gabbro and show none of the features recorded above. These differences in field relationships are possibly due to the presence of two granite phases which have been injected at different times. Further work is required here. The gabbro complex has a complicated igneous history and much more work is required to establish its internal relationships.

(4) POST-GRANITE SHEET INTRUSIONS

Two further sets of intrusive sheets are recognised that truncate the St. Jean-du-Doigt Gabbro Complex. A single tourmaline-bearing granite sheet, c. 120 cm thick, truncates the gabbros on the beach at St. Jean-du-Doigt (GR 1504 1295). The relationship of this sheet to the late granites is unknown. Similar tourmaline granites are recognised in the St. Pol-de-Léon Metamorphic Complex, but here their relationship to the late granites is also unclear.

Three lamprophyre sheets have been observed that truncate the gabbros and the granites in the section west of the beach at St. Jean-du-Doigt. The sheets are orientated 030^{o}-045^{o} - 210-225^{o} NE-SW and vary in thickness from 60-120 cm.

(5) SUMMARY

The St. Jean-du-Doigt Gabbro Complex is composed of several different components, the most important being a gabbro which has been injected by later igneous phases. Granite injection occurred in two phases; an early phase which may be a differentiate of the gabbro complex; and a later phase, related to a period of granite plutonism between 290-303 m.y. Both phases have led to the widespread development of agmatites. Heterogeneous deformation of the complex was reflected in the development of shear zones, and an associated metamorphism preceeded the later phase of granite emplacement. The granites are in turn cut by dykes.

The relationship of the gabbro complex to surrounding lithological units is difficult to establish. As discussed earlier, possible satellites of the gabbro occur at the Pte. du Corbeau and Roc'h Ledan within the

Moulin de la Rive Orthogneiss Complex. These satellites are deformed and metamorphosed, but lack the well-developed more penetrative foliation (except along their margins) recognised in the gabbro component of the orthogneiss complex. The various possibilities regarding the relationship of the gabbro complex to the orthogneiss complex have been previously discussed (p.246) and none of the three possibilities considered can be dismissed on current field evidence.

An Hercynian age for the gabbro complex has been proposed by Cabanis et al. (1979a) and Autran et al. (1979). The metabasic Formation de Barnénez (sensu this thesis) has also been considered as the extrusive equivalent of the complex by these authors. No direct evidence has been found that supports an Hercynian age other than the localized development of granite pipes and intimate boundaries at Pors Rodou. Generally, forceful emplacement of Hercynian late granites has occurred with the development of sheets and irregular bosses.

Late Cadomian basic-intermediate igneous complexes are recognised within the northern Massif Marmoricain, e.g. the St. Peter Port Gabbro (Roach 1977), the St. Quay-Portrieux Diorite (Ryan 1973; Vidal 1980), the Brée basic complex (Le Gall and Mary 1982), the Diorite de Keralain of the Trégor (Auvray 1979) and Gabbro de Belle Isle-en-Terre (Peucat et al. 1981). Nowhere are Hercynian basic complexes recognised with the possible exception of undated mafic rocks which are enveloped by the late Hercynian Ploumanac'h Granite (Barriere 1976).

It is clear from the evidence presented in this chapter, and from a consideration of conclusions drawn on the timing of metamorphism in the adjacent Upper Palaeozoic Morlaix Basin sequence (Chapter 6), that the emplacmenet of the St. Jean-du-Doigt Gabbro Complex occurred prior to the main Hercynian deformation and metamorphism. The main Hercynian metamorphism is probably early-Carboniferous. The gabbro complex may be late Devonian in age as suggested by Cabanis et al. (op. cit.). It is also possible that the gabbro complex may represent a mafic component of the Moulin de la Rive Orthogneiss Complex and was emplaced during the Cadomian Orogeny.

(C) THE HERCYNIAN GRANITES

(1) INTRODUCTION

A large number of different Hercynian granite intrusions occur throughout the area studied (Delattre et al. 1966). These have been examined in order to establish their relative ages and relationships to basement or host rocks in the Morlaix to St. Michel-en-Grève area.

There have been several previous studies on these granites. Lelubre (1983) described the Granite de Primel and its relationship to the gabbro complex. Sandréa (1950a and b, 1953) gave brief descriptions of granites and their enveloping rocks around the northwest Baie de Morlaix. His most detailed descriptions (Sandréa 1958) covered all the major intrusions (including the Perros-Guirec Granitoid Complex and Moulin de la Rive Orthogneiss Complex) from Roscoff to Perros-Guirec. Other shorter studies are those of Jérémine and Sandréa (1952) on the Granite de Sterec-Térenez, and Chauris (1975) on part of the Granite de Primel-Carantec.

The Hercynian granites vary in their composition and grain-size, and a two-fold field classification is used that is based on the recognition of a foliation; the granites may be either foliated or non-foliated. Foliated varieties show a crude alignment of feldspar and phylloslicate minerals and may have been emplaced during deformation episodes or were deformed subsequently. Non-foliated granites show no preferred orientation of minerals, they are structurally homogenous and are considered to be late-stage or post-orogenic granites.

All Hercynian granites recognised to the east of the Carantec Shear Belt (CSB) are considered as post-tectonic granites with the possible exception of acid differentiates in the St. Jean-du-Doigt Gabbro Complex, a sheared granite near Bois de la Roche (also known as the Granite de Runiou) and the Granite de Plouaret of the Petit Trégor. To the west of the CSB in the St. Pol-de-Léon Metamorphic Complex at least two generations of magmatism are recognised and both the early foliated granites and later non-foliated varieties are recognised.

Table 7:1 shows the major granite types present within the three delimited tectono-metamorphic areas referred to in this thesis. Not all of the granites have been named and the sequence of emplacement is only given for the early granites.

(2) THE ST. POL-DE-LÉON METAMORPHIC COMPLEX

In the St. Pol-de-Léon Metamorphic Complex Hercynian plutonism is extensive and three granite and one granodiorite phases are recognised that pre-date the more extensive later granites. The most important volumetrically of these early granites is the foliated Granite de Roscoff.

The Granite de Roscoff crops out in the area of Roscoff and Porz Ar Bascoun and to the south in the area east of St. Pol-de-Léon (Map 1). The granite is composed of orthoclase + plagioclase (An_{12}) + quartz + biotite + muscovite ± chlorite. A foliation is depicted by the crude alignment of the long axes of orthoclase feldspars and by the moderately well-developed parallel orientation of the phyllosilicate minerals, principally biotite, which is usually aggregated as small foliae. It should be stressed, however, that the Granite de Roscoff and the other early granites do not possess the strong planar and linear fabric that distinguishes the Gneiss Granitique d'Île Callot.

	St-POL-DE-LEON METAMORPHIC COMPLEX	MORLAIX BASIN AREA	PETIT TREGOR	
			GABBRO CMPX. St-JEAN	BAIE DE LANNION AREA
POST-GRANITE SHEETS	Pegmatite Sheets	Pegmatite Sheets	Lamprophyre Sheets Tourmaline Granite Sheets	-
LATE GRANITES	Granite de Primel-Carantec Tourmaline Granite Biotite Granite	Granite de Primel-Carantec Granite de Ile Sterec Granite de Térénez Granite de St-Fiacre	Granite de Primel-Carantec (= Gran. de Beg An Fry) Granite de Kerprigent	Granite de Ploumanac'h Granite de Trédrez
EARLY "FOLIATED" GRANITES	Monzonite Granite Granite de Roscoff Hornblende granodiorite Foliated biotite granite		Leucogranite phase (differentiate rel. to gabbro compx or Hercynian)	Granite de Plouaret (?) Granite nr Bois de la Roche (Granite de Runiou)

TABLE 7:1 AGE RELATIONSHIPS OF PRINCIPAL HERCYNIAN INTRUSIONS

A common feature of the granite in thin-section is myrmekitic intergrowth of K-feldspar and quartz. Large sub-rectangular to augen-shaped orthoclase and sub-hedral plagioclase grains (up to 3 mm) are both usually slightly cloudy. Quartz occurs as large undulose grains (up to 2 mm) and as recrystallized small unstrained granoblastic grains. Sphene forms a common accessory mineral.

Inclusions within the Granite de Roscoff comprise biotite-rich schlieren (lenses c. 2-3 x 1 cm), ghost lenses rich in quartz and biotite (c. 10 x 2 cm maximum dimension) and large rafts (c. 20 x 30 m) of meta-sediment and amphibolite.

The other Hercynian early granites that occur in the St. Pol-de-Léon Metamorphic Complex are a foliated biotite-rich granite, a horn-blende-bearing granodiorite and a quartz monzonite granite which crops out in the area between Roscoff and St. Pol-de-Léon, around Creac'h Andre (GR 1369 1323). The relationships between the four early granites are not always clear. However cross-cutting relationships exposed along the coast between St. Pol-de-Léon, Île St. Anne and Roscoff indicate the sequence given in Table 7:1.

The question arises as to the nature of the foliation present in the early granites. Two possibilities are considered; 1) it represents an essentially igneous fabric formed during syntectonic emplacement; 2) it represents a metamorphic fabric produced after the emplacement of the intrusion.

The Granite de Roscoff shows variable development of the foliation. In areas of poor development it is defined by the alignment of K-feldspar phenococrysts (areas of low-strain?). Here, the feldspars are not deformed but quartz may show strain extinction and partial dynamic recrystallization as noted above. In zones where the foliation is moderately well-developed quartz occurs as polygonal aggregates and the feldspars also show deformation structures (undulose extinction and kinked twin-lamallae are common) and some recrystallization. Other early granites show variable development of the foliation. Usually it is best developed in the biotite-rich type. Mafic inclusions present in the early granites are consistently elongated parallel to the foliation.

It is concluded that the early granites have not undergone the peak metamorphic and deformation episode in the St. Pol-de-Léon Metamorphic Complex (that, for example, led to the well-developed planar and linear fabric in the Gneiss Granitique d'Île Callot) but were emplaced during deformation (the major D2 episode). The foliation is a syn-tectonic fabric developed as the magma was cooling and strain continued post-quartz crystallization to give the deformational microfabrics observed.

Although there is no published data concerning the age of the early granites, it may be argued (see further discussion in Chapter 8), that the emplacement of this generation of granites accompanied the major deformation and metamorphic episode which reached peak conditions during post early-Carboniferous times.

The late granites within the St. Pol-de-Léon Metamorphic Complex are more diverse in composition compared to the late granites that occur elsewhere within the area studied.

The Granite de Primel-Carantec is important in the eastern part of the complex where it forms many of the small islands and reefs within the Baie de Morlaix. In the Pte. St. Jean area (GR 1376 1275) rafts of amphibolite are occasionally enclosed within the Granite de Primel-Carantec (Map 1), and the granite also forms dykes within the host amphibolites parallel to the 045^{o} NE-SW foliation. Tourmaline-rich granite is important volumetrically within the complex. The relationship of this granite to the Granite de Primel-Carantec is unclear as no cross-cutting relationships have been found. The tourmaline granite is highly leucocratic and is orthoclase and quartz-rich with some white mica (muscovite) and abundant tourmaline.

Leutwein et al. (1969) obtained the following Rb-Sr dates on the pink medium-grained part of the Granite de Primel-Carantec; 310 m.y. (whole-rock), 305 m.y. (K-feldspar) and 290 m.y. (biotite). A K-Ar biotite date of 275 ± 5 m.y. was also obtained.

