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

Vol I

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THE GEOLOGY OF THE MORLAIX-ST. MICHEL-EN-GRÈVE REGION, NW BRITTANY, FRANCE

ABSTRACT

Detailed mapping of the area between Morlaix and St. Michel-en-Grève has been carried out within the northwest part of the Massif Armoricain and three distinct tectono-metamorphic areas have been recognised.

In the western area a medium-high grade metamorphic complex comprised of an older basement complex of amphibolites and metasediments, originally Brioverian supracrustals, and Cadomian granitic orthogneisses is recorded These units have been truncated by numerous syn-tectonic and post-tectonic Hercynian granites and this area is termed the St. Pol-de-Léon Metamorphic Complex.

In the central part of the area a restricted basin of Devonian-Lower Carboniferous metasediments and basic metavolcanics is recognised. The Morlaix Basin lithologies are of low metamorphic grade and are in contact with the St. Pol-de- Léon Metamorphic Complex across a major tectonic lineament termed the Carantec Shear Belt (CSB). A new stratigraphy of the basinal sequence is presented and the timing of peak Hercynian deformation is established at c. 350 M.y. using available geochronological and field evidence.

In the eastern part of the area a low-grade metamorphic terrain composed of Brioverian metabasic volcanics and metasediments occurs, known as the Petit Trégor. This succession is truncated by a multi-component Cadomian intrusive complex which has undergone major, heterogeneous deformation. The recognition of a major shear belt the Locquirec Shear Belt and numerous smaller shear zones within the Moulin de la Rive Orthogneiss Complex has resulted in the re-appraisal of the whole stratigraphy of the Petit Trégor area. Field evidence shows that deformation in the Petit Trégor is somewhat earlier than in the Morlaix Basin and St. Pol-de-Léon

Metamorphic Complex and occurred in the period late Cadomian-early Hercynian. Discussion is then given to the timing of regional deformation events in the light of evidence from the study area.

Acknowledgements

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To my supervisor Dr Robert Roach I am deeply indebted for his teachings, advice, enthusiasm and friendship during my stay at Keele, in the field and more recently on the telephone from France - thanks Bob!

Most of the technical staff at Keele have contributed in one way or another to this work, I would like to thank Peter Greatbatch and David Wilde for producing over 450 thin-sections for me, Mike Stead, David Kelsall and David Emley for the photographs and to David Emley and Graham Lees for help and advice in the geochemistry lab. Special thanks are due to Christine Owen for doing the vast majority of the typing, to Marie-Therese Brenet, at SPG, Poligny, for typing the tables and figure captions, and also to Liz Attfield for drafting the geochemical diagrams.

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On a personal note thanks to my parents for the encouragement that they have given me whilst I have been in the Jura. Thanks also to Rachel for helping me with diagrams, typing, excellent cooking and general perseverence.

I would like to dedicate this thesis to the memory of my grandfather who died in 1984.

CONTENTS

VOLUME 1

CHAPTERS 1 - 4

CHAPTER ONE

INTRODUCTION

CHAPTER ONE

INTRODUCTION

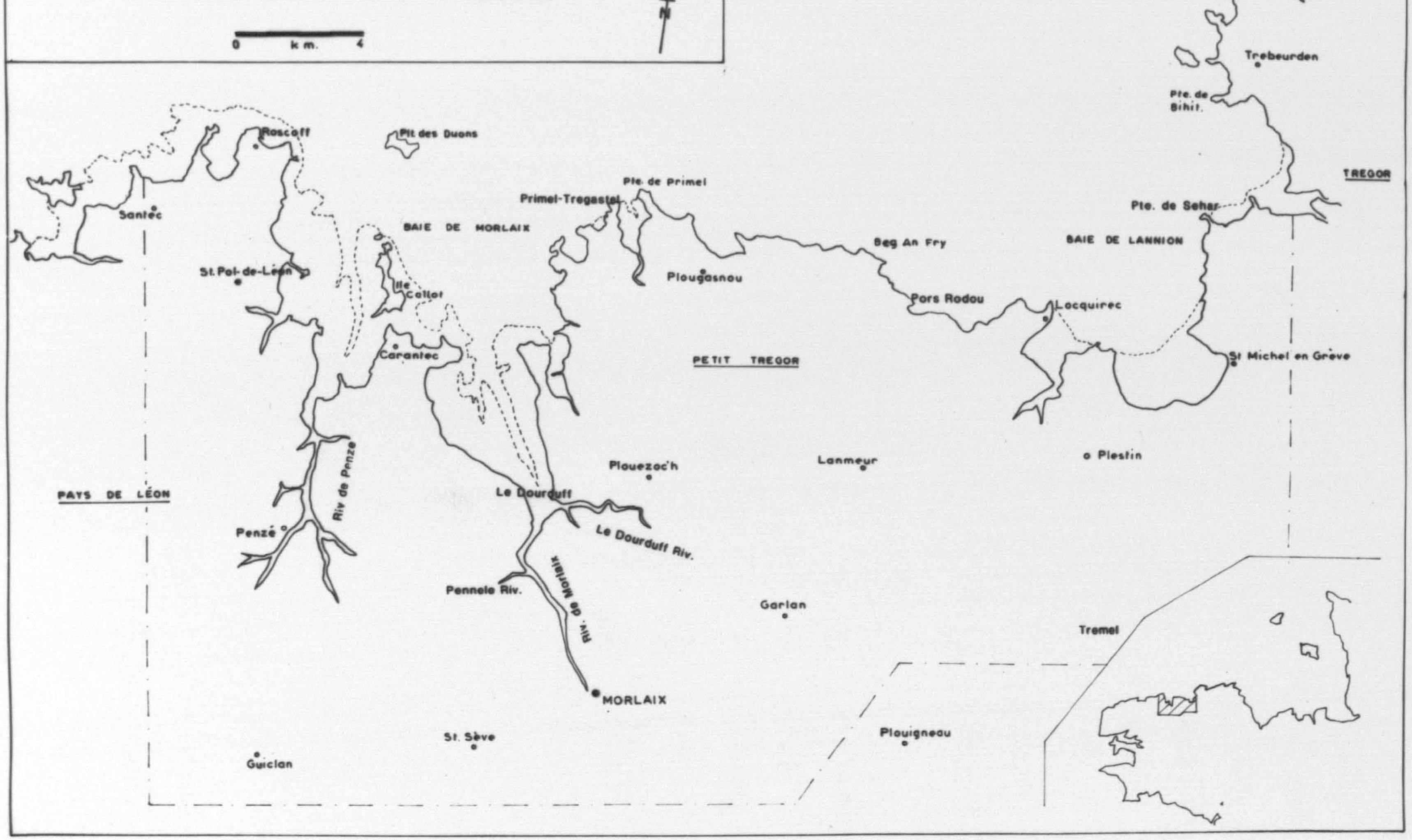
(A) LOCATION AND TOPOGRAPHY

The area studied is located in northwest Brittany, France and extends for approximately 34 km from Santec, in the northeast of the Department of Finistère, eastwards to Pointe de Séhar, in the northwest of the Department of Côtes-du-Nord. The northern boundary of the area is defined by La Manche (the English Channel) whilst the southern boundary approximates to a line drawn from near Ploumilliau to Guiclan and northwards to Santec (Fig. 1:1).

The coastline is strongly indented with two major bays; the Baie de Morlaix in the west of the area and the Baie de Lannion in the east. The area of north Finistère that lies to the west of a line drawn approximately between Carantec and Morlaix is known as the Pays de Léon, while the area between Morlaix and St. Michel-en-Grève is known as the Petit Trégor.

The town of Morlaix, population approximately 20,500, is the largest town within the area studied and is principally a market town with some commerce. It is also a busy small vessel port. Carantec and St. Pol-de-Léon are popular holiday resorts within the Pays de Léon and Roscoff is a cross-channel ferry port. In the central part of the area Plougasnou and Lanmeur are the largest centres of population and to the east Plestin-les-Grèves and Locquirec are popular, well established holiday centres.

FIG. 1:1 LOCATION OF AREA OF STUDY



There is a marked contrast in coastal and inland topography between (i) the Pays de Léon, (ii) the area around the Baie de Morlaix, (iii) the Petit Trégor, and this corresponds to three geologically distinct areas discussed in this thesis. In the western area the coast-line is low-lying with extensive sand dunes and a large inter-tidal zone within which numerous reefs and islands extend offshore. Inland, the eastern Pays de Léon shows little relief, being essentially a plateau of between 60 and 100 m in height. The Rivière de la Penzé is the major drainage channel for the area and provides a major incision into the plateau. There is a thick loëss cover and natural rock exposures are rare in this region except for those within the valley of the Rivière de la Penzé.

The irregular-shaped Baie de Morlaix extends eastwards from Roscoff to Primel-Tregastel and southwards to Le Dorduff (Fig. 1:1). Within this bay there is a large inter-tidal zone with many reefs. Two rivers enter the bay, the Rivière de la Penzé and the Rivière de Morlaix, which are both strongly tidal in the range of 15-20 m. Inland of the Baie de Morlaix the topography is more undulating than to the west and east, with hills up to 92 m and steep-sided valleys, for example the Pennelé Valley. Exposure in this area is fair, due to the steep-sided nature of the river valleys but there is a dense vegetation cover, unlike surrounding areas, and this inhibits access to outcrops in the summer months. The Petit Trégor is a plateau area in the height range 60-105 m. Its coastline, in contrast with the areas to the west, is more rugged, particularly between Primel-Tregastel and Pors Rodou (Fig. 1:1), where there are steep cliffs up to 70 m high above a narrow intertidal zone. There are however several sandy bays, the largest of which, the Grève de St. Michel, has a wide intertidal zone of over 2 km. Inland exposure in this area is generally poor and most information here was obtained from exposures in road cuttings and quarries.

(B) OUTLINE OF THE GEOLOGY OF THE MASSIF ARMORICAIN AND DEVELOPMENT OF MAJOR CONCEPTS

The area studied lies within the Massif Armoricain, the name given to the region of pre-Mesozoic rocks in Brittany, Normandy and Vendée and which also includes islands such as Île de Groix, Belle Île, the Îles d' Ouessant and the Channel Islands. The eastern boundary of the Massif Armoricain extends from Cherbourg on the Cotentin Peninsula southeastwards towards Caen and then southwards towards Angers. South of Bressuire the boundary swings west to reach the eastern side of the Bay of Biscay near Les Sables d'Olonne (Figs. 1:2 and 1:3).

The rocks that comprise the Massif Armoricain range in age from Lower Proterozoic to Upper Palaeozoic. The effects of at least three major orogenic events can be recognised:-

1. The earliest orogenic event deformed and metamorphosed the older Proterozoic sediments and igneous rocks which are now exposed in very limited areas within the north of the Massif. These rocks constitute the Pentévrien basement (anglicized to Pentevrian) as defined by Cogné (1959a).

2. The late Precambrian to early Palaezoic Cadomian orogeny which principally affected the extensive outcrops of the Upper Proterozoic Brioverian Supergroup (composed of clastic sediments with basic volcanics near its base).

3. The Upper Palaeozoic Hercynian orogeny.

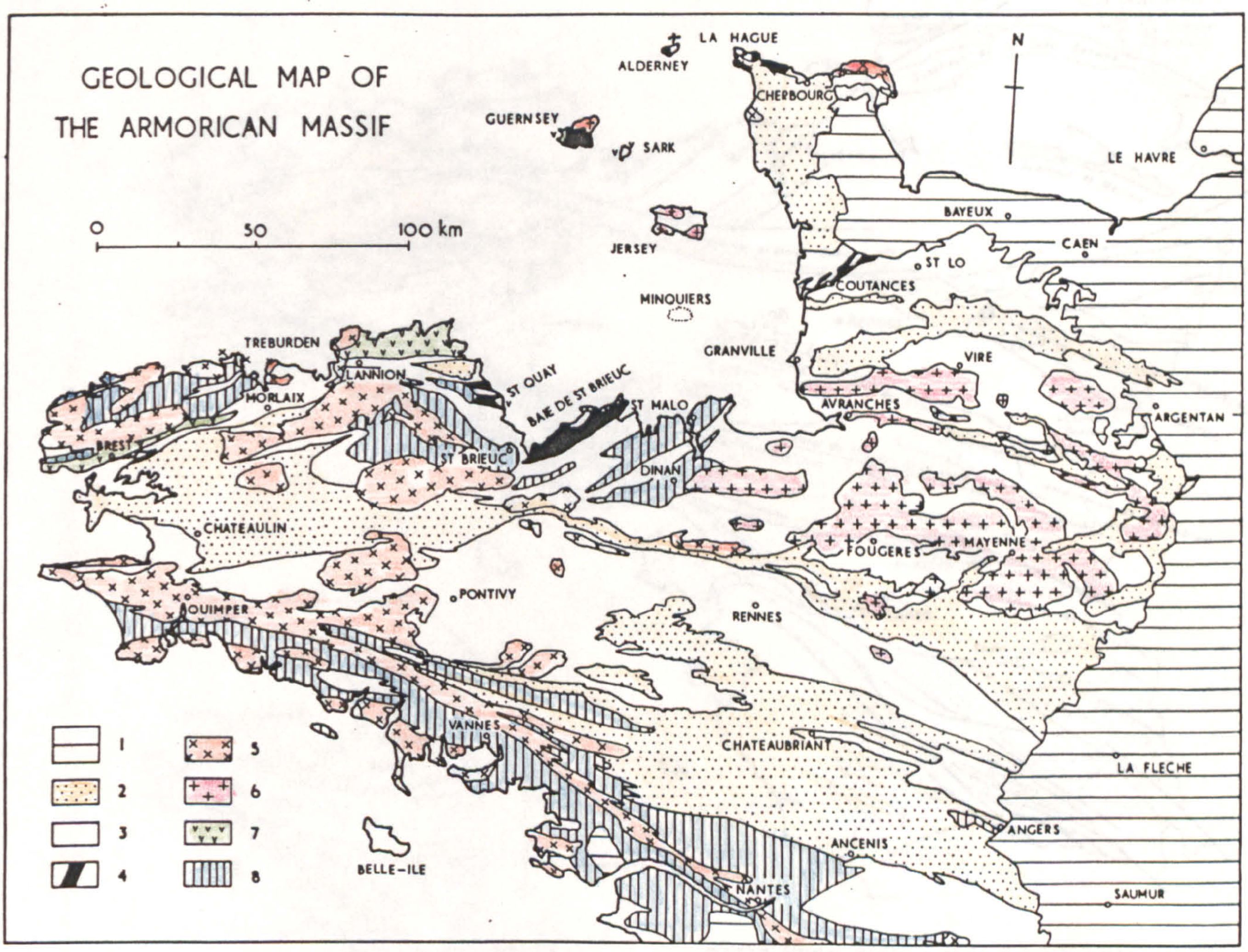


Fig. 1:2 – Simplified geological sketch map of the Armorican Massif. 1. Mesozoic and Tertiary. 2. Palaeozoic supracrustals. 3. Brioverian supracrustals. 4. Pentevrian basement. 5. Hercynian granites. 6. Younger Cadomian granites. 7. Older Cadomian granites. 8. Undifferentiated metamorphic rocks.

Fig. 1:2 Geological map of the Armorican Massif (Roach 1972)

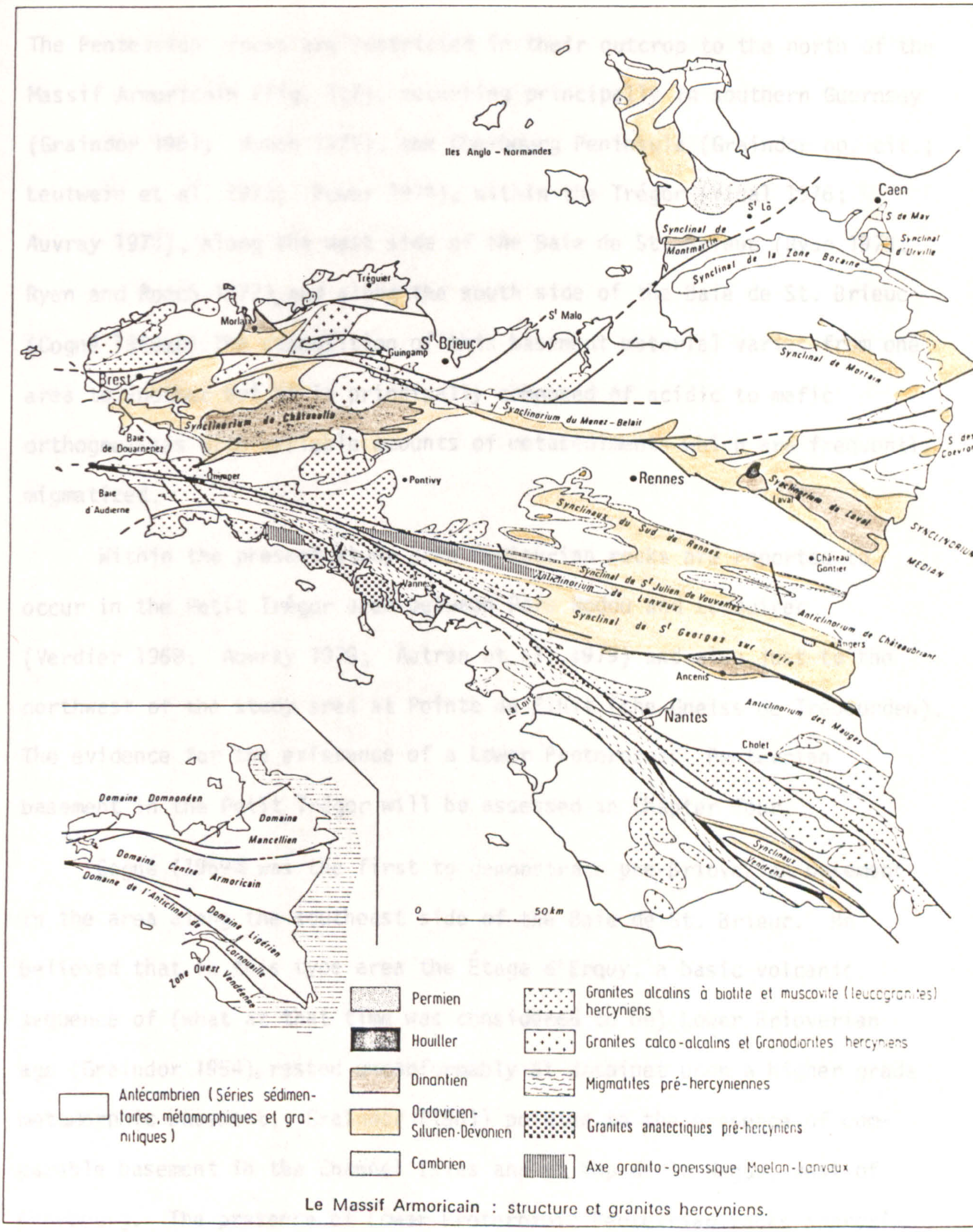


Fig. 1:3 Geological map showing distribution of the Palaeozoic rocks and Hercynian granites in the Armorican Massif (Cogné 1974)

The Pentevrian rocks are restricted in their outcrop to the north of the Massif Armoricain (Fig. 1:2), occurring principally in southern Guernsey (Graindor 1961; Roach 1977), the Cherbourg Peninsula (Graindor op. cit.; Leutwein et al. 1973; Power 1974), within the Trégor (Vidal 1976; Auvray 1973), along the west side of the Baie de St. Brieuc (Ryan 1973; Ryan and Roach 1977), and along the south side of the Baie de St. Brieuc (Cogné 1959a,b). The composition of this basement material varies from one area to another but it is principally composed of acidic to mafic orthogneisses with variable amounts of metasediments which are frequently migmatized.

Within the present study area Pentevrian rocks are reported to occur in the Petit Trégor area between Pors Rodou and Locquirec (Verdier 1968; Auvray 1979; Autran et al. 1979) and also just to the northwest of the study area at Pointe de Bihit (the Gneiss de Trébeurden). The evidence for the existence of a Lower Proterozoic Pentevrian basement in the Petit Trégor will be assessed in Chapter Four.

Cogné (1959a) was the first to demonstrate pre-Brioverian basement in the area along the southeast side of the Baie de St. Brieuc. He believed that in this type area the Étage d'Erquy, a basic volcanic sequence of (what at that time was considered to be) Lower Brioverian age (Graindor 1954), rested unconformably at Jospinet upon a higher grade metamorphic basement. Graindor (1961) pointed to the presence of comparable basement in the Channel Isles and at Cap de la Hague, west of Cherbourg. The presence of Lower Proterozoic Pentevrian rocks approximately 2000 m.y. old at Cap de la Hague, on Guernsey, Alderney, and in the Trégor, is now generally accepted on geological and geochronological grounds (Leutwein et al. 1973; Auvray and Vidal 1973; Power 1974; Vidal 1976; Roach 1977; Auvray 1979; Auvray et al. 1980a; Calvez and Vidal 1978; Vidal et al. 1981).

In the type area along the southeast side of the Baie de St. Brieuc there is currently some dispute as to the age of the basement. An Rb-Sr whole rock isochron age of 482±10 m.y.* has been obtained on the basic volcanics of the Brioverian Étage d'Erquy (Vidal et al. 1971), whilst part of the basement complex (the Diorite Gneissique de Coëtmieux-Fort-la-Latte) has yielded a Rb-Sr whole rock isochron age of 630±60 m.y. and U-Pb zircon ages of 593±15 m.y. (Vidal et al. 1974; Vidal et al. 1981). These authors concluded that the gneisses of Cogné's type area for the Pentevrian did not constitute such a basement but were produced during the late Precambrian Cadomian orogeny. However Roach and Shufflebotham (pers. comm.) point to the existence at Cesson, at the southern end of the Baie de St. Brieuc, of a basal Brioverian conglomerate, the Poudingue de Cesson (Barrois 1895b), which is generally considered to be of Lower Brioverian age. This conglomerate contains pebbles and boulders of foliated granites, quartz diorites, amphibolites and their mylonitized equivalents which are petrographically identical to lithologies present within the adjacent 'Pentevrian' basement of the type area. Field evidence therefore suggests the presence of nearby Pentevrian (i.e. pre-Brioverian by definition) even though this particular crustal segment may be partly or wholly late Precambrian in age.

Other areas of Pentevrian basement may include the St. Malo, Dinan and St. Cast Migmatite Belts (Fig. 1:2) (Brown et al. 1971; Brown 1974, 1978; Roach et al. 1972), although there is disagreement as to the age of migmatization in these belts and a Cadomian age is suggested by Jeanette (1971), Hameurt and Jeanette (1971), Brun (1977) and Brun and Martin (1978, 1979).

* All Rb-Sr whole rock isochron ages are quoted with $\lambda^{87}Rb = 1.42 \cdot 10^{-11} yr^{-1}$

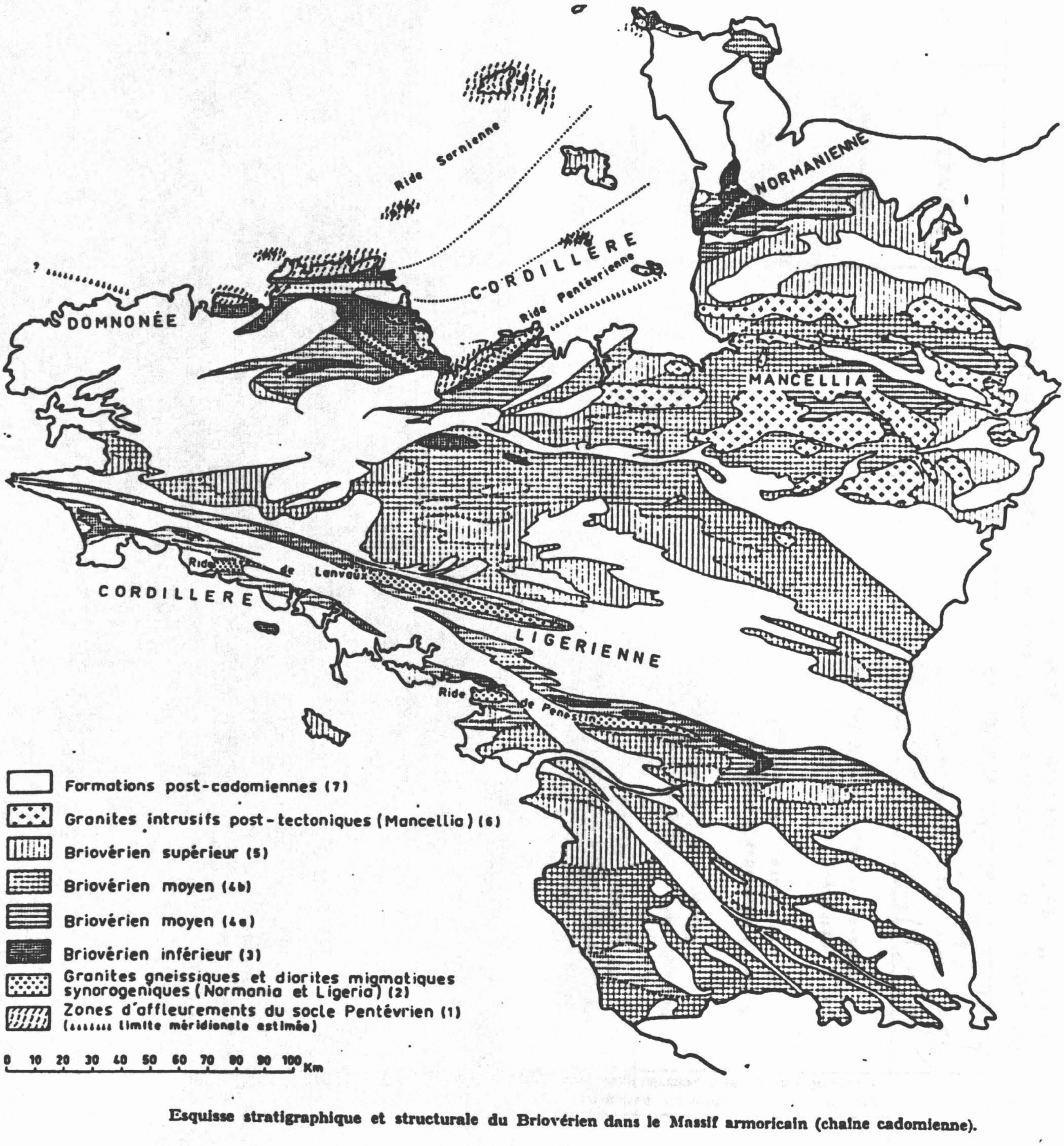
The Briovérien (anglicized to Brioverian) is the name Barrois gave (1895a) to a thick sequence of dominantly clastic sediments which crop out over large areas of Brittany. There has been much argument as to the stratigraphy of this thick sequence, and the problems inherent in regional correlation of the Brioverian Supergroup (Roach 1972) have been outlined by Renouf (1974) and Roach (1977). This thesis is in part concerned with examining the stratigraphy of rocks assigned to the Brioverian along the east side of the Petit Trégor.

Early in the 19th Century Bunel (1829-1833) recognised in Calvados, north Normandy, a fossiliferous sequence (with a base character-ised by purple conglomerates) unconformably overlying a non-fossiliferous phyllitic-greywacke sequence. The two divisions were recognised else-where in the Massif by Dufrenoy (1838) and Dufrenoy and De Beaumont (1841). The lower division was termed the Schistes or Phyllades de St. Lô from the type area in Normandy. In western Brittany the Phyllades de Douarnenez were correlated with these. Barrois (1886) assigned these phyllitic rocks to the Cambrian whilst Hébert (1886) considered them to be Precambrian; later Barrois (1888b) described them as 'Infracambrien'.

Barrois (1895a) introduced the term Briovérien to refer to the Phyllades de St. Lô and divided these rocks into three lithostratigraphic units, the Lower, Middle and Upper Brioverian. Their relative ages remained a controversial problem, although Kerforne described an angular unconformity between the Brioverian and a purple conglomerate and sand-stone sequence of possible Cambrian age as early as 1901. Barrois (1934) while considering the Lower Brioverian (Xa on maps) to be Precambrian in age still assigned the Middle and Upper Brioverian (Xb and Xc respectively) to the Lower and Middle Cambrian.

In an effort to clarify a confused nomenclature, Pruvost (1949) used the term Brioverian to apply exclusively to rocks hitherto termed the Lower Brioverian. The Precambrian age of the Brioverian, however, was more firmly established by Chauris et al. (1956) and Chauris (1956) in Le Bocage, Lower Normandy, where it was shown that granites intruded into the Upper Brioverian were overlain unconformably by fossiliferous Middle Cambrian sediments. Graindor (1957) compiled a stratigraphy for the northeast sector of the Massif Armoricain and developed the concept of both an early, post-Middle Brioverian/pre-Upper Brioverian phase of Cadomian earth movement and a post-Upper Brioverian Main Cadomian orogenic phase. Cogné (1962) modified and extended Graindor's Brioverian stratigraphy over the whole of the Massif Armoricain and incorporated Graindor's concept of two phases of Cadomian tectonism (Figs. 1:4 and 1:5). Cogné (1972, 1974, 1976b) adapted these concepts to accord with isotopic age determinations so that the Cadomian Phase I occurred at 640 m.y. and Cadomian Phase II at 590 m.y. (Fig. 1:6).