(3) THE MORLAIX BASIN AREA

Early granites are absent in the Morlaix Basin area. Late granites are extensive, and in the Carantec area the Granite de Primel-Carantec truncates the Carantec Shear Belt (Map 1), and therefore the later granites were emplaced after the development of the mylonitic banding in the CSB. The Granite de Primel-Carantec in the Carantec area (GR 1399 1276) contains numerous rafts of basement material (amphibolites and metasediments) which are discussed in part (D) under the heading "Mixed Metasediments and Amphibolites of the Baie de Morlaix". These may be Brioverian and/or Palaeozoic in age.

At Plage Porz Pol in Carantec (GR 1402 1275) unusual lobate shaped inclusions of pure biotite occur within the Granite de Primel-Carantec. These are restricted in their occurrence to this locality and they may represent either an early magmatic segregation phase or highly modified (metasomatised) xenolithic material. Chauris (1975) has examined stannowolframite and non-metal mineralization associated with the Granite de Primel-Carantec in the Baie de Morlaix area and has mapped out three contrasting facies of granite within this pluton.

Other post-tectonic granites in the Morlaix Basin include the Granite d'Île Sterec, sheets of which invade the Strunian-Dinantian Formation de Barnénez at Pte. de Perrohen. This granite can be clearly distinguished from the Granite de Térénez which crops out to the east of Île Sterec. The Granite de St. Fiacre is responsible for the contact metamorphism of the Lower Devonian Formation de Kerolzec in the area south of Morlaix. Several small granite intrusions truncate the Formation de Morlaix (the Schistes Zébrés) and the Formation de Dourduff, but no attempt has been made to determine their sequence of emplacement.

(4) <u>THE PETIT TRÉGOR</u>

Gabbro-granite relationships within the gabbro complex have been described in section (B) of this chapter. Two generations of granite are recognised that truncate the gabbros. An earlier phase resulted in the partial agmatization of the gabbro complex in zones which are frequently sheared. The later phase is considered to be related to the emplacement of the large granite bodies, principally the Granite de Primel-Carantec, of which the Granite de Beg An Fry is its easternmost satellite (Delattre et al. 1966), and the extensive Granite de Kerprigent. Leutwein et al. (1969) obtained a Rb-Sr whole-rock date of 290 ± 10 m.y. for the Granite de Kerprigent.

A sheared leucogranite occurs in the area north of Bois de la Roche (GR 1503 1212) along the southern margin of the gabbro complex. The granite is medium-grained and is composed of K-feldspar + plagioclase + quartz + muscovite + chlorite. Quartz is strongly deformed and now displays strong ribbon texture. The granite possesses a single mylonitic fabric depicted by stretched quartz grains and alignment of chlorite. The relationship of this granite to the gabbro and other granite phases is uncertain and two possibilities may be considered; 1) The granite may represent an early phase (related to the earlier phase that truncates and agmatizes the gabbro complex) which has been deformed prior to the injection of the late granites recognised elsewhere; or 2) it may be a late granite which has undergone a localized deformation. Lack of cross-cutting relationships and poor exposure do not allow a further field interpretation. However, Leutwein et al. in their 1969 geochronology paper called this body the Granite de Runiou and noted its foliated character. They obtained the following K-Ar dates; 345 ± 2 m.y. (whole-rock), 320 ± 5 m.y. (orthoclase) and 340 ± 10 m.y. (amphibole). This suggests that the intrusion may well be one of the early granites.

In the Baie de Lannion area two large granite intrusions are recognised, the Granite de Trédrez and the Granite de Plouaret. Outside of the immediate area studied the multi-component Granite de Ploumanac'h, dated at 303 ± 15 m.y. (Barriere et al. 1983) truncates the heterogeneously deformed Cadomian Perros-Guirec Granitoid Complex.

The Granite de Trédrez has a large contact aureole and truncates the Brioverian and Palaeozoic sequences in the eastern Baie de Lannion area. It has yielded a K-Ar biotite date of 320 ± 10 m.y. and a Rb-Sr biotite age of 300 ± 10 m.y. (Leitwein et al. 1968). The Granite de Plouaret was emplaced into metasediments of unknown age (Brioverian and/or more probably Palaeozoic, discussed in Chapter 6) in the Tréduder-Ploumilliau area (Map 2). Contact metamorphic minerals include sillimanite, cordierite and andalusite. Granite sheets and bosses are common and the metasediments are considered to be preserved in the roof zone of this granite.

Barriere et al. (1983) consider the Granite de Plouaret to be of Strunian (Bretonic?) age based on its geochemical similarity to the Granite de Huelgöat of central Brittany, dated at 336 ± 13 m.y. by Peucat et al. (1979). Adams (1967) obtained a 4 point Rb-Sr whole-rock isochron date of 348 ± 5 m.y. for his older Variscan granites, which included the Granite de Plouaret, and a K-Ar date of 310 m.y. on biotite from this granite. This can be compared with the 310-330 m.y. Rb-Sr mineral dates obtained by Leutwein et al.

(1968) from the same granite.

(5) SUMMARY

Two major periods of granite emplacement are considered to have occurred within the area studied. This is based upon the recognition of a crude planar (syn-tectonic) fabric developed in the early granites and lack of such a fabric in the late granites.

The early granites are considered to have accompanied the peak metamorphic episode which climaxed during early Dinantian times. The frequency of the early granites within the high-grade St. Pol-de-Léon Metamorphic Complex is of note, although there is some evidence to suggest that they are widespread across the area studied.

The late granites, principally the Granite de Primel-Carantec, the Granite de Kerprigent and the Granite de Trédrez are considered to be equivalent to the late tectonic subalkaline red granites of Chauris (1978) and Barriere et al. (1983) which Chauris (op. cit.) considers to be generated along the major "lineament nord armoricain". Other major granites along this lineament are the Granite de Aber Ildut (290 m.y.) and the Granite de Ploumanac'h (303 ± 15 m.y.).

The Granite de Primel-Carantec truncates the Carantec Shear Belt thus indicating that the evolution of the shear belt had finished before the emplacement of this late granite.

(D) THE MIXED METASEDIMENTS AND AMPHIBOLITES OF THE BAIE DE MORLAIX

(1) INTRODUCTION

A distinct group of metasediments collectively termed the Mixed Metasediments of the Baie de Morlaix occur as rafts, in association with amphibolites, within the Hercynian granites of the Île Callot, St. Pol-de-Léon and Roscoff areas, along the northwest side of the Baie de Morlaix (Map 1).

The blocks or rafts are variable in shape and they range in diameter from 10 cm up to 30 m (e.g. Figs. 7:6 and 7:7). The metasediments may be psammitic, semi-psammitic or semi-pelitic in composition and all three lithologies are commonly in association with amphibolites. The amphibolites may represent basic sheet intrusions or primary interleaved/ interbanded flow units of extrusive origin. The metasediments may represent the hornfelsed equivalents of the Brioverian Micaschistes de Penzé (Chapter 2) or they be part of the Devono-Carboniferous sequence of the Morlaix Basin (CHapter 6). A discussion as to their possible age is given on p. 266.

(2) METASEDIMENTARY XENOLITHS

1. Psammitic (meta-quartitic) xenoliths: These are made up of approximately 90-95% quartz, with muscovite ± cordierite ± plagioclase (albite) forming subsidiary minerals. Quartz is completely recrystallized with a coarse, saccarhoidal texture. Muscovite concentration defines a strong banding which may represent original bedding and cordierite (usually retrogressed to pinnite) is occasionally present in these thin bands.

2. Semi-psammitic xenoliths: This lithology is banded with a marked millimetric-scale fabric that may represent bedding (S0) or a segregation banding S1 (as in the Micaschists de Penzé). The banding is defined by the alternation of quartz-rich bands, which may also contain albite and K-feldspar and cordierite, with dark bands containing biotite, chlorite and muscovite. Quartz totals some 60-70% of the rock and it is totally recrystallized. Large biotite plates may overgrow the early banding and andalusite is developed in restricted bands (Fig. 7:6).

3. Semi-pelitic xenoliths: This lithology is finely banded due to alternate concentrations of quartz + feldspar and biotite-rich bands. Cordierite and chiastolite are restricted to the biotite-rich bands (Figs. 7:8 and 7:9). Hornblende is occasionally present and garnet has been recorded in one specimen.

Of the three lithologies the psammitic and semi-psammitic xenoliths are the most common.

(3) AMPHIBOLITES ASSOCIATED WITH METASEDIMENTARY XENOLITHS

In the Pte. St Jean area amphibolite bodies (up to 30 m diameter) correlated with the Amphibolites de Pte. St. Jean (discussed in Chapter 2) occur within the Hercynian granites. They are therefore considered as basement rocks belonging to the St. Pol-de-Léon Metamorphic Complex. These are distinct from amphibolites that are petrographically similar to the amphibolite sheets (also discussed in Chapter 2) that commonly truncate the Gneiss Granitique d'Île Callot, and which also occur within the Hercynian Granites. In the Granite de Primel-Carantec of the Île

Fig. 7:6 Mixed Metasediments and Amphibolites of the Baie de Morlaix

Semi-psammitic xenolith within the Granite de Primel-Carantec at Porz Pol, N-Carantec. Large andalusite blades are present within pelitic fractions of the metasedimentary xenolith. The size of the preserved block at this locality is c. 3x4 m.

Scale: Hammer Shaft 36 cm

Fig. 7:7 Mixed Metasediments and Amphibolites of the Baie de Morliax

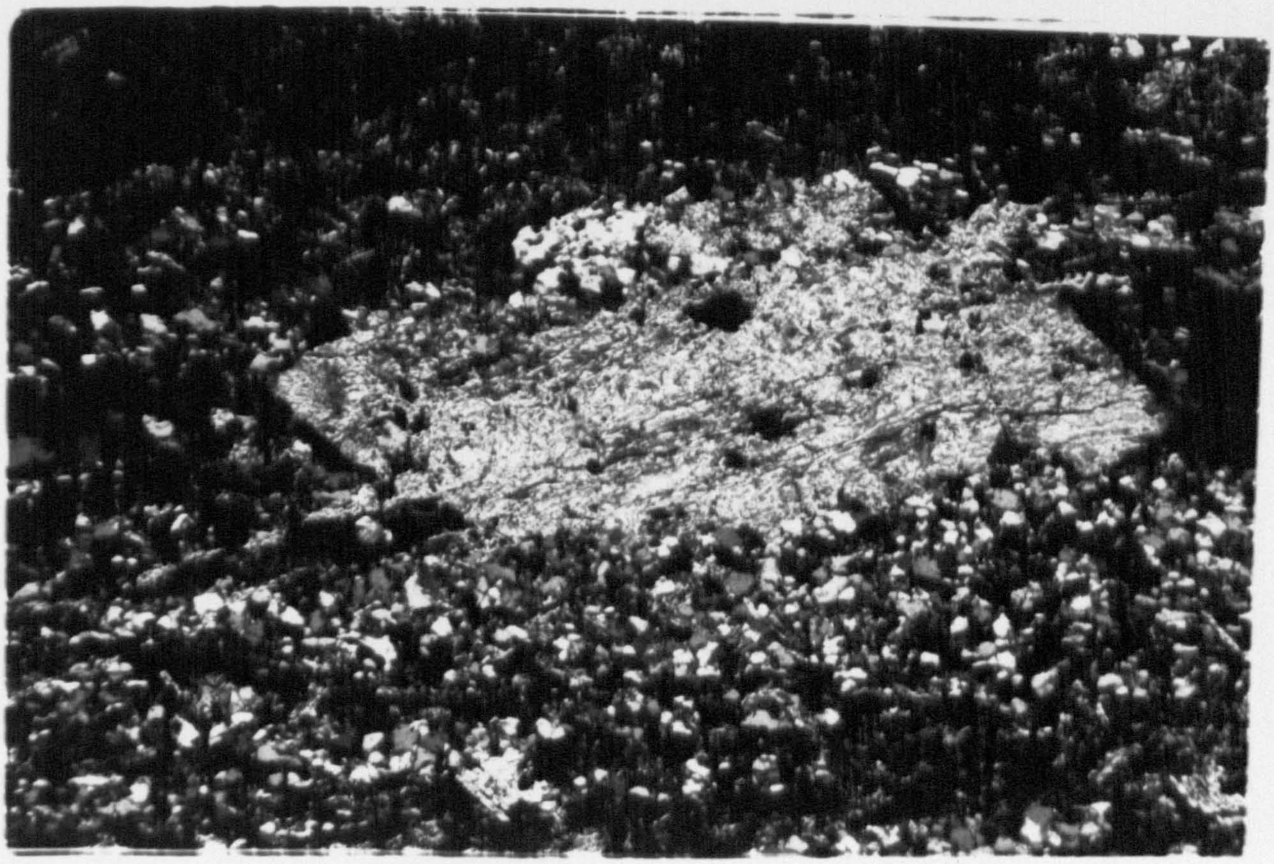
Unusual biotite-rich lithology present within the Gneiss Granitique d'Ile Callot which is in turn enveloped by the Granite de Primel-Carantec. The block of basement lithology is c. 40x25 m.