Radiometric dating of whole-rocks and minerals largely in the northeast sector of the Massif Armoricain has helped to established the timing and duration of the Brioverian volcanism and sedimentation. Leutwein (1968) constructed a chronology for Brioverian sedimentation which lasted from c. 750 m.y. to c. 650 m.y. Roach et al. (1972) and Bishop et al. (1975), however, suggested that the sedimentation occurred sometime between 900 m.y. and 750/650 m.y. although Roach (pers. comm.) now states that the evidence upon which this time interval was based is thought to be untenable. As has already been stated with reference to the age of the Pentevrian basement in the type area along the southeast side of the Baie de St. Brieuc, it is possible that the Brioverian sediments and basic volcanics in this area may have been deposited upon a late Precambrian Pentevrian basement less than 630 m.y. ago.



Esquisse stratigraphique et structurale du Briovérien dans le Massif armoricain (chaîne cadomienne).

Fig. 1:4 Distribution of Brioverian lithologies in the Massif Armorican (Cogné 1962)

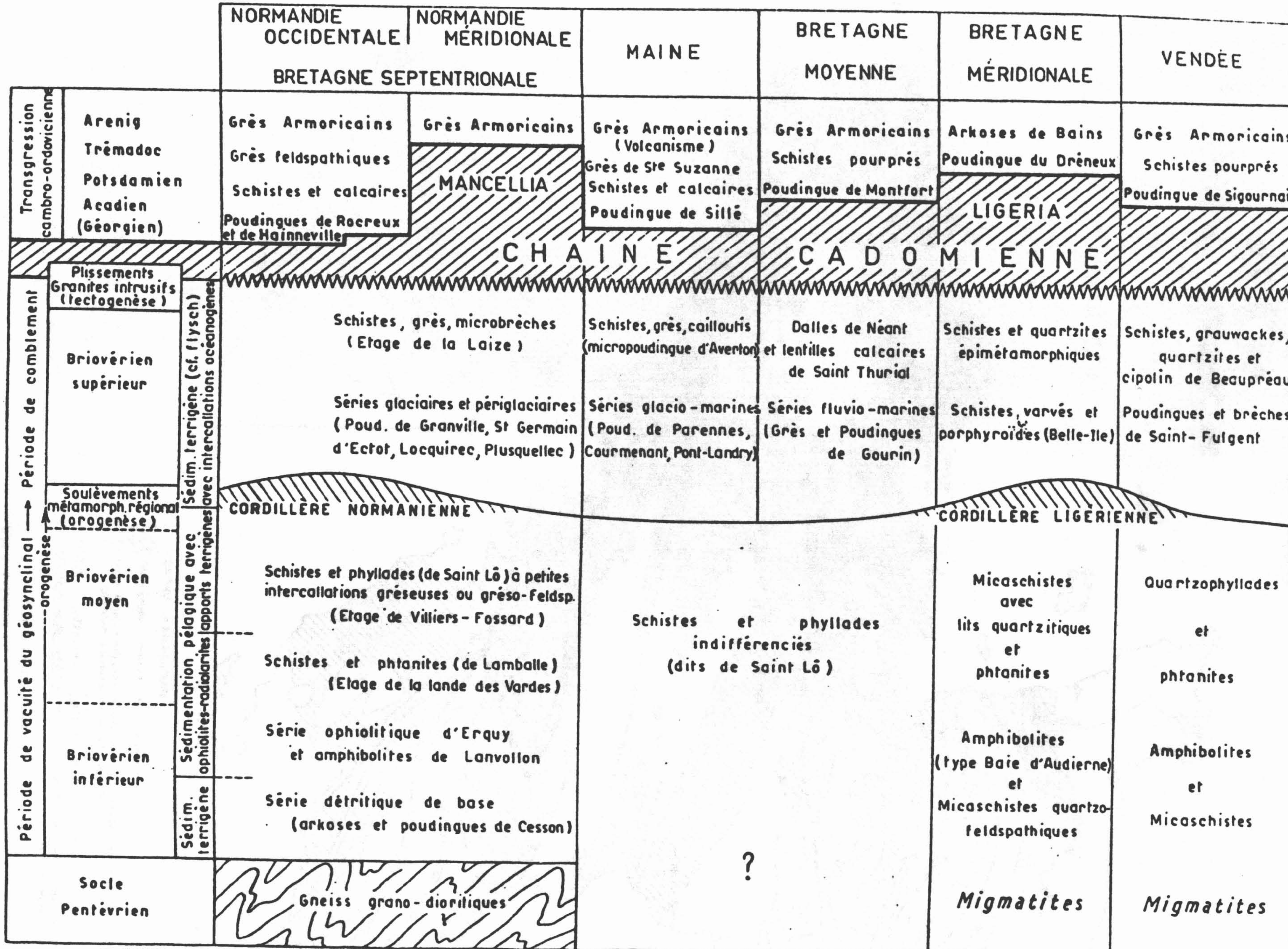
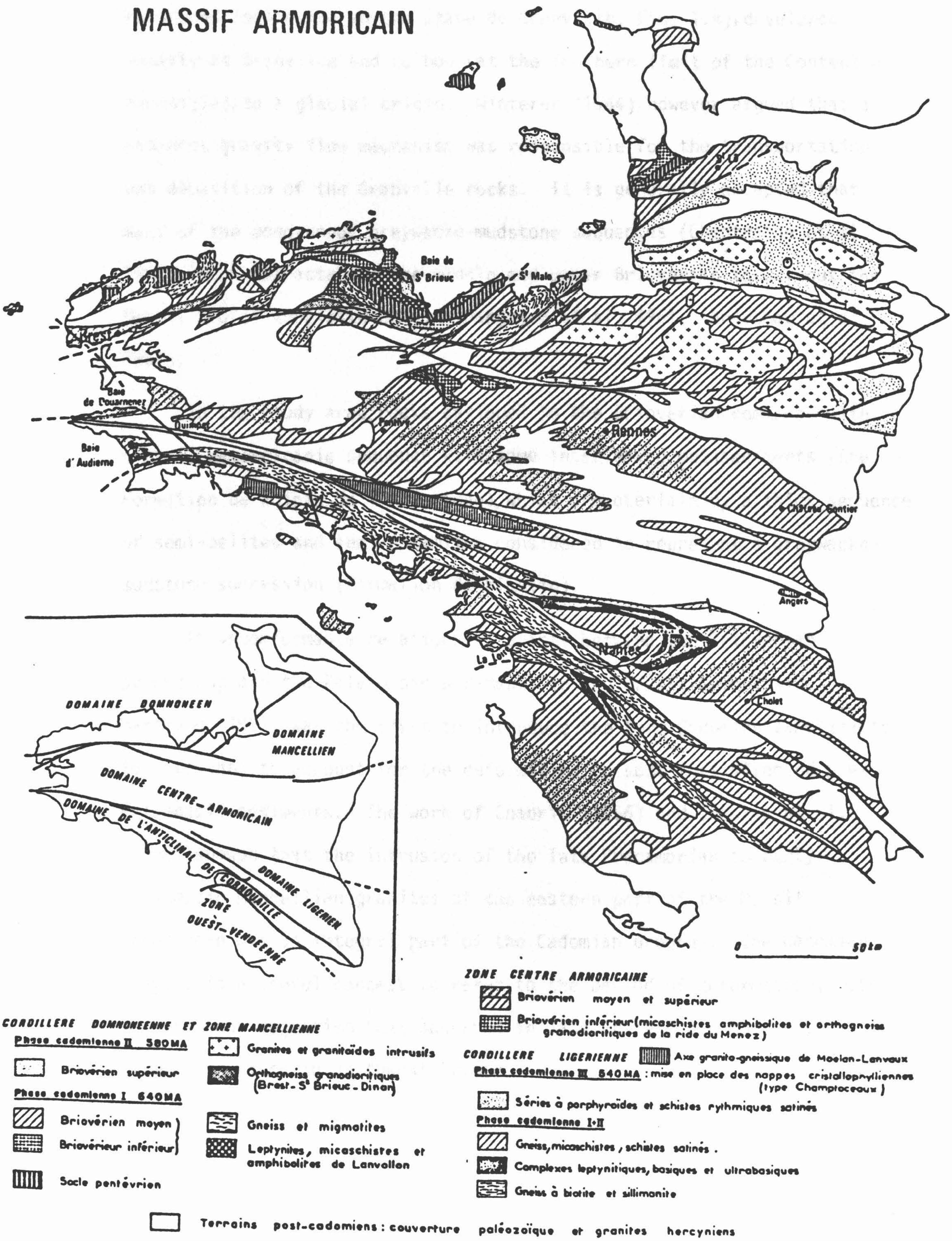


Fig. 1:5 Brioverian Stratigraphy and Cadomian orogenic episodes in the Massif Armorican (Cogné 1962)

LE BRIOVERIEN ET LE CYCLE OROGENIQUE CADOMIEN DANS LE MASSIF ARMORICAIN

Fig. 1:6



Graindor (1954) attributed the lowermost Upper Brioverian pebbly mudstones (belonging to the Étage de Granville, Fig. 1:4), developed locally at Granville and Quibou (at the southern limit of the Contentin Peninsula), to a glacial origin. Winterer (1964) however argued that a sediment gravity flow mechanism was responsible for the transportation and deposition of the Granville rocks. It is generally accepted that many of the monotonous greywacke-mudstone sequences (Chantraine et al. 1982) which characterise the middle and upper Brioverian throughout the Massif are of turbidite origin (Dangeard et al. 1961; Bradshaw et al. 1967).

In the study area, rocks assigned to the Brioverian commence with a basic metavolcanic sequence with some interleaved metasediments (the Formation de Pointe de l'Armorique), which are overlain by a thick sequence of semi-pelites and semi-psammites considered to represent a greywacke-mudstone succession (Formation de Plestin).

An uncomformable relationship exists between the Brioverian Supergroup and the Palaeozoic sediments in the Massif Armoricain. Bertrand (1921) was the first to introduce the term Cadomien (anglicised to Cadomian) to account for the deformation episode that affected pre-Palaeozoic sediments. The work of Chauris (1956) and Chauris et al. (1956) showed that the intrusion of the late Precambrian to early Palaeozoic Mancellian granites of the eastern part of the Massif Armoricain was an integral part of the Cadomian orogeny. The Cadomian orogeny is a useful concept to refer to the period of deformation, metamorphism and magmatism that occurred in late Proterozoic to early Palaeozoic times in northwest France.

The Palaeozoic rocks of the Massif Armoricain are largely sediments with minor volcanic sequences (Chauvel et al. 1980). The Palaeozoic is most complete in the Laval Basin in the east of the Massif (Fig. 1:3) where a succession ranging from Cambrian to Westphalian in age, with some breaks, is almost 6 km thick. Generally, the Palaeozoic is much thinner in other areas (less than half of the Laval thickness), principally because of major breaks in the succession. Due to the late Cadomian earth movements (extending into Cambrian times) and Hercynian earth movements, the Cambrian and Carboniferous successions are more restricted in their geographical extent than those of early Ordovician to mid/late-Devonian age. The Cambrian generally has the character of a late to post-orogenic red-bed molasse, although shallow-marine clastic and carbonate sediments occur in the northeast of the Massif Armoricain (Doré 1969, 1972). Many of the local sequences lack fossils, and their precise stratigraphical position is uncertain.

The more extensive early Ordovician to mid/late Devonian successions of sandstones, shales and limestones were generally deposited under shallow marine conditions in a relatively stable epicontinental framework except possibly in southeast Brittany (Babin et al. 1968; Babin et al. 1972; Lardrieux et al. 1977; Chauvel et al. 1980). The Grès Armoricain reflects a major marine transgression in early Ordovician times and it oversteps the Cambrian to rest upon various Precambrian rocks (Bishop et al. 1967). Maximum extension of Palaeozoic sedimentation occurred during Llanvirn times, and the only major break recorded in the Ordovician to mid-Devonian succession is that at the Ordovician-Silurian boundary.

The increasing tectonic instability of the Massif Armoricain with the onset of the Hercynian orogeny is reflected in the development of Culm-type sandstone and shale deposition, with occasional limestone lenses, which fill relatively isolated basins in late Devonian and early Carboniferous times (Morzadec et al. 1975; Pelhate 1971; Poncet 1973; Riviere 1977). The early Hercynian Bretonic earth-movements are reflected in a discordance between upper Devonian or Lower Carboniferous and older rocks (Cogné 1974). Subsequent paralic sedimentation (with thin coals) was further interrupted as a result of mid-Carboniferous movements, and late Westphalian and Stephanian sediments are now restricted to several small, fault-bounded limnic basins filled with molasse deposits often containing thin coals (Mathieu 1937; Pelhate 1960; Dvorak et al. 1977). Possible Permian deposits are restricted to a red-bed sequence forming the Carentan Basin in the northeast of the Massif (Bigot and Pruvost 1925).

The broad outline of Palaeozoic stratigraphy for the Massif Armoricain is shown on Fig. 1:7, taken from Chauvel et al. (1980) and the effects of the several phases of Hercynian earth movement (according to the nomenclature of Stille 1951)(Fig. 1:8) in producing local unconformities within the Devonian-Carboniferous succession is shown on Fig. 1:9. This diagram highlights the care that should be taken in applying the concept of a widespread Bretonic event at the Devonian-Carboniferous boundary. Events are particularly hard to correlate in areas away from the Upper Palaeozoic basins.

The Palaeozoic successions now occupy several major synclines as a result of the Hercynian earth movements. The more important of these synclines (most of which are located on the sites of sedimentary basins) are shown on Fig. 1:3.