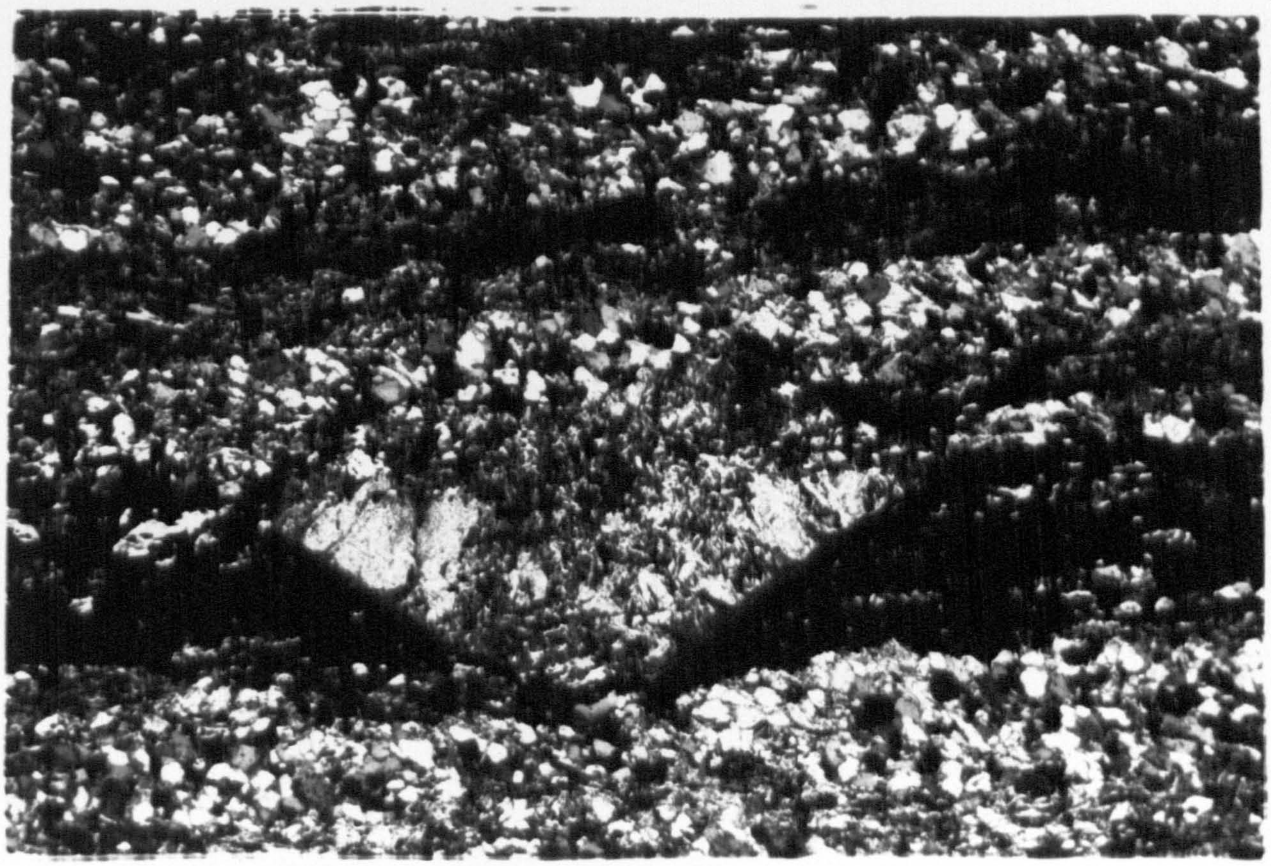
Scale: Hammer Shaft 36 cm. Location: N. Carantec

Figs. 7:8 and 7:9 Mixed Metasediments and Amphibolites of the Baie de Morlaix

Partially retrogressed chiastatolite developed in pelitic (phyllosilicates = biotite, chlorite and muscovite) bands within a semi-pelitic xenolith at Pen Al Lann, northeast of Carantec. The banding is considered to be an S1 segregation banding rather than a primary sedimentological banding S0. The chiastolite is only partially developed as the mineral growth is apparently restricted by the thickness of the individual phyllosilicate-rich bands.

Scale: x16 XPL





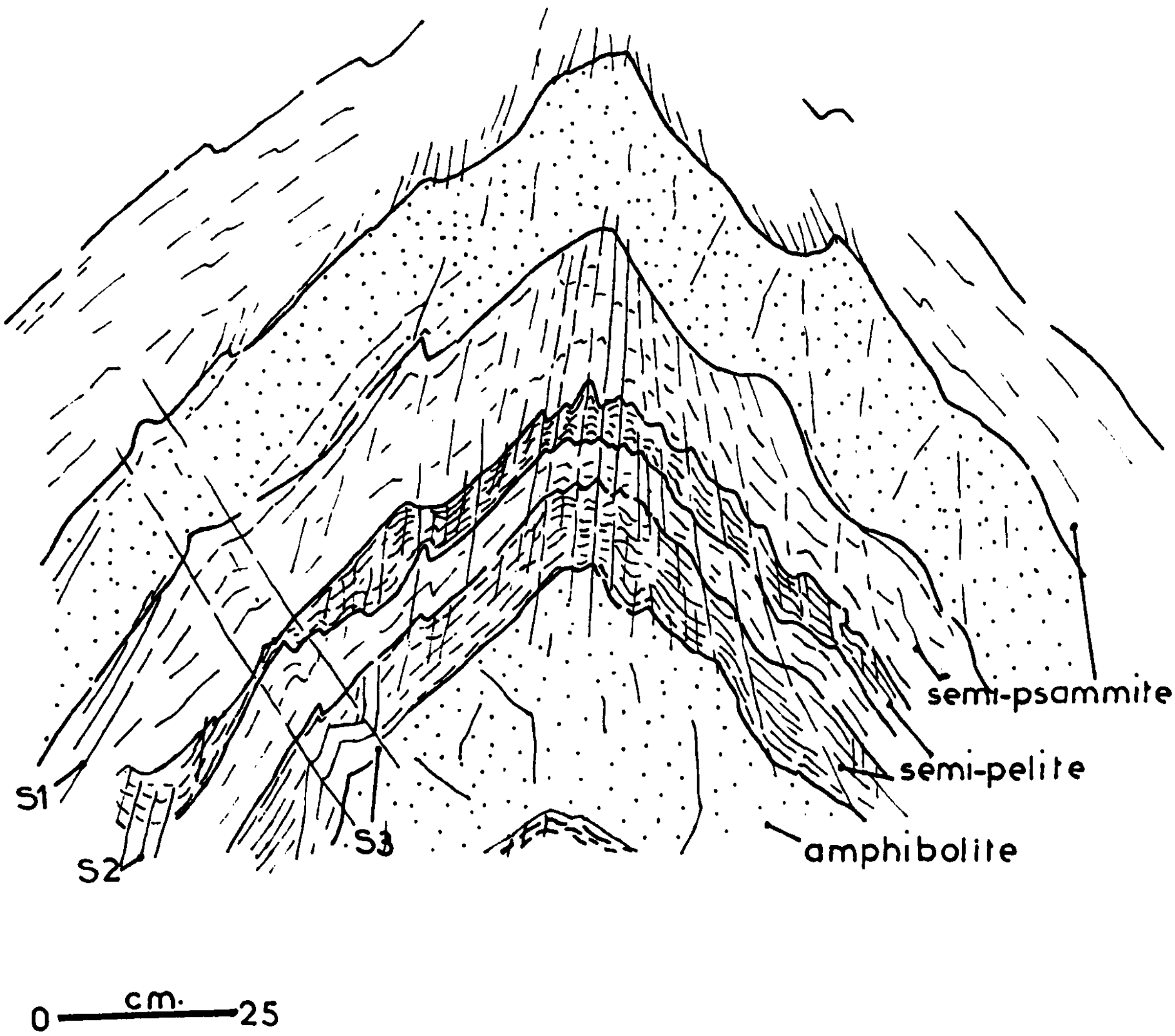
Callot area and in the Granite de Roscoff around the Pointe du Beron (GR 1368 1324) the amphibolites occur as rafts in two forms; 1) As 1-25 m thick sheet-like bodies that may be in association with the metasediments; 2) More rarely as relatively thin (25-80 cm thick) bands of amphibolite that are interleaved with semi-psammite.

Two localities are briefly described that indicate the different nature of the metasediment/amphibolite relationships:-

1. Pointe du Beron (GR 1368 1324): At this locality a 2 m thick amphibolite unit lies within a mixed semi-psammite and semi-pelite succession. The amphibolite is sheet-like in form and possesses a mineralogy similar to that of the extensive suite of metabasic sheets that truncates the Gneiss Granitique d'Île Callot. The boundary of the amphibolites and metasediments is sharp, and there is a strong planar fabric present within the amphibolites that is parallel to the well-developed schistosity in the metasediments, indicating that the two units have undergone the same deformation.

2. Île Blanche, north of Île Callot (GR 1393 1306): At this locality there is a thick sequence of interbanded hornfelsed amphibolites and metasediments. Banding in the metasediments is considered to represent a primary lithological banding and this is parallel to contacts with the 25-80 cm thick amphibolites. Both units are truncated by an early fabric, S1, which is developed at a low angle to, (a) contacts between metasediment and amphibolite and (b) the primary lithological banding in the semi-psammitic sediments (Fig. 7:10). The interbanded sequence and the S1 fabric have been subsequently folded into a series of upright NE plunging folds and the metasediments possess an associated well-developed crenulation cleavage.

Fig. 7 : 10 AMPHIBOLITE AND METASEDIMENT RELATIONSHIPS, ILE BLANCHE



F2 fold in the Mixed Metasediments of the Baie de Morlaix. Two c. 20-30 cm. thick amphibolite bands are interbanded with the semi-psammitic and semi-pelitic metasediments. An early fabric is developed sub-parallel to the lithological banding and this is interpreted as S1. S1 is crenulated by the well-developed S2 clevage which is axial planar to the upright F2 folds. Kink-bands are developed in part and deform earlier structures. Sillimanite and andalusite are conspicuous contact metamorphic minerals developed in the metasediments.

(4) AGE OF THE METASEDIMENT AND AMPHIBOLITE XENOLITHS

The amphibolites and metasediments appear to have had an intimate primary (possibly concordant) relationship prior to the D1 event. The recognition of an S1 fabric oblique to the lithological banding indicates a structural history that is identical to that of the Morlaix Basin sequence. In the St. Pol-de-Léon Metamorphic Complex the D1/S1 event produced the dominant lithological banding observed which is of metamorphic origin.

The frequency of metabasic sheets in association with mixed metasediments is of note. It may be argued that the metasediments are of Devono-Carboniferous age because the association of metabasic material and metasediments in the Morlaix Basin, both as dyke phases and as primary metavolcanics interleaved with metasediments, is more common than in the Brioverian groups. In the St. Pol-de-Léon Metamorphic Complex only one possible case of primary interleaving is recognised in the West Riviere de Penzé area (described in Chapter 2, part B).

The nature of the metasediments taken in isolation does not resolve the problem as to the age of the Mixed Metasediments and Amphibolites of the Baie de Morlaix as similar mixed lithologies occur within the Brioverian group of the St. Pol-de-Léon area and in the Devono-Carboniferous (the Formation de Kerolzec and the Grès de Plouézoch) of the Morlaix Basin.

It is suggested here that the primary interleaved amphibolite and metasediments recognised at Île Blanche have been deformed in a similar manner to the lithologies of the Morlaix Basin. The amphibolites are considered to be of the same generation as those recognised across the area and which are regarded as the hypabyssal equivalents of the Formation de Barnénez of lowermost Carboniferous age. Therefore a Devonian-Carboniferous age is argued for the amphibolites and for the primary interleaved succession at Île Blanche. Elsewhere, such arguments cannot be applied to the metasediments and elements of both the Brioverian and Devono-Carboniferous sequences may be contained with the Hercynian granites in the Baie de Morlaix area.

CHAPTER EIGHT

CONCLUSIONS

(A) SUMMARY

The country between Morlaix and St. Michel-en-Grève comprises three distinct tectono-metamorphic areas. From west to east these are:-

1. The St. Pol-de-Léon Metamorphic Complex. This complex is dominated by Brioverian metavolcanics and metasediments that have been truncated by Cadomian granitic orthogneisses and later Hercynian intrusives. The complex has undergone polyphase deformation and metamorphism to upper amphibolite facies.

2. The Morlaix Basin. This basin is composed of Palaeozoic metasediments and metavolcanics deformed and metamorphosed under greenschist facies conditions. The Morlaix Basin is separated from the St. Pol-de-Léon Metamorphic Complex by a major tectonic feature, the Carantec Shear Belt.

3. The Petit Trégor. This area comprises Brioverian metavolcanics and metasediments that have been truncated by a composite,mainly Cadomian igneous complex. Both the supracrustal assemblage and plutonic rocks have undergone heterogeneous deformation. The Locquirec Shear Belt is recognised as a major shear zone that has developed along the eastern margin of the Cadomian Moulin de la Rive Orthogneiss Complex. The lithologies in this area are within the greenschist facies, except in the contact aureoles of Hercynian granites.

In this thesis an attempt has been made to correlate geological events across the three areas and with adjacent areas. The suggested correlation of events is given in Table 8:1 (in end-pocket).

The area studied is situated between and partly encompasses two larger major tectono-metamorphic regions or domaines of markedly different geological character. These are, the Pays de Léon which comprises northern Finistère to the west, and the Trégor region to the east. Both of these regions have been previously included within a single tectonic domain, the Domaine Domnonée of Cogné (1974), see Fig. 1:3 and discussion in Chapter 1. However, this concept of a single domain is now outdated as it does not recognise the zone of Hercynian deformation, metamorphism and migmatization which characterizes the Pays de Léon.

In Chapter 2 the lithologies of the St. Pol-de-Léon Metamorphic Complex, which forms the eastern most part of the Pays de Léon, were described. In this area an older basement is recognised, partly composed of medium-high grade metabasites (the Amphibolites de Pte. St. Jean) and extensive metasediments (the Micaschistes de Penzé). These are truncated by the Gneiss Granitique d'Île Callot which is composed of several granitic phases. The amphibolites and metasediments are considered to be Brioverian in age and analogous with the metabasalt and metasedimentary association recognised elsewhere across the northern Massif Armoricain. The granitic gneiss was emplaced during the Cadomian Orogeny and may have been broadly contemporaneous with the extensive Gneiss de Brest of the southwest Pays de Léon. Equally, the Gneiss Granitique d'Île Callot may be a western extension of the Perros-Guirec Granitoid Complex, of which the Moulin de la Rive Orthogneiss Complex is also an important part. A suite of metabasic sheet intrusions truncate the St. Pol-de-Léon Metamorphic Complex and these are considered to be related to the metabasic sheets of the early Carboniferous (Strunian-Dinantian) Formation de Barnénez of the Morlaix Basin.

Roper (1980) and Chauris (1972, 1977) have demonstrated the importance of Hercynian deformation and metamorphism in the Pays de Léon. This region represents a medium-high grade metamorphic belt in which migmatites are developed in the northwest part of the area and anatectic granites are widespread, as indicated in Chapter 2. In the Pays de Léon any Cadomian structures are strongly overprinted, but there is evidence of an early fabric (in the St. Pol-de-Léon Metamorphic Complex) and a related fold phase in the western part of the Pays de Léon (Roper op. cit.; Cogné and Shelley 1966).

In the Petit Trégor the Brioverian Supergroup consists of a basal metavolcanic sequence, the Formation de Pte. de l'Armorique, which is overlain by a metasedimentary (metagreywacke) assemblage, termed the Formation de Plestin (described in Chapter 3). Both formations are truncated by rocks of the Moulin de la Rive Orthogneiss Complex. This is a metamorphosed and heterogeneously deformed igneous complex of Cadomian age (discussed in Chapter 4). At the southeastern margin of this orthogneiss complex a major NE-SW trending shear zone, the Locquirec Shear Belt (LSB) is recognised (described in Chapter 5), that in part deforms the Brioverian formations and is part of a major shear zone system recognised in the Trégor region. A similar geotectonic situation is recognised therefore in both the Petit Trégor and the St. Pol-de-Léon Metamorphic Complex, whereby a Brioverian basement is intruded by Cadomian granitoids.

The Moulin de la Rive Orthogneiss Complex is formed of several often intimately related rock types, varying from basic to acidic in composition. Within the complex possible remnants of an older Proterozoic (Pentevrian) basement may be preserved as rafts of augen gneiss. A variably foliated metagabbro component makes up an important part of the western end of the complex, and the adjacent St. Jean-du-

Doigt Gabbro Complex may be related to this fraction, or it may be a separate body. In Chapter 7 a late Cadomian age is argued for the St. Jean-du-Doigt Gabbro Complex, however a Hercynian age (contemporaneous with the Formation de Barnénez?) cannot be discounted.

In the Trégor region Auvray (1979) has demonstrated the importance of major Cadomian magmatism with the emplacement of the Perros-Guirec Granitoid Complex during the late Proterozoic. The effects of the Hercynian deformation in this region are restricted to the very gentle folding of the Plourivo-Bréhac Cambro-Ordovician red-beds in the southeast of the Trégor and possibly to the formation of the Trégor Shear Belt and the Pointe de Bihit Shear Belts, see discussion part (B).

A series of metaquartzites and pelites of possible Arenigian age overlies the Brioverian sequence in the Grève-de-St. Michel area. These Palaeozoic sediments show a similar deformation sequence to the adjacent Brioverian succession and are contact metamorphosed by Hercynian granites (the Granite de Trédrez and Granite de Plouaret). These metasediments give way southwards to higher grade psammites and pelites of possible Devonian age. Near their boundary with the Granite de Plouaret the latter contain numerous granite sheets. These mixed rocks have been termed the Migmatites de Tréduder (discussed in Chapter 6).

In the Morlaix area a low grade Palaeozoic metasedimentary and metavolcanic occurs which is adjacent, across the Carantec Shear Belt, to the medium-high grade St. Pol-de-Léon Metamorphic Complex. The presence of fossiliferous sediments within the Morlaix Basin sequence indicates an uppermost Devonian-Lower Carboniferous age for the greater part of the assemblage. The sediments accumulated during an unstable geotectonic regime indicated by the presence of turbidite sandstones, debris-flow conglomerates and contemporaneous basaltic volcanism. Major volcanism is considered to have occurred during the early part of the Hercynian orogeny, possibly during the Bretonic earth-movements. Associated with the volcanism was the emplacement of basic dykes which occur throughout the study area as the hypabyssal equivalents of the basic sheets of the Formation de Barnénez. The correlation of these metabasic dykes helps to establish a regional time-scale for the sequence of lithological, deformational and metamorphic events across the study area and in adjacent areas.

At least two generations of Hercynian igneous intrusions truncate the Brioverian supracrustal rocks and Cadomian igneous rocks. These Hercynian plutons are particularly frequent in the St. Pol-de-Léon Metamorphic Complex. An early phase is recognised (which includes the Granite de Roscoff); and a later phase (which includes several different types of non-foliated leucogranite). Peak metamorphism, D2/M2, was reached during a post-early Carboniferous (Bretonic?) phase of the Hercynian Orogeny and the early granite emplacement may have accompanied this episode.

Table 8:1 shows the sequence of lithological, deformational and metamorphic episodes together with a proposed time-scale for the area studied and the adjacent Trégor region.

(B) THE GEOLOGICAL EVOLUTION OF THE ST. POL-DE-LÉON METAMORPHIC COMPLEX, MORLAIX BASIN, PETIT TRÉGOR AND ADJACENT AREAS

The earliest geological episode recognised in the study area is the occurrence of possible Pentevrian basement gneisses. Auvray et al. (1980a) have dated the Moulin de la Rive Orthogneiss Complex (the Gneiss de Morguignen-Trebeurden sensu Auvray et al.) at c. 2000 m.y. based on the U/Pb dating of zircons. However, it is considered in this thesis that Auvray et al. (op cit.) have dated either xenocrysts of 'inherited' zircons derived from a true Pentevrian basement, or xenoliths of true basement material.

An augen gneiss component has been recognised within the orthogneiss complex that is petrographically similar to a well-established Pentevrian lithology that crops out at Port Beni (northern Trégor) as rafts of basement within the Cadomian Perros-Guirec Granitoid Complex. Therefore, whilst the product of a Lower Proterozoic Pentevrian event is tentatively recognised within the study area, the outcrop of this basement material is limited to rafts within a younger Cadomian igneous complex. In the Trégor, feldspar augen granitic gneisses with minor amphibolites and migmatites of probable sedimentary origin are recognised within a similar albeit undeformed igneous host.

After a significant time interval the next recognisable geological event was the deposition of a thick sequence of basic volcanics with associated intrusive-sheets and some interleaved sedimentary horizons. The presence of pillow-lavas points to a subaqueous origin for these rocks. This sequence is represented in northwest Brittany by the Amphibolites de Pte. St. Jean in the St. Pol-de-Léon Metamorphic Complex, the Formation de Pte. de l'Armorique in the Petit Trégor, the Spilites de Paimpol in the Trégor and the Amphibolites de Lanvollon along the western side of the Baie de St. Brieuc. The Formation de Pte de l'Armorique is currently c. 2 km thick and in the Baie de St. Brieuc area the Amphibolites de Lanvollon are at least 1·5 km thick.