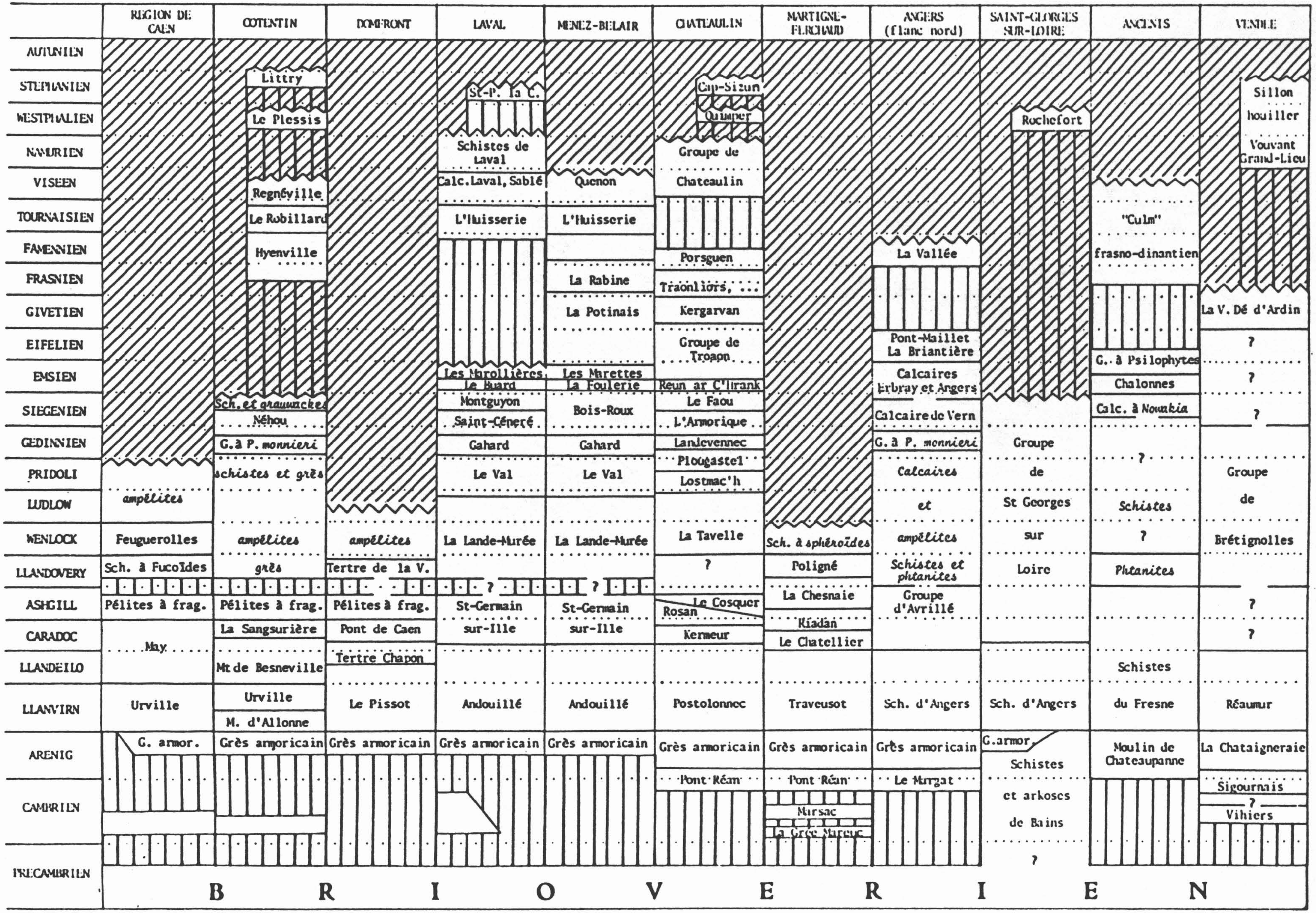
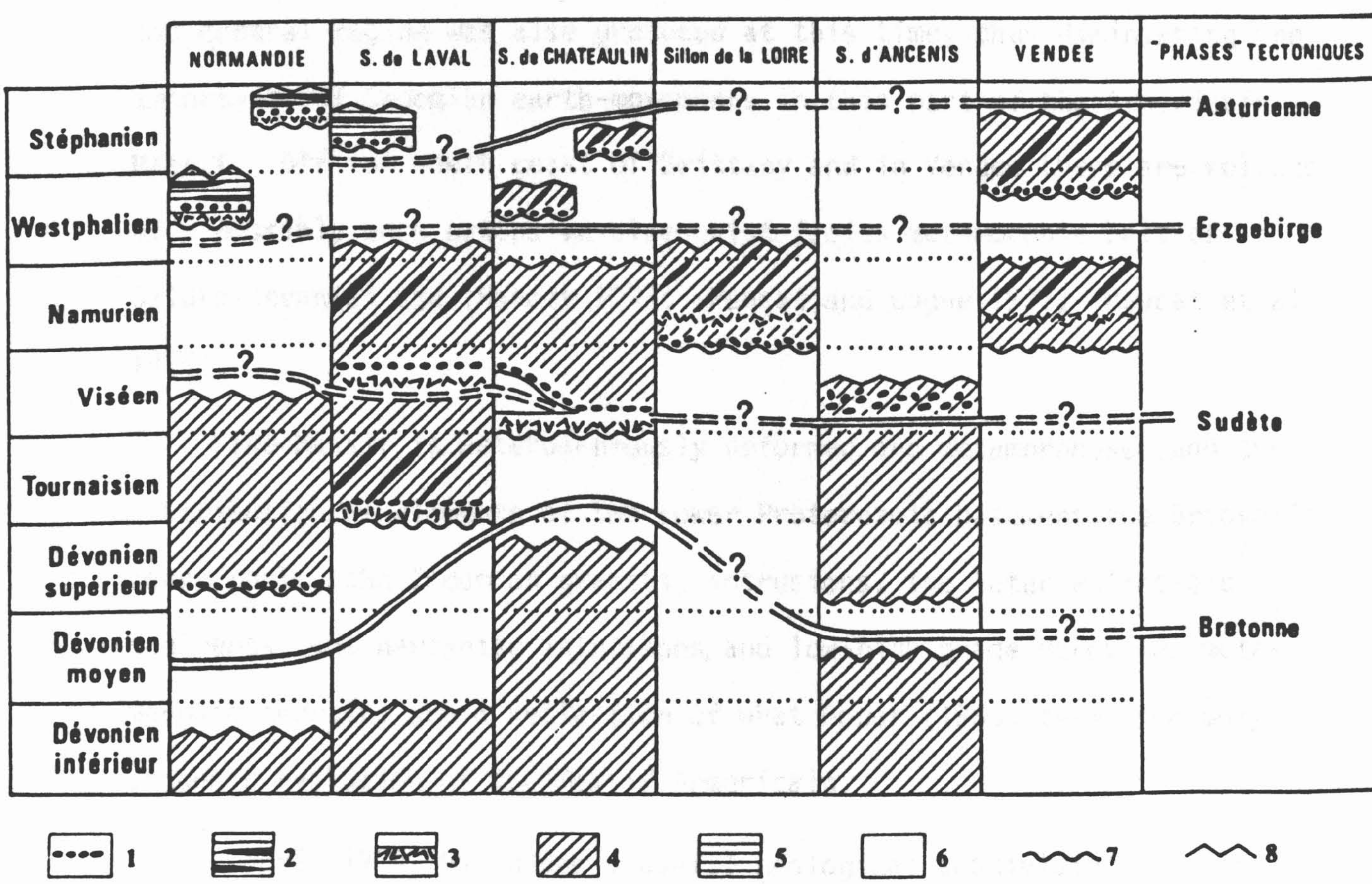


Fig. 1:7 Palaeozoic stratigraphy of the Massif Armorican (Chauvel et al. 1980) *Vertical lines: hiatuses; Oblique lines: erosion.*

Fig. 1:8 **STILLE'S TECTONIC PHASES OF THE HERCYNIAN CYCLE**

Phase	Date
Pfalzic	between Permian and Triassic
Saalic	Lower Permian
Asturic	uppermost Carboniferous (pre-Stephanian): the main phase in the foredeep
Erzgebirgic	Upper Carboniferous (pre-Westphalian)
Sudetic	between Lower and Upper Carboniferous: the main phase in the interior of the belt
Bretonic	between Devonian and Carboniferous

Fig. 1:9 Hercynian earth - Movements and breaks in the Devonian - Carboniferous succession (Chauvel et al. 1980)



Le Carbonifère et l'orogenèse varisque.

1: conglomérats; 2: niveaux de houille; 3: volcanites; 4: séries plissées; 5: séries non plissées; 6: lacunes; 7: discordance de base; 8: surface d'érosion.

Carboniferous sedimentation and volcanism and the variscan orogeny.

1: conglomerates; 2: coal measures; 3: volcanites; 4: folded series; 5: unfolded series; 6: Stratigraphical gaps; 7: basal unconformity; 8: erosion surface.

Hercynian regional metamorphism is at low grade or very-low grade in these synclines and in adjacent Brioverian rocks. There are, however, two major belts of medium to high grade Hercynian metamorphism and migmatization, one in southern Brittany (Cogné 1960) and the other in northwest Finistere (Roper 1980). Numerous Hercynian granites were emplaced into both the medium-high grade metamorphic belts and the Palaeozoic synclines (and the surrounding Brioverian formations) particularly in south and west Brittany and the Vendeé. Recently, Hanmer et al. (1982) have proposed that in central Brittany the main synmetamorphic Hercynian deformation structures are directly related to the emplacement of the Hercynian leucogranites, and follow Le Corre (1977) in maintaining that the main cleavage present in the Brioverian rocks of the central region was also produced at this time, thus diminishing the importance of Cadomian earth-movements in this part of the Armoricain Massif. Off the south coast of Brittany and in Vendeé there are relicts of a possibly once extensive blueschist facies metamorphic belt of Siluro-Devonian age (Hanmer 1977; Peucat and Cogné 1977; Peucat et al. 1978).

The Massif is heterogeneously deformed and metamorphosed, and the distribution of elements of the Lower Proterozoic basement, the Brioverian cover rocks, the Cadomian granitic intrusions, the later Palaeozoic sediments, the Hercynian intrusions, and low-high grade Hercynian metamorphic terrains are a reflection of what Roper (1980) terms the poly-orogenic evolution of the Massif Armoricain.

Cogné (1974) has given a useful geological subdivision for the Massif Armoricain as shown in Fig. 1:3. Cogné classifies the Massif in terms of domains based on the different degrees of deformation, metamorphism and plutonic activity during the orogenic cycles. Each domain is therefore envisaged as having a distinct geological history.

In the northern part of the Massif Armoricain, Cogné recognises two domains:

1. The Domaine Mancellien; a zone in which Upper Proterozoic rocks (the Brioverian) are intruded by late Precambrian/Lower Palaeozoic granitic bodies (i.e. associated with the Cadomian orogeny), which are in turn unconformably overlain by sedimentary rocks of Lower Palaeozoic age.

2. The Domaine Domnonéen; this zone is composed of sedimentary, metamorphic and igneous rocks that range in age from the Lower Proterozoic to Upper Palaeozoic. The lithologies are deformed and metamorphosed to varying degrees. The study area of the thesis lies within this domain.

Cogné (op. cit.) has termed the central part of the Massif Armoricain the Domaine Centre-Armoricain. It is characterised by the presence of Upper Proterozoic sediments overlain unconformably by Palaeozoic sequences. The rocks are of a low metamorphic grade and are intruded by many large granite plutons emplaced during the Hercynian orogeny.

The southern part of the Massif Armoricain is geologically complicated and here Cogné recognised three further domains:

1. The Domain Ligerien;

2. The Domaine de L'Anticlinal de Cournouaille-

3. The zone ouest Vendéene (Fig. 1:3). In these southern-most domains the effects of Hercynian orogeny have led to the widespread development of migmatites, high grade metamorphic assemblages and extensive granite plutonism. Structures possess a strong WNW-ESE Hercynian trend.

More recent workers have attached great importance to two major tectonic lineaments which occur in north and south Brittany. The easterly trending North Armoricain Shear Zone (NASZ) separates the Domaine Domnonéen from the Domaine Centre-Armoricain. This was first recognised by Chauris (1969). The WNW-ESE trending South Armoricain Shear Zone (SASZ or Zone Broyée sud-Armoricain) separates the Domaine Centre-Armoricain from the southern-most domains (Jegouzo 1980).

Cogné 's concept of domains provides a useful framework for the Armoricain Massif in that it provides some information as to the nature of the distribution of the different lithological units and the effects of the Cadomian and Hercynian orogenies.

(C) PREVIOUS GEOLOGICAL RESEARCH IN THE STUDY AREA

In part (B) of this chapter the development of certain concepts used to interpret the geology of the Massif Armoricain was examined. In this section the history of geological research in the immediate area of study is discussed briefly. Three distinct geological regions are recognised, (i) the eastern sector of the Pays de Léon (here formed mainly of the St. Pol-de-Léon Metamorphic Complex), (ii) the Morlaix Basin and (iii) the Petit Trégor. Previous literature has generally concentrated on studies within the individual areas.

In order to clarify a confused nomenclature that has arisen in the three regions recognised,a history of research is considered at the beginning of each appropriate chapter. However, in order to give an overall view of the study area and to familiarize the reader with the fundamental lithological names and place-names,a brief summary of the previous geological research in the whole of the study area is given here.

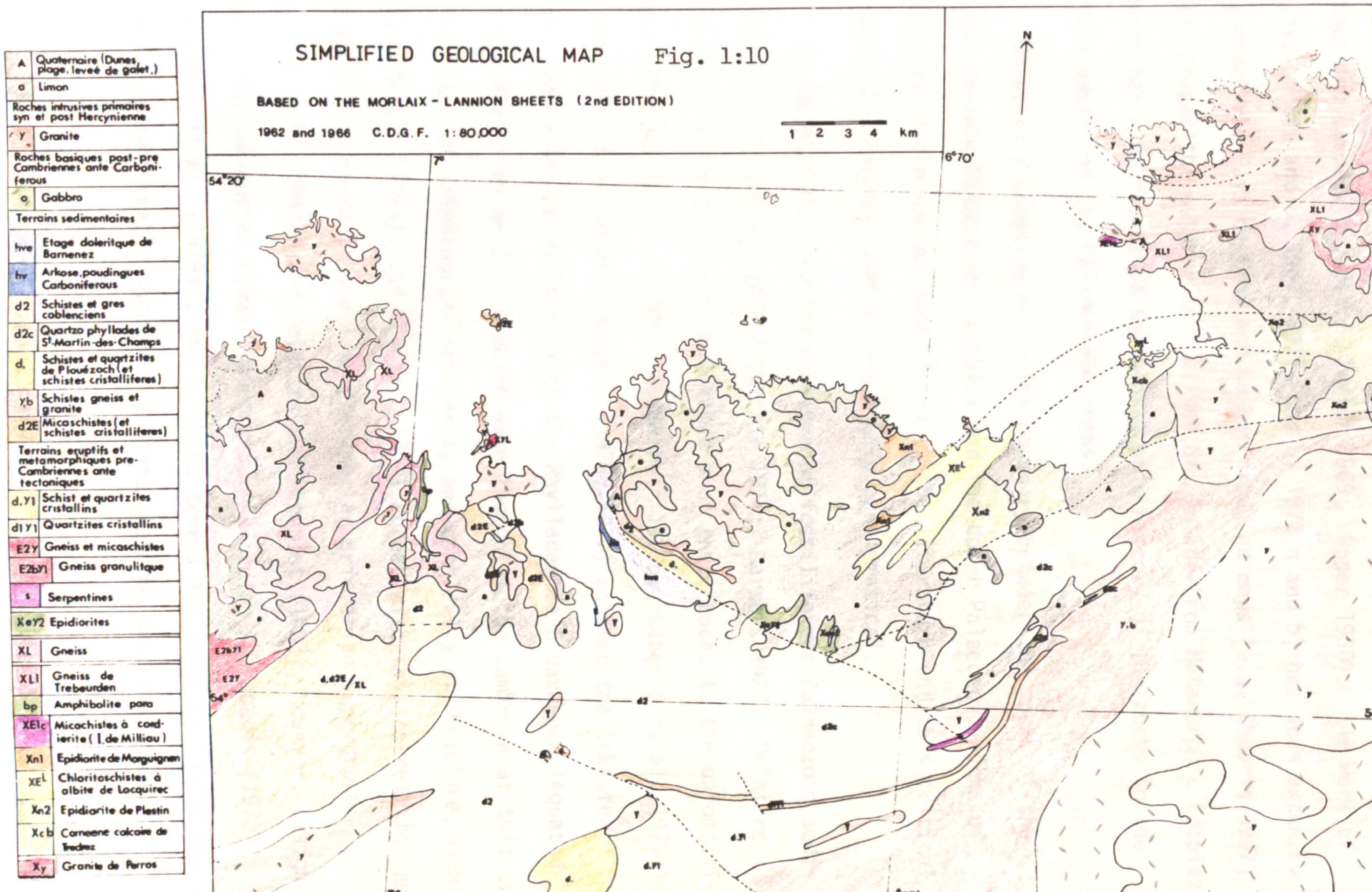
The following geological maps of the study area have been published or are in the course of publication:-

Sheet	Scale	1st Edition	2nd Edition
MORLAIX	1:80,000	Barrois (1905a)	Pruvost et al. (1962)
LANNION	1:80,000	Barrois (1909)	Delattre et al. (1966)
BREST-LORIENT	1:320,000	Pruvost et al. (1943)	Kerrien et al. (1970).
MORLAIX	1:50,000	Cabanis et al. (1981)	
PLESTIN-LES-GRÈVES	1:50,000	In press	

Figure 1:10 is a compilation of the main geological units as represented on the 2nd edition of the Morlaix and Lannion 1:80,000 sheets.