Field and geochemical evidence from the Petit Trégor, Trégor and Baie de St. Brieuc areas points to a period of major basic volcanism during Lower Brioverian times associated with crustal rifting. The volcanics, represented by the formations mentioned above, were erupted onto continental crust possibly within a marginal basin in which thick turbidite sequences were subsequently deposited, now represented in the study area by the Formation de Plestin, see below.

Towards the base of the Brioverian metavolcanic sequence in the Locquirec area, there are c. 5 m of possible conglomerates (the Poudingues de Locquirec) which occur as several thin bands within the LSB granitoid mylonites. A similar association is seen at the southern end of the Baie de St. Brieuc where a basal conglomerate (the Poudingue de Cesson) is developed at the base of the Amphibolites de Lanvollon. The true nature and age of the Poudingue de Locquirec however remains very uncertain, but its apparent stratigraphical position is of note.

A thick sequence of metagreywackes and pelites overlies the basic volcanic succession, and a similar relationship is recognised in other localities across northern Brittany and Lower Normandy. In the Pays de Léon they are recognised as the Quartzophyllades de l'Elorn and the Micaschistes de Penzé, in the Petit Trégor as the Formation de Plestin, and in the Trégor as the Schistes et Grès de la Roche Derrien (cf. Auvray 1979).

Several authors have proposed various time periods for the deposition of the Brioverian Supergroup,and by consensus the principal period of deposition was late in the Upper Proterozoic c. 800-560 m.y. (Cogné 1972) and 900-750 (or 650) m.y. (Roach et al. 1972; Bishop et al. 1975). There is current argument as to the age of the so-called Pentevrian type-area along the southern side of the Baie de St. Brieuc, and the bearing of the geochronological data of Vidal (1980) on the timing of the Brioverian deposition. Vidal (op. cit.) has obtained an Rb-Sr whole-rock isochron date of 631 ± 60 m.y. for the Coetmieux-Fort la Latte Orthogneiss Complex (previously considered as Pentevrian basement) upon which the whole Brioverian sequence is deposited in the Baie de St. Brieuc area. Therefore, the whole question as to the age of the lower limit of Brioverian volcanism and sedimentation remains problematical (see also discussion in Chapter 1). An upper age limit of c. 583 m.y. is considered possible for Brioverian sedimentation as this is the age obtained for the St. Quay Gabbro-Diorite Complex (Vidal 1980) which truncates the Series de Binic (forming the uppermost part of the Brioverian sequence along the west side of the Baie de St. Brieuc). This problem is currently under investigation (Roach and Shufflebotham, pers. comm.).

In late Precambrian to early Lower Palaeozoic times the Brioverian was affected by the Cadomian Orogeny. Outside the study area the Cadomian earth-movements resulted in a major unconformity between Brioverian and Cambrian strata and also in the major marine transgression at the base of the Ordovician (the Grès Armoricain). The effects of the Cadomian Orogeny were highly variable throughout the Massif Armoricain in terms of deformation history, metamorphism and plutonism.

The importance of the Cadomian Orogeny within the study area is difficult to establish. An early fabric was produced (during regional D1/M1 episode) prior to granite emplacement (the Gneiss Granitique d'Île Callot) in the St. Pol-de-Léon Metamorphic Complex. An early fabric has also been recognised in the western Pays de Léon that has been folded by a later Cadomian episode (Roper 1980). Direct evidence for a Cadomian deformation episode cannot be firmly established in the Petit Trégor, but by analogy with the Trégor region and the knowledge of an early event in the western area it may be argued that there was a Cadomian episode, but that any structures present have been overprinted by later Hercynian deformation. For example, it is not possible to identify a primary structural discordance between the possible Arenigian meta-quartzites (the Quartzites de Grand Rocher) and the Brioverian Formation de Plestin around the Grève-de-St. Michel.

The formation of an igneous complex of batholithic proportions was an important product of the Cadomian Orogeny. The emplacement of this major igneous complex occurred after the D1/M1 episode, and in the study area the Brioverian sequence has been truncated in the Petit Trégor and the eastern Pays de Léon by Cadomian Granitoid Complexes which are thought to form parts of this major batholith. The following Cadomian granitoid complexes are recognised, 1) The Moulin de la Rive Orthogneiss Complex, Locquirec Shear Belt granitoid mylonites and the Granodiorite de Beg Ar Forn which crop out in the Petit Trégor, 2) The Gneiss Granitique d'Île Callot of the St. Pol-de-Léon Metamorphic Complex. The two gneiss complexes are now in a different structural state and possess different metamorphic assemblages.

The heterogeneously deformed most westerly occurrence of the batholith is possibly represented by the Gneiss de Brest of the Pays de Léon, the unstrained equivalent of which (the Renards Granite, Roper 1980) has been dated by Adams (1967) at c. 550 ± 40 m.y. In the Trégor, Auvray (1979) has given a broadly similar age for the emplacement of some of the components of the Perros-Guirec Granitoid Complex at 547-537 m.y. This latter age range of c. 550-535 m.y. is preferred for the period of major plutonism across the region. Roper (op. cit.) has pointed out the difficulties of sampling homogeneous material from widely scattered localities along the outcrop of the Gneiss de Brest (which yielded an isochron date of 690 ± 40 m.y., Adams 1967) as there is a large statistical error on the Rb-Sr regression line of Adam's (op. cit.) date.

The position of the large St. Jean-du-Doigt Gabbro Complex is difficult to establish within the scheme of geological events. On structural grounds, the emplacement of the complex can either be related to the Cadomian or Hercynian Orogenic events, but by analogy with other basic complexes in the northern Massif Armoricain a Cadomian age is preferred.

It is clear that across northwest Brittany, from the western Pays de Léon to the Baie de St. Brieuc, there are major outcrops of Cadomian igneous rocks. These multi-component complexes are in different tectonic and metamorphic states, but they appear to have a common origin related to a major Cadomian event they may have involved the closure of a Brioverian ensialic basin in northern Brittany and Lower Normandy.

In the eastern Trégor the Plurivo-Bréhec red-bed sequence (Barrois 1908a and b; Delattre and Waterlot 1958; Delattre et al. 1966) which is only slightly flexured, rests with major unconformity on more strongly folded and cleaved Brioverian metasediments. Porphyritic andesitic and trachy-andesitic lavas occurring within the red-bed sequence have yielded a 12 point whole-rock isochron date of 472±5 m.y. (Auvray et al. 1980b), which has been interpreted as their eruption age. If correct, this would place the red-bed sequence at the Tremadoc-Arenig boundary according to Odin's (1982) time-scale for the Palaeozoic. Red beds of probable similar age occur along the southeast side of the Baie de St. Brieuc, where the Grès d'Erquy and the Grès de Cap Fréhal (Pruvost and Waterlot 1936; Cogne 1963; Auvray et al. 1980b) rest unconformably on Pentevrian basement and Brioverian basic volcanics. Chauris (1971a) has equated these north Brittany red beds with the Quartzites de Grand Rocher at St. Michel-en-Grève.

In the St. Michel-en-Gréve area, the now metamorphosed Palaeozoic succession commenced with the deposition of a sequence of quartzites, pelites and semi-psammites, known as the Quartzites de Grand Rocher. These are in contact with a series of dark pelites termed the Schistes à chiastolite de St. Michel-en-Gréve. The massive nature of the meta-quartzites has led previous authors (e.g. Verdier 1968) to assign this formation to the Arenigian Grés Armoricain. The meta-quartzites give way southwards to a series of contact metamorphosed and granite injected metasediments, termed the Migmatites de Tréduder which are of probable Palaeozoic (Devonian?) age and possibly the lateral equivalents of the meta-quartzitic, psammitic and semi-pelitic Formation de Kerolzec of the Morlaix Basin area.

In the Morlaix Basin the Palaeozoic sedimentation commenced with the deposition of quartzites and dark mudstones which comprise the Formation de Kerolzec. These are thought to be equivalent of the Grès a Platyorthis and Schistes Carburés of Cabanis et al. (1979a) which are of Lower Devonian age.

Discordantly overlying the Lower Devonian sediments is the Formation de Morlaix (the Schistes Zébrés) which occupies the major part of the Morlaix Basin. This formation is composed of dark mudstones with thin interbedded feldspathic sandstone units of possible turbidite origin.

The Formation de Morlaix is succeeded conformably by the Formation de Dourduff which has yielded Strunian micro-fossils. This formation is characterised by the Poudingue de Dourduff Member, which is formed of several closely related debris-flow units separated by mudstones and sandstones. A second distinctive part of this formation is the Arkose de Kerarmel Member.

The Formation de Dourduff passes conformably upwards into the Formation de Barnénez, which is characterized at its base by black pelites intruded by basic sheets. There is strong field evidence to show that the basic sheets were emplaced into muds as very shallow intrusions, although no true pillow lavas have been encountered.

The presence of debris flows and evidence for penecontemporaneous basaltic volcanism reflects crustal instability during the evolution of the Morlaix Basin in late Devonian-early Carboniferous times. The basalts of the Formation de Barnénez are considered to be the product of a major period of basic volcanism, reflected in adjacent areas by the presence of a basic dyke suite which, as stated in part A, can be used as a time marker from the Trégor westwards into the Pays de Léon. Geochronological evidence presented in Chapter 6 indicated a c. 350 m.y. age for the emplacement of the basic dyke suite and therefore the Formation de Barnénez. This age is broadly coincident with peak metamorphism in the western Pays de Léon (Roper 1980) and this date also approximates to the Devonian-Carboniferous boundary.

Roper (op. cit.) attributes peak metamorphism (D2/M2 in his nomenclature) in the western Pays de Léon to the Bretonic earth-movements and he places this episode in the period 345-380 m.y., with peak metamorphism occurring at 350 m.y. Roper's evidence is based on the interpretation of previously published geochronological data.

The Devonian/Carboniferous boundary has been placed at 345 m.y. (Fig. 1:11), based on the guidelines of Harland et al. (1964). Odin (1982), however, has argued for a 360 m.y. Devonian/Carboniferous boundary. This has important implications in matching-up the peak D2/M2 episode in the Pays de Léon, as by lowering the age of this boundary, the Strunian dated Formation de Dourduff could be approximately 360 m.y. old. Field evidence points to this formation being deposited during a period of crustal instability and then subsequently isoclinally folded (locally D1/M1) and re-folded (locally D2/M2). Peak metamorphism in the Morlaix Basin sequence (indicated by garnet growth) post-dates the D1 episode (equivalent to the regional D2/M2 episode and to Roper's D2/M2 episode in the western Pays de Léon. This may therefore have occurred at around 350 m.y., based on Roper's re-interpretation of geochronological data.

Therefore, if Odin's (1982) revised geological time-scale for the Palaeozoic is used in preference to that of Harland et al. (op. cit.), then peak regional metamorphic episode can be correlated within the Pays de Léon (including the St. Pol-de-Léon Metamorphic Complex) and the Morlaix Basin as an early Carboniferous (post-Formation de Barnénez and dyke suite, possibly Bretonic?) disturbance.