Barrois' early geological mapping of northern and western Brittany was excellent and,although many of the rock units have been re-interpreted as to their age and origin, his recognition of different lithological units has remained largely valid (eg. Barrois 1888a, 1908c, 1909).

The eastern sector of the Pays de Léon has received relatively little attention in the literature,and most publications have been concerned with more localized areas or individual lithologies within the western sector of the Pays de Léon, e.g. Berthois (1954), De Lapparent (1934), Michot and Lavreau (1965). Discussion as to the origin of the


SIMPLIFIED GEOLOGICAL MAP Fig. 1:10
BASED ON THE MORLAIX - LANNION SHEETS (2nd EDITION)
1962 and 1966 C.D.G.F. 1: 80,000
1 2 3 4 km
N
7°
6°70'
54°20'
54°
A Quaternaire (Dunes, plage, leveé de galet.)
a Limon
Roches intrusives primaires syn et post Hercynienne
Y Granite
Roches basiques post-pre Cambriennes ante Carboniferous
o Gabbro
Terrains sedimentaires
hve Etage doleritque de Barnenez
hv Arkose, poudingues Carboniferous
d2 Schistes et gres coblenciens
d2c Quartzo phyllades de St-Martin-des-Champs
d. Schistes et quartzites de Plouézoch (et schistes cristallifères)
Yb Schistes gneiss et granite
d2E Micaschistes (et schistes cristallifères)
Terrains eruptifs et metamorphiques pre-Cambriennes ante tectoniques
d.Y1 Schist et quartzites cristallins
d1Y1 Quartzites cristallins
E2Y Gneiss et micaschistes
E2bY1 Gneiss granulitque
s Serpentines
XeY2 Epidiorites
XL Gneiss
XL1 Gneiss de Trebeurden
bp Amphibolite para
XE1c Micachistes à cordierite (I. de Milliau)
Xn1 Epidiorite de Morguignon
XE1 Chloritoschistes à albite de Locquirec
Xn2 Epidiorite de Plestin
Xcb Corneene calcaire de Tredrez
Xy Granite de Perros

of the extensive lithology known as the Gneiss de Brest and its relationship to the metasedimentary Quartzophyllades de l'Élorn (correlated with the Phyllades de St. Lô, Barrois 1886) is of fundamental importance (Michot and Lavreau op. cit.; Taylor 1969; Roper 1980). The work of Chauris (1965a and b, 1967, 1971a and b, 1972 a and b) has been extensive throughout the Pays de Léon and he has produced maps (e.g. Chauris 1967) which include the outcrop area of the St. Pol-de-Léon Metamorphic Complex. Chauris has also discussed the metamorphic history of the rocks in the Morlaix Basin and St. Pol-de-Léon areas.

Detailed discussion as to the boundary between the rocks of the St. Pol-de-Léon Metamorphic Complex and the Upper Palaeozoic rocks of the Morlaix Basin has not been found in the literature and this critical boundary has remained unknown and highly problematical.

In the Morlaix area the presence of fossiliferous Palaeozoic sediments has long been recognized (Le Hir 1871; Barrois 1927; Delattre 1949, 1952a and b), but the relationship of these rocks to the unfossiliferous Schistes Zébrés de Morlaix (Barrois 1905b; Cabanis et al. 1979a) has remained in question. Barrois (1876, 1877) equated the Schistes Zébrés (Phyllades de Morlaix) with the Phyllades de Douarnenez (equated with the Phyllades de St. Lô which were thought to be Cambrian at this time). On the basis of lithological similarity and complexity of structure, Bradshaw (1963), Renouf (1965), and Chauris (1967) agreed with this correlation and assigned these rocks to the late Precambrian Brioverian Supergroup. Delattre (1949, 1952a) and Delattre and Waterlot (1957), however, assigned them to the Coblencian (Lower Devonian). According to Cabanis (1972) and Cabanis et al. (1979a), the Schistes Zébrés are Lower Carboniferous in age as they conformably succeed and share the same deformational history as the Poudingue de Dourduff (dated as Lower Carboniferous by Barrois 1927; Milon 1928; and Strunian, i.e. latest Devonian-earliest Carboniferous by Coquel and Deunff 1977) (Fig. 1:11).

Adjoining the Morlaix Basin is an area known as the Petit Trégor. This region is dominated by a basic igneous complex, the de St. Jean-du-Doigt Gabbro Complex, whose age is considered Hercynian (Cabanis et al. op. cit.; Autran et al. 1979). Barrois (1908c) and Sandrea (1958) considered this complex pre-Carboniferous in age.

In the area of Moulin de la Rive and Locquirec, in the Petit Trégor, (Map 2) a basement complex has been recognised (Barrois 1908c, 1909; Sandrea 1958; Verdier 1968; Autran et al., 1979; Auvray 1979; Auvray et al. 1980a). According to Verdier (op. cit.), Auvray (op. cit.), and Autran et a,. (op. cit.), the basement complex (Moulin de la Rive Orthogneiss Complex, sensu this thesis) is overlain by a basal Brioverian sequence of acid volcanic tuffs and volcaniclastics, known as the Schistes or Series de Locquirec, which crop out in the Locquirec-Pte. de Séhar areas. This sequence is in turn said to be overlain (Autran et al. op. cit.) by a thick sequence of basic volcanic rocks (Formation de Pte. de l'Armorique, of this thesis) which pass gradationally upwards into a thick metasedimentary group (Formation de Plestin, of this thesis) which they have attributed to the Upper Brioverian.

Along the south and east sides of the Grève de St. Michel is a sequence of massive quartzites which were originally assigned to the Lower Ordovician by Barrois (1908c), then to the Lower Devonian by Delattre et al. (1966), and more recently to the Arenig (Verdier 1968; Auvray 1979).

The Hercynian granites that occur within the area have been examined in terms of mineralization by Chauris (1975) and geochronological work has been carried out by Adams (1967) and Leutwein et al. (1969)

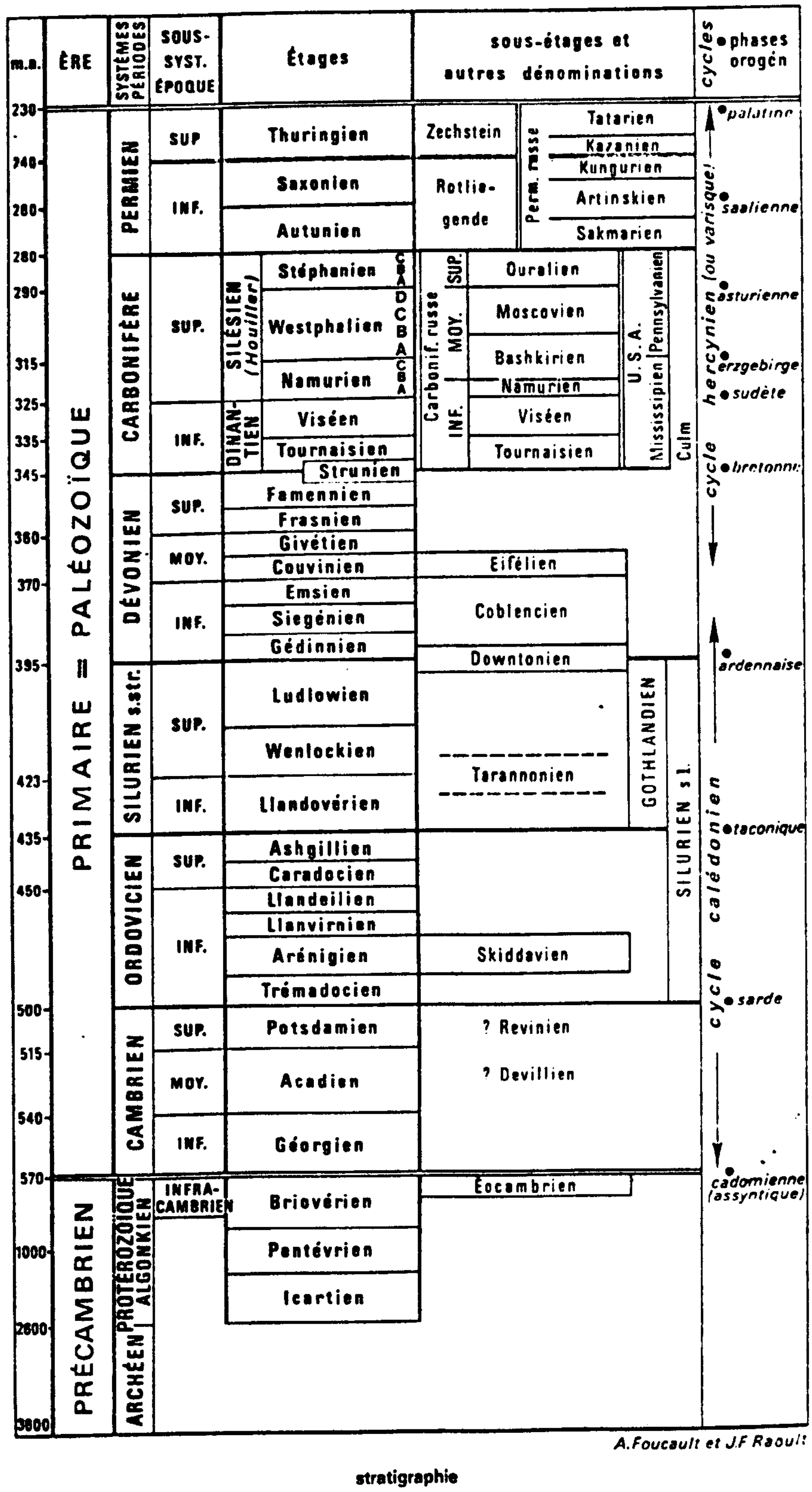


Fig. 1.11 Stratigraphical column ; Precambrian - Palaeozoic (Foucault and Raoult 1980)

on some of the later granite bodies.

A more detailed history of geological research is given in the appropriate chapters as follows:-

<u>CHAPTER 2</u> : The St. Pol-de-Léon Metamorphic Complex. As previous work in this area has been somewhat limited, the Pays de Léon as a whole has been examined.

<u>CHAPTERS 3, 4 and 5</u> : The Petit Trégor. The rocks that make up this area are examined in three chapters.

<u>CHAPTER 6</u> : The Morlaix Basin. The paleontological and structural evidence used to date the formations in this area is considered.

(D) AIMS AND SCOPE OF RESEARCH

Detailed mapping on the scale of 1:5,000 and 1:10,000 (coastal exposure) and 1:25,000 (inland) was undertaken within the defined area between Morlaix and St. Michel-en-Grève. The object of the research was principally to establish the structure and stratigraphy of this region and to establish metamorphic conditions. In doing this the following areas and lithologies were examined:-

1. The St. Pol-de-Lèon Metamorphic Complex which constitutes the eastern part of the Pays de Léon, hitherto a poorly documented area.
2. The nature of the contact between the St. Pol-de-Léon Metamorphic Complex and rocks that occur within the Morlaix Basin.
3. The structure and stratigraphy of rocks within the Morlaix Basin.

4. The nature of the contact between the Morlaix Basin and the rocks that lie within the area known as the Petit Trégor, principally the Brioverian metasedimentary rocks and the St. Jean-du-Doigt Gabbro Complex.

5. The Moulin de la Rive Orthogneiss Complex of the Petit Trégor. This complex has been described as sôcle (basement) in the French literature and was studied in order to establish its relative age and relationship to adjacent lithological units.

6. The structure and stratigraphy of a thick sequence of metavolcanic and sedimentary rocks assigned to the Brioverian Supergroup, including the basal acid tuff and volcaniclastic sequence in the Locquirec and St. Michel-en-Grève areas.

7. The Hercynian granites that occur throughout the area.

The thesis is also aimed at linking the recent work of Auvray (1979) in the Trégor and Roper (1980) in the western part of the Pays de Léon, in order to gain a regional understanding of the geological evolution of northern Brittany.

(E) MAPPING PROCEDURE, RESEARCH TECHNIQUES AND NOMENCLATURE OF LITHOLOGICAL UNITS

Fieldwork was carried out during the summer of 1980 and Easter and summer of 1981 with short visits in 1979 and 1982. Field-mapping required the use of differently scaled maps that reflected the amount of rock exposure. Coastal areas were mapped using photographic enlargements of marine charts published by the Service Hydrographique et Oceanique de la Marine - Paris (S.H.O.M.A.) 1947, at an original scale of 1:20,000, together with air photographs (Royal Air Force 1944). Where possible,Institute Geographique Nationale (I.G.N.) topographic maps, scale 1:25,000 were used,but their coastal representation was found to be poor. Final base maps used for coastal sections were therefore enlarged overlays of the map, chart, or aerial photograph considered to be the most accurate for a particular outcrop or section.