The effects of the peak deformation and metamorphic episode, D2/M2, was to produce; 1) the dominant S1a mylonite fabric in the CSB, 2) isoclinal folds and associated planar fabric in the Palaeozoic formations of the Morlaix Basin and St. Pol-de-Léon Metamorphic Complex, 3) upper-amphibolite facies metamorphism in the metamorphic complex, and 4) a well-developed planar and linear fabric in the Gneiss Granitique d'Ile Callot. Major vertical movements occurred along the CSB so that the medium-high grade St. Pol-de-Léon Metamorphic Complex was juxtaposed against the low-grade Morlaix Basin.

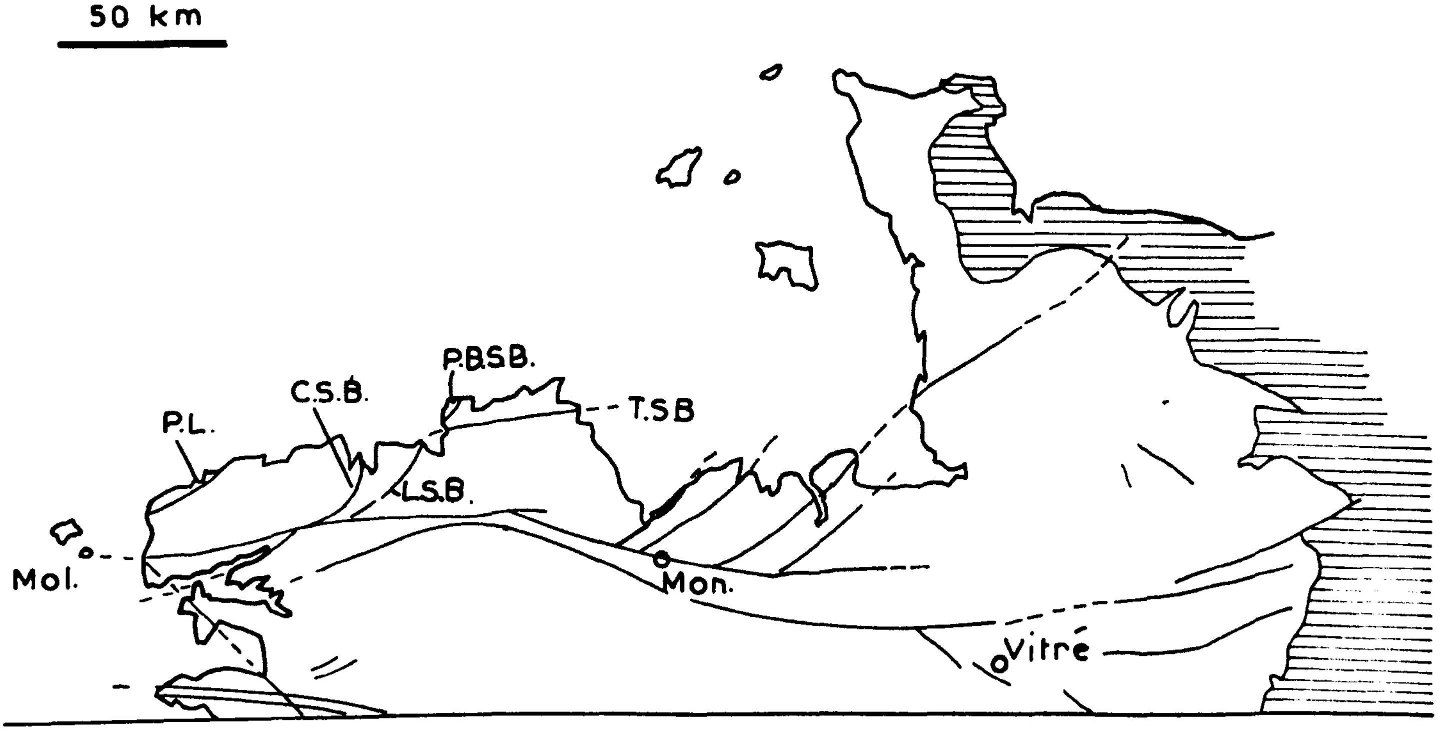
The emplacement of granites (now frequently foliated), termed the early granites in this thesis, may have accompanied the D2 episode. In the St. Pol-de-Léon Metamorphic Complex a number of different early granite types are recognised, the largest being the Granite de Roscoff. Roper (1980) has recognised syn-D3 granites in the western Pays de Léon and he brackets their emplacement within the period 315-300 m.y. However, Barriere et al. (1983) consider the early granites of this thesis, principally the Granite de Plouaret (equated with the 336 ± 13 m.y. Granite de Huelgoät, discussed Chapter 7) to have been emplaced during the period 335-350 m.y. and therefore possibly syn-late D2/M2.

The current outcrop pattern observed in the study area appears to be largely governed by the formation of the Carantec and Locquirec Shear Belts. In the St. Pol de Léon Metamorphic Complex and in the Morlaix Basin the dominant foliation is broadly parallel to the mylonitic foliation along the lengths of the CSB. Thus, as Chauris (1972) has already noted the regional foliation in the eastern Pays de Léon swings anti-clockwise from its general WSW-ENE trend around to a SSE-NNW trend when followed east towards the Morlaix Basin. The main early foliation in the Morlaix Basin also follows this latter direction. Similarly, in the Petit Trégor, the outcrop trend of the Brioverian metavolcanic and metasedimentary formations is parallel to the curved eastern margin of the LSB. Inland mapping of these two major shear belts is difficult, but there is sufficient exposure to indicate that both are curved.

Figure 8:1 illustrates several major shear zones recognised in northern Brittany, all displaying a significant degree of curvature. Many of the shear zones are possibly related to the North Armoricain Shear Zone (NASZ), and may be regarded as splays or accommodation shear-band structures that develop obliquely to the major east-west trending NASZ. Chauris (1969) and Watts and Williams (1979) consider the major movement along the NASZ to have occurred during the Precambrian, with only minor and more cataclastic deformation occurring during the Hercynian. Watts and Williams (op. cit.) evidence is based on the fact that the Quintin Granite (340 ± 5 m.y., Adams 1967) truncates mylonitic rocks in the Guingamp area and that this granite has subsequently been displaced by brittle movements some 10 km. The main movement along the NASZ is suggested to have occurred between 600 m.y. (emplacment of the Cadomian granites) and 340 m.y. (emplacement of the Quintin Granite).

In the Petit Tregor, however, the dating of the initial main movements along LSB and other smaller belts is difficult to establish. The basic dykes were emplaced after the development of the mylonitic banding in the Locquirec Shear Belt and the other shear zones cutting the Moulin de la Rive Orthogneiss Complex. This indicates a pre-early

FIG. 8 : 1 MAP OF THE NORTH ARMORICAIN SHEAR ZONE SYSTEM



The North Armoricain Shear Zone trends approximately E-W and extends from Molène (Mol) through Moncontour (Mon) eastwards towards Vitré. Several major NE - SW trending mylonite zones are related to the shear zone system and may be regarded as splays. Such structures develop obliquely to the main shear zone and they are considered to form as accommodation structures in response to the dextral shear zone movement.

From original map by Cogné 1974 with addition by present author (CSB, LSB and TSB)

P.L.	Porspoder Lineament	P.B.S.B.	Pointe de Bihit Shear Belt.
C.S.B.	Carantec Shear Belt	T.S.B.	Trégor Shear Belt.
L.S.B.	Locquirec Shear Belt.		

Carboniferous age for the development of the mylonitic banding in the LSB (on the assumption that the basic dykes are early Carboniferous). The early movements along the LSB therefore pre-date those along the Carantec Shear Belt. On this evidence the LSB and other shear zones in the Petit Trégor were developed in the time interval late Cadomian to post-early Carboniferous (i.e. between c. 535 and 350 m.y.).

In Chapter 3 evidence for a major Cadomian deformation and metamorphic event was discussed for the eastern Trégor. However, in the Baie de Lannion there is no direct evidence of a Cadomian event. This is based upon the fact that the quartzites of possible Arenigian age (discussed Chapter 6), the Quartzites de Grand Rocher, have apparently undergone the same deformation as the Brioverian metasediments in this area. This indicates that structures are post-Arenigian in age and therefore Hercynian. It may also be argued, however, that there was a Cadomian deformation and metamorphic event, the effects of which have been masked or destroyed by later events. In support of this argument there are relatively simple Cadomian structures recorded in the Pte. de Guilben-Paimpol area of the eastern Trégor which have not been modified by Hercynian deformation. Evidence for a Cadomian event has been presented above and in Chapter 2 for the early deformation of the metasedimentary and metavolcanic formations of the St. Pol de Léon Metamorphic Complex. There is, therefore, some evidence for an important Cadomian deformation episode and, as mentioned above, Watts and Williams (1979) and Chauris (1969) have considered the main movement along the NASZ and associated splays to be Cadomian. However, there is some evidence to suggest that the major deformation in the Petit Trégor (that gave rise to S1-S2 in the LSB and Moulin de la Rive Orthogneiss Complex) was a post-Cadomian event, possibly early Hercynian (Devonian?).

Thus the Quartzites de Grand Rocher, of possible Arenigian age, possess similar structures to the adjacent Brioverian metasediments indicating a post-Arenigian deformation in the Petit Trégor.

In the Morlaix Basin the presence of debris flow deposits and basic volcanism indicates movement and instability in other parts of the Massif (possibly in the Trégor). Thus major shearing could have occurred at a deeper structural level during the regional D2/M2 episode. Auvray et al. (1980a) note a lower discordia-concordia U/Pb intersection date of 384 m.y. which may correspond to a deformation episode within the Moulin de la Rive Orthogneiss Complex. The age of deformation, particularly with respect to the development of the LSB and other shear zones, remains problematical. There is some evidence to suggest a Cadomian (late-post emplacement of the orthogneiss complex (535-550 m.y.) age but an early Hercynian (pre-basic dyke) age cannot be discounted.

A fundamental division exists between the Petit Trégor and the Trégor areas. In the Trégor area the Hercynian deformation is very weak. In the Petit Trégor, however, the Brioverian and Palaeozoic formations are strongly deformed and there is significant granite plutonism, which is largely absent from the Trégor with the noticeable exceptions of the early Granite de Plouaret and the late Granite de Ploumanac'h at the western margin of this area.

A major, dominantly upright fold phase can be correlated across the study area that post-dates the LSB and CSB formation. There is a well-developed crenulation cleavage associated with this fold phase (regionally D3/F3), with common pressure-solution cleavage and a low-grade metamorphism. A foliation S2 is recognised in the LSB and this also affects the meta-basic dyke suite. Folds of similar geometry occur in all the metasedimentary formations of the Pays de Léon and Petit

Trégor, but they have not been recognized in the east of the Trégor region, where the only firmly established Hercynian structures are the broad open folds in the early Palaeozoic Plurivo-Bréhec red-beds sequence and faults (e.g. the Tregorrois Fault, see below). This again reflects the important contrast between the strongly Hercynian tectonized western part of northern Brittany (Petit Trégor westwards) and the comparatively weakly tectonized eastern part.

Late Hercynian granites truncate all the major formations in the study area, the largest being the Granite de Primel-Carantec and the Granite de Trédrez. These late granites post-date the D3/F3 structures and often cause significant contact metamorphism. Chauris (1978) considered the late Hercynian granites (sensu this thesis) to have been emplaced in the period c. 290-305 m.y. These include the Granite de Aber Ildut of the western Pays de Léon, the Granite de Primel-Carantec and the Granite de Ploumanac'h.