Inland the 1:25,000 I.G.N. maps could be satisfactorily used, together with photographically enlarged (1:10,000) copies for detailed sections, e.g. river valleys.

The following I.G.N. 1:25,000 maps published in 1974 were used and fully cover the study area defined:-

AREA	SHEETS
St. Pol-de-Léon	1-2, 3-4, 5-6, 7-8
Plestin-les-Grèves	1-2, 3-4, 5-6, 7-8
Morlaix	1-2, 3-4
Lannion	1-2, 3-4

N.B. Grid references cited use the kilometric grid of the 1:25,000 maps, the first figure used in the latitudinal scale is ignored, so that, e.g. 1123 becomes 123 and defines a kilometre square. The addition of the final figure, e.g. 1236 gives the locality to the nearest 100 m.

The field-mapping was supplemented by laboratory studies. Some 450 thin-sections were examined and 45 samples were chemically analysed using 'wet' and X-ray fluorescence (X.R.F.) methods. Appendix A gives details of preparation methods of the analysed samples.

Wherever possible, the nomenclature used on the Lannion sheet (2nd edition 1966) compiled by Delattre et al. and the Morlaix sheet (2nd edition 1962) Pruvost et al. has been maintained. However, in those instances where a different interpretation is put upon certain rock units a new nomenclature has been used. Details of such changes in nomenclature are given in the appropriate chapters.

CHAPTER TWO

THE ST. POL-DE-LÉON METAMORPHIC COMPLEX

CHAPTER TWO

THE ST. POL-DE-LÉON METAMORPHIC COMPLEX

(A) INTRODUCTION

(1) DEFINITION OF THE ST. POL-DE-LÉON METAMORPHIC COMPLEX

The St. Pol-de-Léon Metamorphic Complex is here recognised as being a medium to high grade metamorphic complex that is truncated by a large number of Hercynian granites (Chauris 1967; Barriere et al. 1982) and which, in north Finistère, forms the eastern part of the region known as the Pays de Léon. The structural and metamorphic history of the complex can be demonstrated to be distinct from that of neighbouring areas where rocks of lower metamorphic grade occur.

(2) LOCATION OF THE COMPLEX

The St. Pol-de-Léon Metamorphic Complex is bounded to the north by La Manche (English Channel), to the south and southeast by a major belt of high strain, here called the Carantec Shear Belt, and to the west by a line drawn between Palud and Mespaul, Mespaul and Guiclan (9 km WSW of Morlaix), see Map 1. West of this line the complex extends towards Lesneven and continues as a unit that Roper (1980) has called the Lannilis Metamorphic Complex.

(3) RELATIONSHIP OF THE ST. POL-DE-LÉON METAMORPHIC COMPLEX TO SURROUNDING ROCK UNITS

The area known as the Pays de Léon has been shown (Chauris op. cit.; Roper op. cit.) to be composed of a variety of metasediments, orthogneisses and migmatites all of which have been extensively injected by granites of Hercynian age.

Two contrasting metamorphic complexes have been identified by Roper (op. cit.) in the NW Pays de Léon. These are separated by a major E-W trending tectonic feature called the Porspoder Lineament. To the north of this lineament the rocks are largely migmatites and anactectic granites. These form the Plouguernou Migmatite Complex. South of this lineament the rocks are essentially non-migmatitic schists, paragneisses and ortho-gneisses that form the Lannilis Metamorphic Complex. Comparisons are drawn later between the Lannilis and St. Pol-de-Léon Metamorphic Complexes.

The belt of WSW-ENE trending low-grade greywackes and mudstones lying immediately to the south of the medium to high-grade metamorphic complex of north Finistère, and which extends from Brest to Morlaix, has been the subject of much debate. On the 1:80,000 Brest and Morlaix sheets, Barrois (1902a, 1905a) labelled these rocks the Quartzophyllades de Morlaix, and assigned them to the Brioverian. In the second edition of the 1:80,000 Morlaix sheet, Pruvost et al. (1962) assigned them to the Lower Devonian. The second edition of the 1:320,000 Brest-Lorient sheet covering west Brittany (Kerrien et al. 1970) shows these rocks as Brioverian, as does the third edition of the 1:80,000 Brest sheet (Chauris et al. 1972), and the 1:50,000 Brest sheet (Chauris et al. 1980). However, the 1:50,000 Morlaix sheet (Cabanis et al. 1981) shows them as undifferentiated Brioverian and/or Siluro-Devonian. There is, however, general agreement to the south of this belt as to the presence of an extensive area of Devonian rocks forming the northern flank of the Chateaulin Basin.

In the Morlaix area low-grade Upper Palaeozoic metasedimentary rocks of the Morlaix Basin (Cabanis et al. 1979a) are in contact with the rocks of the St. Pol-de-Léon Metamorphic Complex. The nature of the boundary between these two terrains has largely been ignored in previous literature concerning this area. Along the west side of the Morlaix Estuary south from Carantec (Map 1), a band of mylonitic rocks can be demonstrated to separate these two tectono-metamorphic areas. It is considered that these mylonites were formed in a S-SW trending shear zone, movement along which has brought the relatively high-grade metamorphic rocks of the St. Pol-de-Léon area into juxtaposition with the low-grade dominantly metasedimentary rocks of the Morlaix Basin. This structural feature is here termed the Carantec Shear Belt (CSB) and it forms the eastern boundary of the St. Pol-de-Léon Metamorphic Complex.

(4) PREVIOUS GEOLOGICAL RESEARCH IN THE ST. POL-DE-LÉON METAMORPHIC COMPLEX AND THE PAYS-DE-LÉON.

In Chapter 1 an introduction ot the previous geological research on the complex was given, in this section a summary is given of previous research in the actual study area and the Pays de Léon as a whole.

Barrois (1893a and b, 1902a and b) was the first person to study the area on a regional basis. He suggested that the rocks of the Pays de Léon occurred within an 'anticlinal zone' and they were older than the fossiliferous Palaeozoic sediments that crop out over much of central Finistère. He was the first to publish a map which included the St. Pol-de-Léon Metamorphic Complex and the Pays de Léon west to the Îles d'Ouessant. Little attention was paid to the Pays de Léon for some considerable time until De Lapparent (1934) described the Micaschistes de Conquet and discussed the nature of some of the granites in the south and west of the area. Barrois (1900, 1902b), De Lapparent (op. cit.), Berthois (1954), Michot and Lavreau (1965), and Chauris and Michot (1965) all considered the extensive Gneiss de Brest to be a granitized equivalent of a sedimentary formation termed the Quartzophyllades de l'Elorn. There was disagreement as to whether the granitization event was Precambrian or Devono-Carboniferous in age.

Taylor (1969) described the structure, magmatism and metamorphism of the SW Pays de Léon and demonstrated that the Gneiss de Brest was intruded into the Quartzophyllades de l'Elorn. Taylor (op. cit.) envisaged two

successive Cadomian episodes of granodiorite intrusion to account for the Gneiss de Brest lithology he termed the Granodiorite des Renards.
To account for different structures within these Cadomian bodies, Taylor invoked a major metamorphic episode and deformation event, which occurred in the time interval between the emplacement of the two intrusions. Rb/Sr whole rock dating of the two granodiorites by Adams (1967, 1976) and in Bishop et al. (1975) enabled this deformation/metamorphic episode to be dated between c. 670-550 M.y.

Roper (1980) demonstrated that the Gneiss de Brest was the strongly foliated (moderate to high strain facies) equivalent of the Granodiorite des Renards. The importance of this observation in the evolution of the Pays de Léon will be discussed later.

In the NW Pays de Léon, Shelley (1964, 1966) and Chauris (1965a) described an important mylonite zone termed the Porspoder Lineament (Roper 1980). Chauris (1972) noted that in the southeastern Pays de Léon the main structural trend was WSW-ENE, this gradually changed to an approximate N-S trend in the St. Pol-de-Léon-Morlaix areas. Thus, in the study area, structures of the St. Pol-de-Léon Metamorphic Complex possess a different structural trend compared to that of the western Pays de Léon. Chauris (op. cit.) on the basis of lithological comparison described granodioritic orthogneiss in the St. Pol-de-Léon Metamorphic Complex as Gneiss de Brest.

Chauris also describes other features, for example, the Hercynian grainites and associated mineralization (Chauris 1975), and quartzite bodies that occur throughout the region (Chauris and Hallegouet 1973). The latter have also been encountered by the present author.

Delattre et al. (1951, 1966) briefly described a number of metamorphic and igneous lithologies within the St. Pol de Léon Metamorphic Complex in the Carantec to St. Pol areas including rocks here described as the Gneiss Granitique d'Île Callot and the now amphibolitized dykes within the gneiss.

Cabanis (1974, 1975) has discussed the Hercynian orogeny in northwest Brittany and has attached greater importance to this orogeny than previous workers. He has produced a metamorphic map of the St. Pol-de-Léon Metamorphic Complex which is discussed later. Cabanis et al. (1979b) have discussed the age of some orthogneiss bodies previously attributed by Barrois (1902b) and Chauris (1967) to the Precambrian. Cabanis et al. (op. cit.) attach an Hercynian age (c. 386 m.y. by Rb/Sr whole rock and U/Pb on zircons) to the Orthogneiss de Tréglonou and the Orthogneiss de Plounevez-Lochrist which lie in the central part of the Pays de Léon. These authors also point out that a separate tectono-metamorphic history exists for the Pays de Léon compared to that of the Trégor and St. Brieuc areas. These three areas have previously been considered within the same tectonic unit, the domaine Domnonéen of Cogné (1974), see Fig. 1:3.

The most detailed work to date in the Pays de Léon is that of Roper (1980) who mapped a large area in the western part of this region, includinland areas around Lesneven and Lannilis and the coastal region from Plouescat to Le Conquet. A comparison of Roper's conclusions with those of the present author is considered in part C (structure and metamorphism) and in Chapter 8.

(5) OUTLINE OF THE DEFORMATIONAL AND METAMORPHIC EVENTS AFFECTING THE ST. POL-DE-LÉON METAMORPHIC COMPLEX

Within the complex three major lithological groups are recognised that pre-date the emplacement of a basic dyke suite and the extensive Hercynian granites. These groups are:-

1. The Amphibolites de Pte. St. Jean; this group is composed of both massive and striped amphibolites. Their outcrop is limited to the northwest side of the Baie de Morlaix around Ile Inizan and Pte. St. Jean.

2. The Micaschistes de Penzé; this group is composed mainly of semi-pelites with interbanded semi-psammites and infrequent metaquartzites. The outcrop of this group is extensive throughout the complex.

3. The Gneiss Granitique d'Île Callot; a gneiss complex that crops out in the Carantec and Ile Callot areas.

The terms D1, F1, M1, S1, D2 etc. are used to denote a deformation episode (D), a fold phase (F), a metamorphic episode (M) and a schistosity or cleavage (S). A deformation episode may include folding with an associated cleavage/schistosity and be associated with a contemporaneous metamorphism.

Metamorphic facies that are given follow the classification of Turner (1981) and are used throughout this thesis, unless otherwise stated.

The Amphibolites de Pte. St. Jean and the Micaschistes de Penzé share a common deformational history. The Gneiss Granitique d'Île Callot is structurally simpler and is considered to post-date the early D1 episode. D1/M1 produced a well-developed segregation banding in the amphibolite and schist groups. The metamorphic grade during M1 has not been established, but is considered lower than upper-amphibolite facies. D2/M2 resulted in isoclinal folding of the S1 fabric, a gneissose banding in the granitic gneisses and metamorphism up to upper-amphibolite facies of components of the St. Pol-de-Léon Metamorphic Complex, including the basic dyke suite that truncates the granitic gneisses, but excluding the later Hercynian granites.

The D3/M3 episode produced upright folds with an associated well-developed S3 crenulation cleavage. Some retrogression is considered to have accompanied this episode. Later deformation episodes D4 and D5 resulted in the formation of more brittle structures principally kink-bands and small faults. The deformation and metamorphism of the St. Pol-de-Léon Metamorphic Complex is discussed in detail in part (C). Table 2:3 gives a summary of the events (p. 42).

(6) SUBMERGED BASEMENT AND OFFSHORE GEOLOGY ADJACENT TO THE ST. POL-DE-LÉON METAMORPHIC COMPLEX

Many islands and reefs lie offshore in the Morlaix Estuary and Roscoff areas. Pre-Mesozoic rocks crop out on the seafloor northwards under La Manche (English Channel) for between 7 and 13 km, until the Eocene unconformity is reached.

Most of the islands in this area are made up of resistant Hercynian granite,principally the Granite de Primel-Carantec and the Granite de Roscoff. An area of particular interest is the Plateau des Duons which lies 2 km east of Roscoff (Fig. 1:1). Delattre et al. (1966) have mapped the reef as 'micaschistes à chloritoid et staurotide' which they correlate with micaschistes that crop out onshore in the Carantec area of the St. Pol-de-Léon Metamorphic Complex. In association with these are meta-basic rocks mapped by Delattre et al. (op. cit.) as the Étage Doléritique de Barnenez of the Morlaix Basin. Auvray and Lefort (1972) point to their similarity with the Epidiorites de St. Jean-du-Doigt (the St. Jean -du-Doigt Gabbro Complex of this thesis, see Chapter 7).

Several large faults trending NE-SW are shown immediately north of the present study area by Auvray and Lefort (op. cit.).

(B) FIELD RELATIONSHIPS AND PETROGRAPHY OF THE ROCKS OF THE ST. POL DE LÉON METAMORPHIC COMPLEX

Three major rock units have been outlined that comprise the St. Pol-de-Leon Metamorphic Complex. Their field relationships and petrography are described here.

(1) THE AMPHIBOLITES DE PTE. ST. JEAN

(a) Introduction

A sequence of amphibolitic rocks occurs in the St. Pol-de-Léon Metamorphic Complex that are here called the Amphibolites de Pte. St. Jean (c.f. para-amphibolites of Delattre et al. 1966) (Fig. 1:10). Their outcrop is limited to the west of the Carantec Shear Belt (Map 1). This unit is well exposed at a number of localities around the northwest side of the Baie de Morlaix and along the banks of the Riviere de Penzé.

The amphibolites are variable in appearance and two major types are recognised which occur together, dark amphibolites and striped amphibolites:-

1. Dark amphibolites. These are made up almost entirely of dark hornblende aggregates (90-95% of the rock) which are poorly orientated. The dark amphibolites occur in association with the striped amphibolites as massive bands averaging 1.5 m thick, which are orientated parallel to the S1 foliation/striping in the surrounding striped amphibolite lithology. Thin, irregular leucocratic bands occur within the dark amphibolites but do not define a strong banding as seen in the striped amphibolites.