Late, brittle structures assigned to a D4 episode have affected all the major formations. These structures are principally kink-bands and chevron folds that frequently accommodate open flexural type folds. Such folds are particularly well-developed in the Amphibolites de Pte. de Jean.

Several large faults, for example the western extension of the Trégorrois Fault (Fig. 5:36) (Delattre 1952; Delattre and Pruvost 1967) are developed across the study area. The Trégorrois Fault, which trends parallel to the TSB and LSB, cuts the Hercynian Granite de Trédrez. Another major fault recognised in the study area truncates the western boundary of the St. Jean-du-Doigt Gabbro Complex. Many of the faults are arranged in conjugate sets at NE-SW and NE-SW, the NW-SE set are reverse faults, often occupied by large quartz veins (e.g. West of Plestin-les Greves, GR 1570 1238). The faults may have formed as brittle structures in order to accommodate late movement on the NASZ and associated splay shear zones.

A late geological episode recognised is the emplacement of several lamprophyre dykes in the Petit Trégor which truncate the late Hercynian granites and agmatites within the St. Jean-du-Doigt Gabbro Complex. Roper (1980) has pointed to the existence of several NW-SE trending dolerite dykes in the SW Pays de Léon. These appear to belong to a suite of late Triassic basic dykes which are present in minor numbers across west Finistère.

In summary, evidence from the eastern part of the Trégor points to a major deformation episode and low-grade metamorphism during the Cadomian Orogeny with little super-imposed Hercynian deformation. A general increase in Hercynian metamorphic grade occurs across north-western Brittany from the Trégor to the Petit Trégor, Morlaix Basin and Pays de Léon areas. Evidence from the Pays de Léon points to a pre-Hercynian, probable Cadomian event which has been strongly over-printed by Hercynian polyphase deformation. Climactic metamorphic conditions were reached at approximately 350 m.y. (Roper 1980, p 9-11). If the Devono-Carboniferous boundary is placed at 360 m.y. (as in the scheme of Odin 1980) it is possible that peak metamorphism occurred across the whole Pays de Léon and Morlaix Basin area during the early Carboniferous (Bretonic?) earth movements at c. 350 m.y.. Deformation in the Petit Trégor (responsible for the initial main development of the LSB) occurred prior to this date at some time in the interval 535-c. 350 m.y. (ie late Cadomian-pre dyke emplacement).

Previous authors (Cogné 1972; Roach 1977; Gapais and Le Corre 1980; Brown 1982) have attached greater importance to the Cadomian orogeny in northwest Brittany. However, this must now be questioned in the light of evidence from the Pays de Léon and the Morlaix St. Michel-en-Grève region.

(C) POSSIBLE FURTHER WORK

A number of suggestions are made here for further geological work in the Morlaix-St. Michel-en-Grève area.

1) ST. POL-DE-LÉON METAMORPHIC COMPLEX

Geochronology : No date is available for the foliated Granite de Roscoff or any of the other early granites recognised in this area. A Rb-Sr whole rock age for the Granite de Roscoff would be useful in helping to establish the role of granite plutonism during the syn-late D2/M2 episode.

Structural Geology : A more detailed study of the structures associated with the emplacement of the early and late granites could be made. Such a study may reveal information on the role of the CSB as a zone of pluton generation.

Lithological Mapping : Further work should be carried out to determine the southwestward continuation of the CSB and to find out whether it is linked to the NASZ.

2) MORLAIX BASIN

Geochronology and Geochemistry : There is considerable scope for both geochronological work and geochemical work on the metabasic dyke suite that is developed across the area and its relationship to the metabasaltic Formation de Barnénez. Such a study would help to establish the timing of the peak D2/M2 episode and timing of other geological events. A geochemical study may show the relationship between the two units and indicate an environment into which the metabasalts were emplaced.

Structural Geology : Detailed microstructural work on the role of pressure-solution and low-grade metamorphism within dominantly pelitic lithologies would be an interesting exercise. The Formation de Dourduff and Formation de Morlaix are well-exposed and well-understood and show spectacular segregation banding.

Lithological mapping : More work is required to define the nature of the contact of the Morlaix Basin Palaeozoic lithologies with those of the Brioverian of the Petit Trégor. In addition, the extensive Formation de Kerolzec could be examined in more detail in order to establish the importance of the dark pelites that are developed towards the top of this formation.

(3) PETIT TRÉGOR

Geochronology and Geochemistry : A detailed study of the St. Jean-du-Doigt Gabbro Complex is required in order to establish its age and relationships to the adjacent Moulin de la Rive Orthogneiss Complex and the Formation de Barnénez. The major intrusion has received very little attention and its stratigraphic position is problematical. More detailed mapping of the Moulin de la Rive Orthogneiss Complex is required and the nature of its contact with the LSB in its southeastern outcrop needs further examination.

Lithological mapping : The extensive Migmatites de Tréduder need further mapping in order to establish their age and relationships to other Palaeozoic lithologies. In addition, basic intrusions within these migmatites require further study.

APPENDICES

APPENDIX (1)

ANALYTICAL TECHNIQUES

WHOLE ROCK ANALYSES

Forty meta-igneous rocks were analysed for ten major and eight selected trace elements by X-ray Fluoresence Spectroscopy.

The sample locations and results are listed in Appendices (2) and (3).

Where possible, approximately 1 kg samples were collected for analysis. Samples were split into rough cubes 1-2 cm across using a Denbigh fly-press rock splitter or a hammer and bolster, with the removal of all weathered material and veining.

The split samples were then passed through a Sturtevant 2" x 5" jaw crusher, reducing the rock to chips between 5 mm and 1 cm in size. The samples were homogenized by successive cone and quartering until two quarters were selected each approximately 120 gms in weight. The quarters were crushed in a tungsten carbide Tema disc mill for 15 secs (for FeO determination) and 30 secs (for X.R.F. analyses) respectively. After further homogenization, approximately 20 gms of the X.R.F. fraction was milled for a further 30 minutes in a Glen Greston M280 tungsten carbide ball mill.

Major element analyses were performed on glass beads produced by mixing 0.5 gms of ignited rock powder (ignited to 1000^{o}C) with 2.5 gms of Johnson-Matthey Spectroflux 101A (Lithium Metaborate). After fusing the mixture over a meker burner until a clear quiescent melt was produced, the bead was cast on a brass plate with a copper binding ring, and the liquid promptly pressed out with an aluminium plunger.

Trace elements and Na analyses were determined on pressed powder pellets. These were prepared by mixing 8-10 drops of Mowiol (N90/98) Binder with 6 gms of sample, by hand in an agate mortar and pestle and then subjecting this to a pressure of 25 tons per square inch for 4 minutes in a hydraulic press between two tungsten carbide formers. The pellets were then dried in an oven overnight.

X-ray fluorescence analysis for both major and trace elements was performed on a Phillips PW1212 fully automatic sequential X-ray spectrometer and a Phillips PW1220 semi-automatic spectrometer, both in the Department of Geology at the University of Keele. Details of the operating conditions for the X-ray analysis may be found in Haselock (1982).

For the major elements each bead was run three times and the mean of the three analyses recorded. For trace elements and Na, two cycles were made for each side of the pressed pellet, each side representing a duplicate analysis due to the shallow depth of penetration of the X-rays.

Counts for both peak and background were recorded and the net counts (P - B) were then used with or without corrections for interference effects.

For the major elements, a series of calibration curves were constructed using selected international standard rock powders (Flanagan 1974). Apparent fluorescence values were obtained from a Norrish and Hutton (1969) Correction Matrix. The apparent fluorescence values obtained for the samples were then corrected using the same matrix in reverse.

FeO determinations were made for all samples by titration against Potassium dichromate. 0.5 gms of rock powder were dissolved in a 1:1 mixture of H_2SO_4 and HF over a steam bath for 15 minutes. The acid was neutralised with 500 ml of saturated boric acid and the solution titrated against potassium dichromate using sodium diphenylamine sulphonate indicator.

APPENDIX (2)

GEOCHEMICAL SAMPLE LOCALITIES

MOULIN DE LA RIVE ORTHOGNEISS COMPLEX

(Note: Variably foliated; porphyritic microgranite is highly schistose, other samples are low-moderately strained).

NG 001 Augen gneiss........................W. Moulin de la Rive

GM 002 Porphyritic microgranite...........S.W. Pte du Corbeau

GM 003 Porphyritic microgranite...........Pte du Corbeau

GM 004 Granite............................S.W. Pte du Corbeau

GM 005 Granite............................Pte du Corbeau

GM 006 Microgranite sheet.................E. Pte du Corbeau

GM 007 Metabasic dyke.....................E. Moulin de la Rive

GM 008 Quartz diorite.....................E. Moulin de la Rive

GM 009 Agmatite...........................E. Moulin de la Rive

GM 010 Gabbro.............................W. Moulin de la Rive

GM 011 Granite............................W. Moulin de la Rive

GM 012 Quartz diorite/tonalite............W. Moulin de la Rive

GM 013 Metabasic dyke.....................Pte du Corbeau

GM 014 Porphyritic microgranite...........Pte du Corbeau

GM 015 Porphyritic microgranite...........E. Pte du Corbeau

GM 017 Granite............................E. Pte du Corbeau

GM 018 Quartz diorite/tonalite ....E. Pte du Corbeau

LSB SAMPLES

(In variably strained states according to degree of mylonitization)

SL 019 Quartz-feldspar mylonite...........Poul Rouhan; W. Locquirec

SL 021 Granitic protomylonite.............Poul Rouhan; W. Locquirec

SL022 Quartz-feldspar mylonite........... SW. Pte de Locquirec

SL 023 Feldspathic mylonite...............S.W. Pte de Locquirec

SL 024 Ultramylonite......................S.W. Pte de Locquirec

SL 025 Ultramylonite......................Pte de Locquirec

SL 026 Ultramylonite......................Pte de Locquirec

SL 027 Granitic protomylonite.............Chateau de Locquirec (reef)

SL 028 Granitic protomylonite.............Chateau de Locquirec

SL 030 Feldspathic mylonite...............E. Pte du Corbeau

SL 031 Ultramylonite......................Pte de Locquirec

FORMATION DE PTE DE L'ARMORIQUE

L = least altered (homogeneous); A = highly altered (inhomogeneous);

V = Vesicular.

NG 002 Greenschist (mylonite).............Plage de l'Argent (A)

NG 004 Greenschist (mylonite).............Plage de l'Argent (A)

NG 067 Massive greenstone.................S. Pte de Plestin (A)

NG 1589 Massive greenstone.................Porz Mellec (L)

NG 573 Massive greenstone.................Pte de l'Armorique(L?)