2. Striped amphibolites. These rocks possess a strong banding or striping that is due to the alteration on a millimetric - centimetric scale of dark, amphibole-rich and light, felsic (quartz and feldspar) bands. This rock is analagous with hornblende schist or hornblende gneiss. The degree of striping varies considerably, so that where felsic bands are infrequent the rocks are similar to the dark amphibolites. Where the proportion of felsic minerals is high, a pronounced striping occurs giving the rock a banded gneiss appearance (Fig. 2:1(b)).

The preferred orientation of hornblendes gives the rock a planar fabric and in finely striped varieties a well-developed linear fabric is commonly developed. Where the banding is less distinct a more granoblastic fabric is apparent. Large hornblende porphyroblasts commonly occur and are well-developed in the centrimetric banded striped amphibolites Fig. 2:1(a) and (b).

Fig. 2:1(a) Amphibolites de Pte. St. Jean, Pte. St. Jean

Large hornblende grain with enveloping small, prismatic hornblende, plagioclase (An_{40}) and quartz.

Scale: x16 XPL

(N.B. PPL = Plane polarized light, XPL = crossed polarized light)

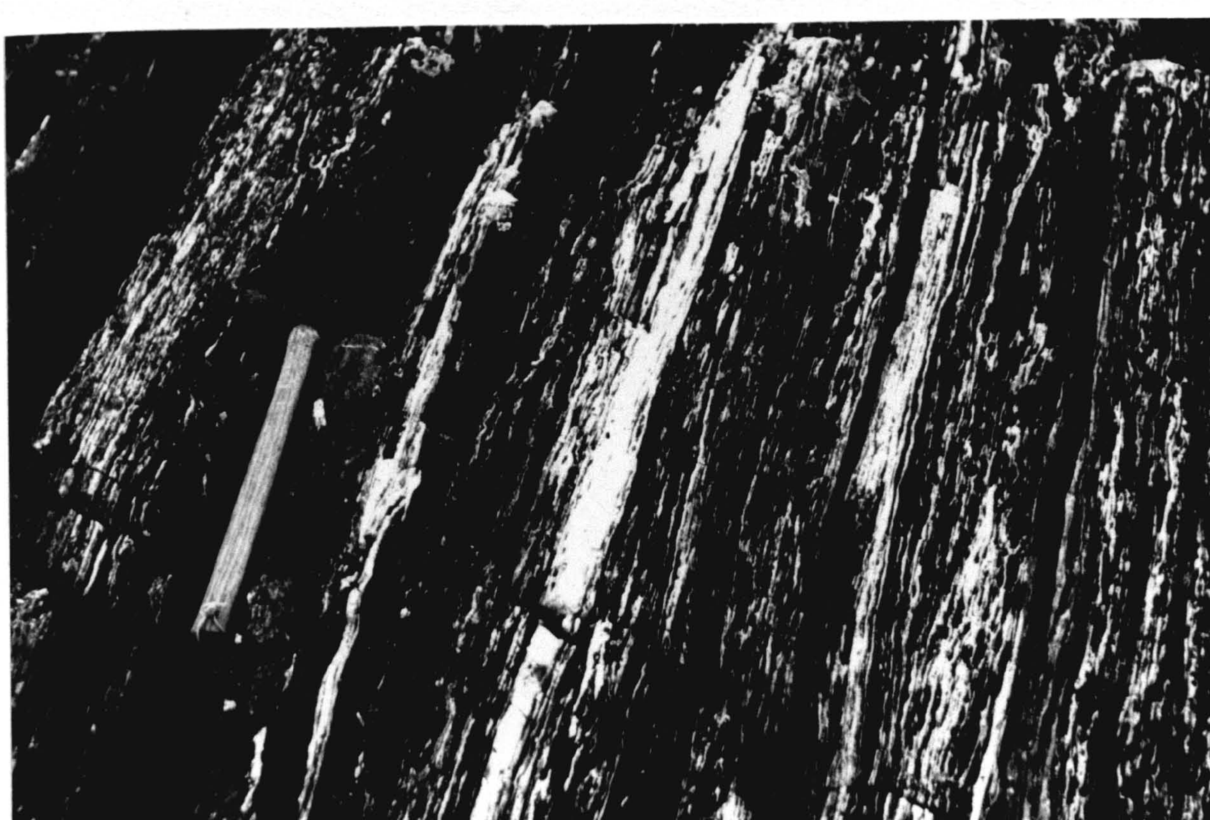
Also note:- the following abbreviations have been used in the figure captions and tables for the various mineral phases.

Qtz	Quartz	Andes	Andesine
Plag	Plagioclase	Labr	Laboradorite
K-felds	K-feldspar	Musc	Muscovite
Hnb	Hornblende	Chl	Chlorite
Cpx	Clinopyroxene	Pist	Pistacite
Epi	Epidote	Gnt	Garnet
Bio	Biotite	Cord	Cordierite
Alb	Albite	Sph	Sphene
Olig	Oligoclase	Chltd	Chloritoid

Fig. 2:1(b) Amphibolites de Pte. St. Jean, Pte. St. Jean

Typical appearance of the striped amphibolites. Hammer lies upon a zone where felsic-rich bands are infrequent to give a rock similar to the thicker bands of dark amphibolite. The porphyroblastic nature of some of the amphibole is seen on the right of the photograph.

Scale: Hammer handle 36 cm



Hornblende porphyroblasts frequently occur within the striped amphibolites. Here they are subhedral and sometimes poikioblastic (Figs. 2:1(b) and 2.3). Euhedral and smaller sub-grains of hornblende occur and the alignment of these smaller grains defines the schistosity which is parallel to the banding. Hornblende makes up some 40-50% of the rock, with the small grains displaying strong pleochroic absorption compared to the larger poikioblastic variety. The more felsic bands are made up principally of plagioclase and quartz. Plagioclase (An_{46}) forms between 15 and 20% of the rock and occurs in two modes, as aggregates, and as individual grains, which may be in part overgrown by quartz and/or clinopyroxene (Fig. 2:4). The plagioclase is commonly zoned and is somewhat more sodic than in the dark amphibolites. Quartz forms some 30-40% of the rock, occurring as small grains (c. 0.5 mm) with a granoblastic form.

Clinopyroxene (augite?) occurs in the striped amphibolites at certain localities (largely to the north of the general outcrop area) but it has not been recognised in the massive varieties. It occurs as small granoblastic, polygonal crystals, usually but not always restricted to the felsic bands. Fig. 2:4 shows the relationship of the pyroxene to the amphibole. Epidote occurs in significant amounts and appears to overgrow the prominent D1/S1 banding in patchy, columnar aggregates. It is also associated with the hornblende porphyroblasts. Sphene is present as an accessory mineral and magnetite occurs in varying amounts. Fig. 2:5 shows folded striped amphibolites with well-developed magnetite.

The metamorphic segregation processes that have resulted in the banding or striping of the Amphibolites de Pte. St. Jean are discussed in the section dealing with the D1/M1 episode, part (C)

Fig. 2:2 Amphibolites de Pte. St. Jean, Pte. St. Jean

Pegmatite band in which plagioclase (An_{40}) is dominant in association with large hornblende grains which may show recrystallization around grain boundaries.

Scale: x16 XPL

Fig. 2:3 Amphibolites de Pte. St. Jean, Île Inizan

Large twinned hornblende grain showing the development of amphibole sub-grains at the grain edges. Quartz is prominent in the matrix in this striped variety.

Scale: x16 XPL

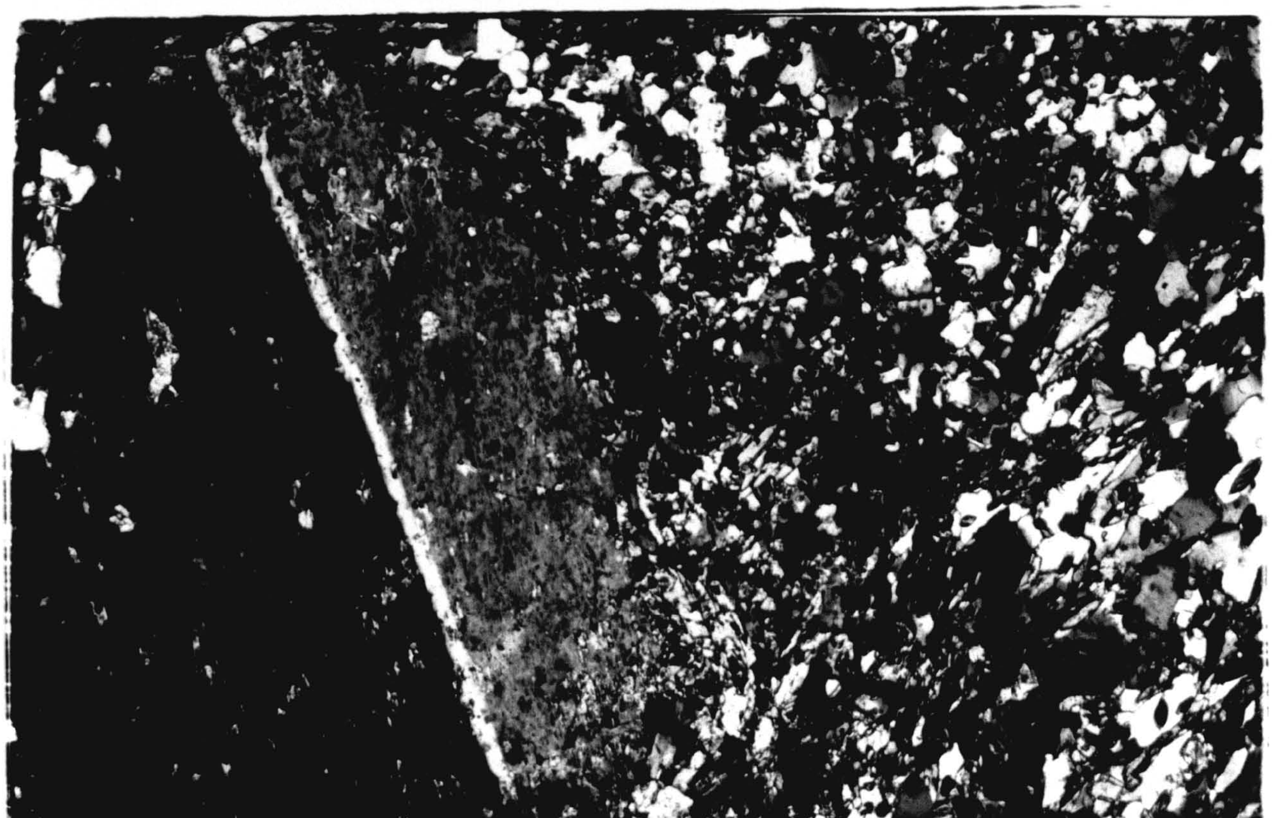


Fig. 2:4 Amphibolites de Pte. St. Jean, Reun-Kerigou

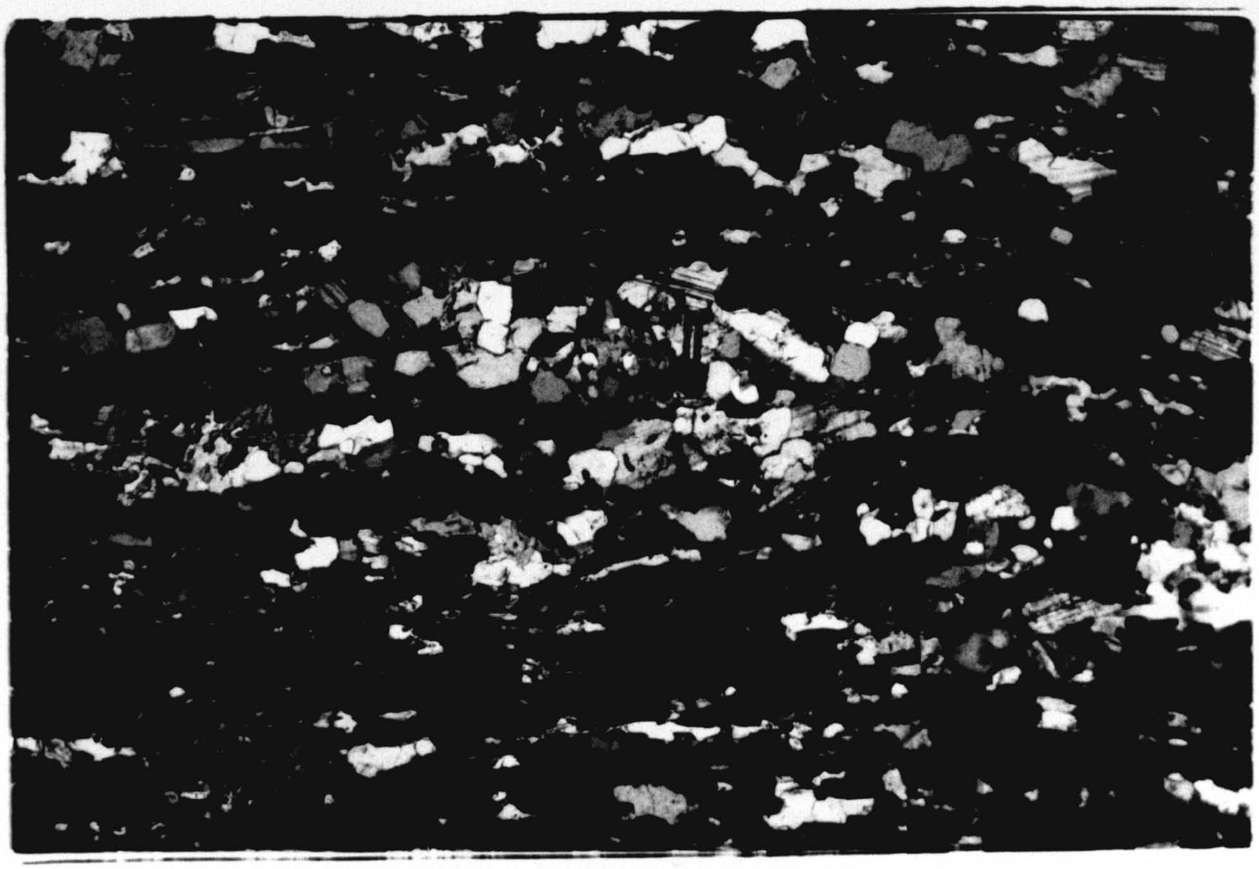
Striped amphibolites with small, poorly-developed clinopyroxene present in the light-coloured quartzo-feldspathic bands. The mineralogy is cpx + labr + qtz + hnb with accessory sphene and magnetite.