NG 593 Massive greenstone.................E. Porz Mellec (L)

PA 029 Massive greenstone.................Pte de l'Armorique (L)

PA 032 Massive greenstone.................E. Plage de l'Argent (L)

PA 033 Pillow lava (core)..................S.W. Pte de l'Armorique (A)

PA 034 Pillow lava (core)..................S.W. Pte de l'Armorique (A/V)

PA 035 Massive greenstone.................E. Plage de l'Argent (L)

PA 036 Massive greenstone.................Pte de Plestin (L)

PA 037 Massive greenstone.................Pte de Plestin (L)

APPENDIX 3

MAJOR AND TRACE ELEMENT ANALYSES

(BDL = Below detection level; ND = Not determined)

APPENDIX 3A. METABASITES OF THE FORMATION DE POINTE DE L'ARMORIQUE

Major Elements

Rock No.	NG002	NG004	NG067	NG1589	NG573	NG593	PA029
SiO_2	44.12	40.09	48.67	47.99	56.51	48.68	49.62
TiO_2	0.51	0.45	0.46	0.46	1.31	0.99	0.50
Al_2O_3	10.84	12.87	12.10	14.29	13.16	15.61	13.53
Fe_2O_3	4.45	4.87	7.03	3.17	2.05	0.96	3.03
FeO	2.58	2.84	1.87	5.82	8.61	7.62	5.62
MnO	0.12	0.13	0.17	0.15	0.11	0.14	0.15
MgO	4.17	3.41	2.99	11.75	9.59	10.68	11.11
CaO	14.87	19.63	19.14	10.46	0.37	6.02	8.26
Na_2O	2.01	1.08	0.32	1.25	1.05	2.78	2.25
K_2O	0.50	0.20	0.12	0.44	0.31	0.62	0.26
P_2O_5	0.09	0.08	0.09	0.04	0.14	0.11	0.06
LOI	14.51	13.80	8.34	4.45	6.35	5.28	4.20
TOTAL	98.76	99.44	101.29	100.26	99.56	99.49	98.59

Trace Elements

	NG002	NG004	NG067	NG1589	NG573	NG593	PA029
Ce	32	34	34	25	33	33	37
Cr	443	363	355	642	569	N.D.	827
Ga	11	13	16	20	18	14	N.D.
La	BDL	BDL	BDL	BDL	BDL	2	1
Nb	6	5	7	3	8	6	4
Nd	23	11	17	18	20	25	27
Ni	156	117	120	252	329	N.D.	294
Rb	8	2	1	7	9	11	1
Sc	38	34	33	42	26	30	38
Sr	113	308	681	190	59	189	188
Y	10	10	11	8	8	17	12
Zr	26	21	19	15	82	83	40

APPENDIX 3A CONTINUED

Major Elements

Rock No.	PA032	PA033	PA034	PA035	PA036	PA037
SiO_2	46.32	45.97	59.90	47.81	53.11	51.45
TiO_2	0.48	0.70	0.62	0.59	0.69	0.66
Al_2O_3	14.83	16.62	13.60	14.78	13.16	14.54
Fe_2O_3	3.84	3.76	8.57	4.16	2.88	3.34
FeO	6.92	5.43	1.41	5.07	5.43	6.10
MnO	0.15	0.17	0.11	0.18	0.18	0.16
MgO	12.54	7.84	1.21	11.27	9.48	9.47
CaO	10.32	8.35	11.33	11.40	8.99	9.28
Na_2O	1.03	2.41	0.55	1.74	2.31	1.52
K_2O	0.38	0.15	0.20	0.26	0.26	0.20
P_2O_5	0.03	0.11	0.11	0.05	0.11	0.08
LOI	4.52	7.14	2.46	3.68	3.65	3.77
Total	101.36	98.64	100.07	101.00	100.24	100.57

Trace Elements

Ce	33	46	42	36	31	37
Cr	758	338	N.D.	N.D.	N.D.	
Ga	N.D.	N.D.	N.D.	N.D.	N.D.	N.D.
La	BDL	2	BDL	BDL	BDL	BDL
Nb	6	7	10	N.D.	4	3
Nd	23	28	27	21	22	33
Ni	285	130	N.D.	N.D.	N.D.	
Rb	5	1	1	N.D.	3	3
Sc	45	29	31	42	37	38
Sr	192	308	695	N.D.	275	197
Y	10	22	18	N.D.	17	18
Zr	7	49	33	N.D.	43	39

APPENDIX 3B. MOULIN DE LA RIVE ORTHOGNEISS COMPLEX

Major Elements

Rock No.	NG001	GM002	GM003	GM004	GM005	GM006	GM007
SiO_2	68.93	70.46	71.98	70.96	72.66	71.24	47.03
TiO_2	0.50	0.24	0.22	0.24	0.24	0.26	3.63
Al_2O_3	14.14	14.90	14.90	14.23	14.12	15.95	13.91
Fe_2O_3	1.92	1.61	1.02	1.93	1.04	1.13	9.43
FeO	2.44	0.76	1.29	0.78	1.53	0.51	7.28
MnO	0.06	0.02	0.03	0.02	0.03	0.02	0.23
MgO	1.67	0.46	0.71	0.60	0.56	0.93	5.81
CaO	1.51	0.34	0.34	0.50	0.61	0.95	6.80
Na_2O	4.47	5.49	5.13	5.56	5.10	6.99	1.38
K_2O	6.63	3.83	3.37	2.71	3.41	1.92	0.49
P_2O_5	0.18	0.03	0.04	0.05	0.06	0.05	0.36
LOI	1.42	1.17	1.31	1.07	1.12	1.26	5.39
Total	103.87	99.31	100.34	98.65	100.48	101.21	101.74

Trace Elements

Ba	1467	1307	1136	970	1362	842	1306
Ce	50	63	72	80	74	3	44
La	32	36	45	41	44	2	20
Nb	28	22	24	22	22	14	12
Nd	31	32	37	48	45	12	33
Ni	N.D.	4	3	6	2	6	4
Rb	68	96	97	79	64	38	17
Sc	8	7	7	14	13	2	48
Sr	234	141	116	135	124	535	243
Y	12	25	20	26	30	3	58
Zr	166	257	249	233	237	63	222

Major Elements

Rock No.	GM008	GM009	GM010	GM011	GM012	GM013	GM014
SiO_2	63.07	70.98	52.47	71.84	57.36	48.67	71.70
TiO_2	0.61	0.28	0.59	0.25	0.81	1.38	0.26
Al_2O_3	17.13	14.77	16.94	14.46	17.62	14.45	14.52
Fe_2O_3	3.65	0.93	3.92	0.00	3.14	5.35	1.66
FeO	1.84	3.02	4.22	3.76	4.37	6.22	1.27
MnO	0.08	0.11	0.15	0.03	0.12	0.18	0.13
MgO	1.30	0.35	6.95	0.34	1.39	6.44	0.60
CaO	4.65	0.46	7.98	0.62	5.46	10.85	0.64
Na_2O	4.26	4.83	4.24	3.18	4.17	2.38	5.54
K_2O	2.37	2.90	0.90	2.92	1.45	0.81	2.92
P_2O_5	0.21	0.06	0.13	0.05	0.25	0.09	0.06
LOI	2.14	2.53	2.88	2.92	3.24	2.95	1.30
Total	101. 31	101.22	101.37	100.37	99.38	99.77	100.60

Trace Elements

Ba	N.D.	N.D.	N.D.	N.D.	N.D.	N.D.	N.D.
Ce	47	43	18	41	46	18	n.d.
La	29	24	5	16	15	1	N.D.
Nb	17	15	9	14	16	6	24
Nd	31	28	27	35	38	10	N.D.
Ni	N.D.	N.D.	N.D.	N.D.	N.D.	N.D.	N.D.
Rb	64	39	22	47	36	32	83
Sc	14	18	46	25	24	45	14
Sr	528	674	502	598	609	345	171
Y	18	15	11	29	37	28	32
Zr	245	360	43	116	345	54	246

Major Elements

Rock. No.	GM015	GM017	GM018
SiO_2	74.59	71.45	54.18
TiO_2	0.25	0.17	0.89
Al_2O_3	13.89	14.45	21.01
Fe_2O_3	1.47	2.09	6.30
FeO	1.15	1.29	1.61
MnO	0.05	0.07	0.12
MgO	0.57	0.95	2.13
CaO	0.26	0.54	7.19
Na_2O	4.23	5.14	5.38
K_2O	3.30	3.57	1.42
P_2O_5	0.07	0.07	0.26
LOI	1.54	1.11	1.33
Total	101.37	100.90	101.82

Trace Elements

BA	N.D.	N.D.	N.D.
Ce	N.D.	N.D.	N.D.
La	N.D.	N.D.	N.D.
Nb	27	27	21
Nd	N.D.	N.D.	N.D.
Ni	N.D.	N.D.	N.D.
Rb	118	85	75
Sc	14	13	11
Sr	77	143	136
Y	32	33	23
Zr	263	250	248

APPENDIX 3C. LOCQUIREC SHEAR BELT MYLONITES

Major Elements

Rock No.	SL019	SL021	SL022	SL023	SL024	SL025
SiO_2	65.15	64.63	66.22	61.66	60.87	59.90
TiO_2	0.62	0.56	1.10	0.59	0.72	0.60
Al_2O_3	16.90	15.89	12.37	16.75	16.06	15.60
Fe_2O_3	2.57	2.41	6.62	2.71	5.89	3.27
FeO	1.78	2.71	0.71	2.69	0.17	2.46
MnO	0.07	0.13	0.12	0.11	0.10	0.13
MgO	1.99	2.78	1.72	2.53	0.66	2.62
CaO	2.27	1.92	2.18	2.72	3.84	3.33
Na_2O	6.24	4.90	4.63	4.07	4.12	6.42
K_2O	1.46	2.11	1.73	3.19	2.95	0.83
P_2O_5	0.19	0.23	0.10	0.22	0.24	0.18
LOI	1.88	2.15	3.44	3.01	4.37	4.72
Total	101.12	100.42	100.94	100.25	99.99	100.06

Trace Elements

Ba	N.D.	N.D.	N.D.	N.D.	N.D.	N.D.
Ce	N.D.	N.D.	N.D.	N.D.	N.D.	N.D.
La	N.D.	N.D.	N.D.	N.D.	N.D.	N.D.
Nb	16	13	14	12	12	13
Nd	N.D.	N.D.	N.D.	N.D.	N.D.	N.D.
Ni	N.D.	N.D.	N.D.	N.D.	N.D.	N.D.
Rb	51	49	66	87	102	27
Sc	12	13	15	14	19	23
Sr	321	295	192	419	167	221
Y	18	14	21	16	27	19
Zr	291	143	272	135	218	155

Major Elements

Rock No.	SL026	SL027	SL028	SL030	SL031
SiO_2	65.92	63.43	64.88	62.37	68.96
TiO_2	0.43	0.55	0.52	0.58	0.43
Al_2O_3	15.45	15.34	14.67	15.52	15.57
Fe_2O_3	1.74	1.16	4.30	3.08	4.67
FeO	1.37	3.12	0.29	2.34	0.31
MnO	0.06	0.09	0.13	0.10	0.02
MgO	1.26	2.51	1.22	2.43	0.82
CaO	2.24	2.40	2.33	2.75	0.20
Na_2O	4.12	5.51	7.53	3.79	0.57
K_2O	2.80	1.41	0.77	3.25	5.36
P_2O_5	0.14	0.20	0.19	0.22	0.10
LOI	3.57	3.52	2.49	1.62	2.72
Total	99.10	99.24	99.32	98.05	99.73

Trace Elements

Ba	N.D.	N.D.	N.D.	N.D.	N.D.
Ce	N.D.	N.D.	N.D.	N.D.	N.D.
La	N.D.	N.D.	N.D.	N.D.	N.D.
Nb	14	17	13	13	19
Nd	N.D.	N.D.	N.D.	N.D.	N.D.
Ni	N.D.	N.D.	N.D.	N.D.	N.D.
Rb	63	37	21	102	186
Sc	9	14	14	12	11
Sr	204	323	403	336	42
Y	10	14	12	12	31
Zr	135	137	135	131	301

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