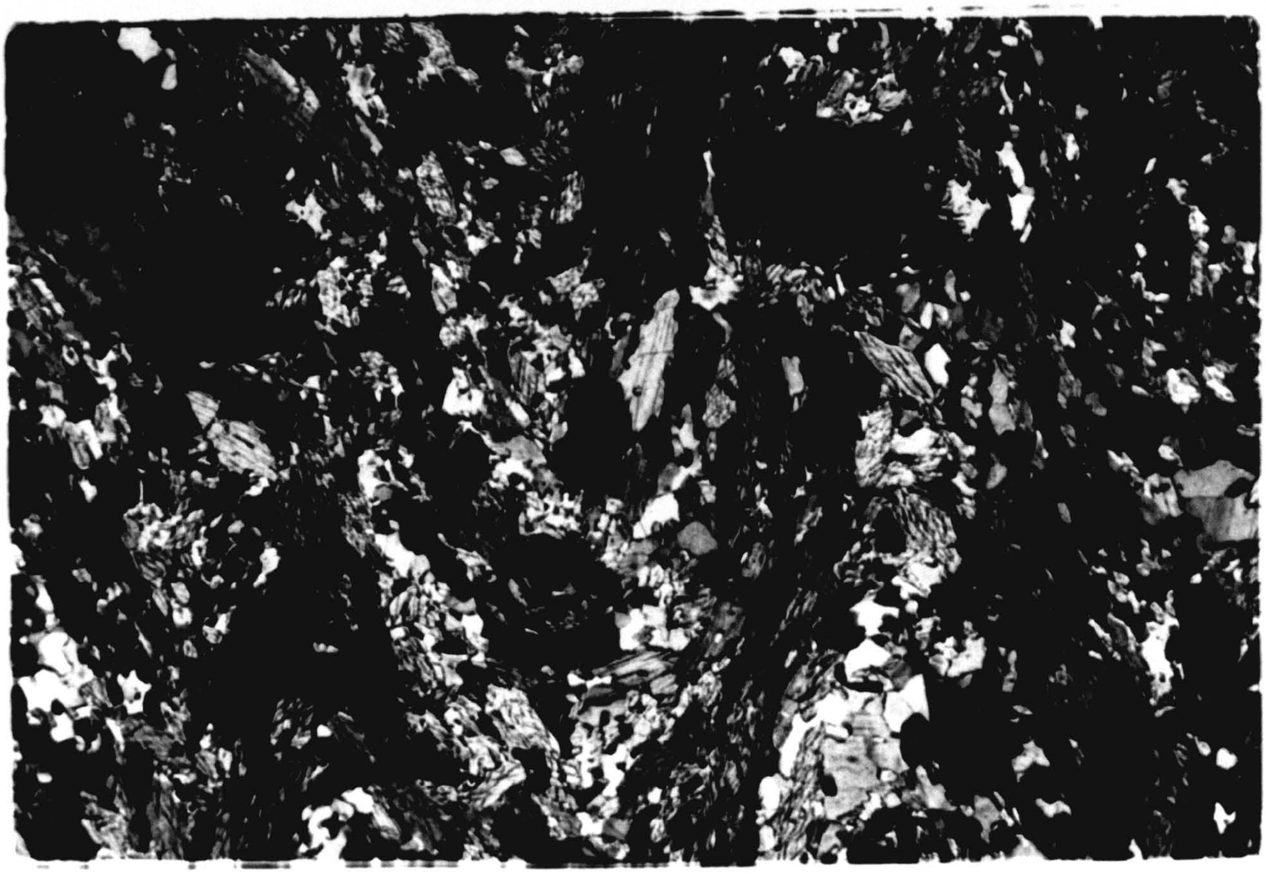
Scale: x16 XPL

Fig. 2:5 Amphibolites de Pte. St. Jean, Pte. St. Jean

Folded striped amphibolites showing mimetic hornblende grains in F2 small-scale hinge zones. Quartz is completely recrystallized. This specimen is highly enriched with magnetite.

Scale: x16 XPL





(b) Petrography of the Amphibolites de Pte. St. Jean

Table 2:1 gives the main outcrop localities of the amphibolites and summarizes mineralogical, metamorphic and structural differences throughout the amphibolite group. Below is a generalized petrographical description.

The dark amphibolites are porphyroblastic or non-porphyroblastic. Porphyroblastic types possess a weak foliation, while the non-porphyroblastic varieties show an alignment of euhedral hornblendes and possess a strong schistosity. Porphyroblastic types possess large, c. 1 cm anhedral plates of hornblende (pleochroism weak, grey-light green-green) that co-exist with smaller, recrystallized euhedral hornblendes (pleochroism moderate, light green-green-dark green). Anhedral plagioclase (An_{52}) is present within the dark amphibolite. The non-porphyroblastic types possess a simple mineralogy of euhedral hornblendes (diameter <0.5 mm, pleochroism moderate, scheme as above) consisting c. 90% of the rock with plagioclase and quartz the remaining 10%. Quartz has a granoblastic texture and forms polygonal intergrowths with the plagioclase. Ore minerals and brown (oxidised) chlorite form common accessory minerals.

Sometimes associated with the dark amphibolites are pegmatites. These are plagioclase±quartz-rich bands, up to 30 cm thick, which may contain single or aggregated hornblendes (<1.5 mm). Plagioclase (An_{52}) is dominant forming between 50 and 55% of the rock, and is always altered (Fig. 2:2). Quartz is recrystallized with a granoblastic texture and forms c. 30% and hornblende up to 20%. The large hornblende aggregates often display pale-coloured cores with euhedral subgrains of hornblende on the rims (Fig. 2:1(a)).

The striped amphibolites are characterized by the strong segregation between amphibole-rich bands and feldspar + quartz-rich bands on a centi-metric-millimetric scale. The striped amphibolites have a more complicated mineralogy than the darker, more massive amphibolites.

LOCALITY	AMPHIBOLITE TYPE	M2 MINERAL ASSEMBLAGE	FOLDS
PTE. St-JEAN	Striped amphibolites dominant, occasional 1m. thick massive bands	Hnb + Qtz + Andes + Cpx	F2 isoclines common F4 open flexures
St-POL-DE-LÉON REEFS	Massive and striped amphibolites	Hnb + Qtz + Labr + Cpx	F2 isoclines occasional
REUN-KERIGOU	Striped amphibolites	Hnb + Qtz + Andes + Cpx	F2 isoclines occasional
ÎLE INIZAN	Massive amphibolites dominant, some striped horizons	Hnb + Qtz + Epi + Andes + Sph	F2 isoclines occasional F3 upright folds rare F4 open flexures
RIV. DE PENZÉ (WEST SIDE)	Striped amphibolites	Hnb + Qtz + Epi + Andes + (Bio)	F4 open flexures
RIV. DE PENZÉ (EAST SIDE)	Massive amphibolites	Hnb + Qtz + Epi + Andes	not seen

TABLE 2:1 PRINCIPAL LOCALITIES, ASSEMBLAGES AND STRUCTURES : AMPHIBOLITES DE PTE St-JEAN.

(c) Relationship of the Amphibolites de Pte. St. Jean to other groups

As indicated earlier there are three major groups of metamorphic rocks within the St. Pol-de-Léon Metamorphic Complex; in addition to the Amphibolites de Pte. St. Jean, there are the Micaschistes de Penzé and the Gneiss Granitiqué d'Île Callot. The nature of the observed contacts and the relationship between the amphibolite group with the other groups is discussed here.

(i) Amphibolites and the Gneiss Granitique d'Île Callot

The author has not observed a contact between the granitic gneiss and the amphibolites. It is important to note that the structure of the two units is quite different. The granitic gneiss possesses a strong foliation which is further deformed only in kink-bands (Fig. 2:10), whilst the amphibolites have a complex deformational history, with at least two fold phases that deform the early metamorphic banding. The structures are described in part (C). Field evidence points to the granitic gneiss being younger than the amphibolite group.

(ii) The Amphibolites and the Micaschistes de Penzé

These two lithologies are often found in parallel contact and share a common deformational history. Interbanding has not been directly observed, but there is some evidence for this along the west side of the Riviere de Penzé (GR 1366 142A). Here, the two units occur together with alternate outcrops of the amphibolite group and the metasedimentary group. There is no evidence for any of the contacts between these two groups being controlled by tectonic processes (eg. slides, thrusts and infolding). prior to the D1 episode.

At the west side of Pte. St. Jean (GR 1367 1278) a thick succession (c. 150 m) of the amphibolites are in parallel contact with 3-4 m of psammites which, in turn, are in parallel contact with biotite-rich schists. There is no interbanding of the two groups at this locality, which was the best exposed contact encountered during this study.

The two groups show possible interbanding in the Riviere de Penzé section, but they are in general distinct with no observed primary interleaving. Within the study area, and in other parts of northern Brittany, similar lithologies (at lower metamorphic grades) occur that commonly show primary interbanding of metabasic and metasedimentary material. These areas are discussed, together with the primary nature of the Amphibolites de Pte. St. Jean, in part (D).

(2) THE MICASCHISTES DE PENZÉ

(a) Introduction

A major group of metasedimentary rocks mapped as the Micaschistes de Penzé occur extensively throughout the St. Pol-de-Léon Metamorphic Complex. Their exposure is generally poor. The best outcrops of the metasediments are those that occur inland along incised valleys leading to the Rivière de Penzé, along the banks of this river and on the coast near the Pte. St. Jean. The relationship of the Micaschistes de Penzé to a group of rocks called the 'Mixed Metasediments and Amphibolites of the Baie de Morlaix' that occur as rafts within the Hercynian granites within the Baie de Morlaix is discussed in Chapter 7.

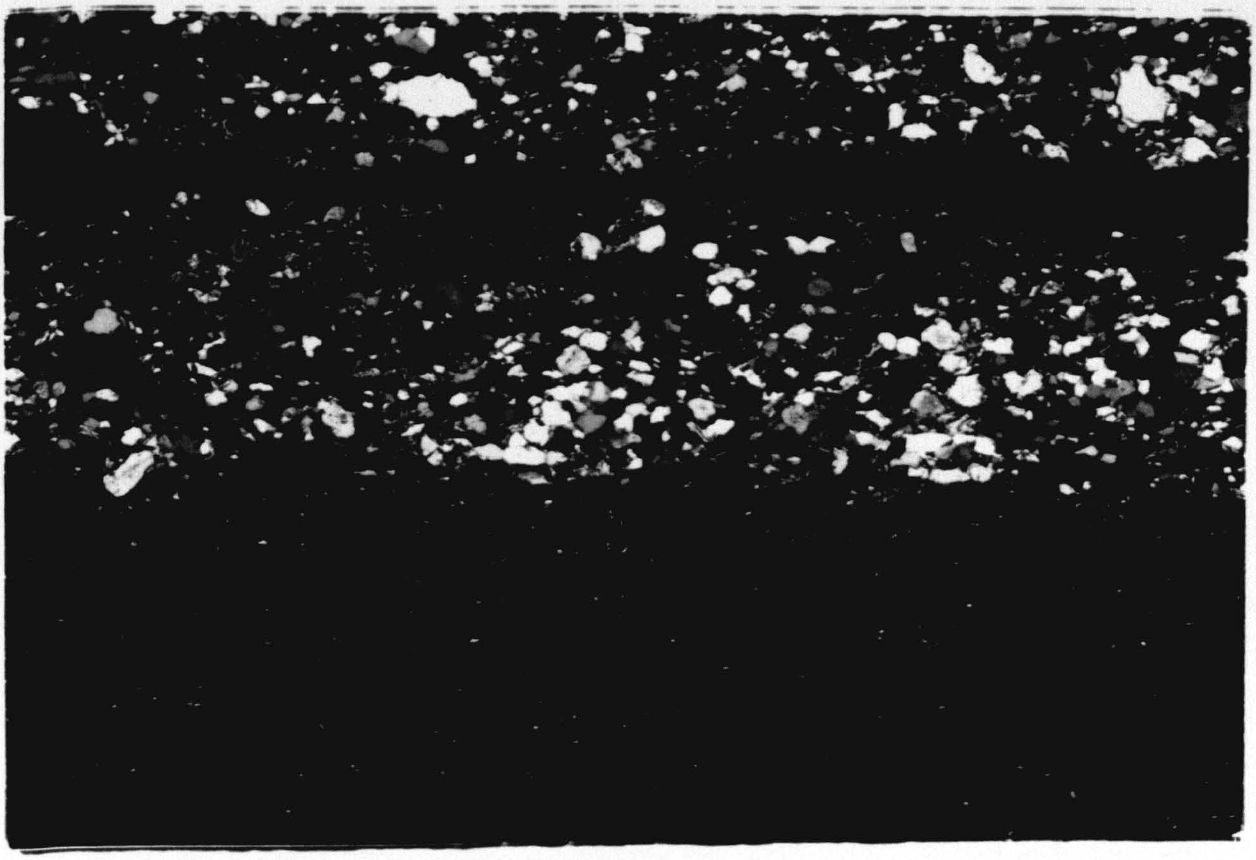
The micaschists are characterised by closely spaced (c. 1 mm) quartz rich (±feldspar) bands alternating with phyllosilicate-rich (biotite ± muscovite ± chlorite) bands (Fig. 2:6). The rocks are strongly folded and schistose and the regular quartz/mica banding is considered to be the result of metamorphic segregation produced during the D1 event (see later discussion on structure and metamorphism). Lithological and mineralogical differences occur in the Micaschistes de Penzé throughout their outcrop in the St. Pol-de-Léon Metamorphic Complex. The major differences are:-

Fig. 2:6 Micaschistes de Penzé, Penzé village

Well-developed S1 segregation banding of quartz-rich and phyllosilicate-rich layers. A later crenulation-cleavage S2 is conspicuous in the phyllosilicate layer. Quartz displays slight undulose extinction.

Scale: x16 XPL

The metasediments recorded in the area have been subdivided into five main lithologies based on their petrography and field appearance; Quartzite >80% quartz, Psammite >80% quartz + feldspar (but percentage of quartz not to exceed 80%), semi-psammite 60-80% quartz + feldspar, semi-pelite 40-80% mica, Pelite > 80% mica, interbanded combinations of these may occur. Boundaries between the five groups may be gradational and therefore difficult to define but depend principally on the proportions if mica to quartzo-feldspathic minerals present (discussed in the appropriate chapter).



1. They vary in terms of ratio of quartz to mica-rich bands so that semi-psammites occur where the quartz-rich bands are dominant.

2. The mica content changes. Biotite-rich schists occur to the north of Pont Eón whilst to the south of this locality the schists are chlorite ± muscovite-rich.

3. Development of the segregation banding varies.

In association with the schists are semi-psammites and psammites. Gradational boundaries occur between the banded semi-pelitic schist and semi-psammites, but boundaries between the psammites and schists are sharp or faulted. At the Pte. St. Jean (GR 1367 1278) psammites and semi-psammites occur in close proximity but separate to the schists. Primary relationships, however, cannot be determined as deformation and metamorphism have largely destroyed original bedding relationships. Semi-psammites occur at Pte. St. Jean and Keryenevet, near Inizan (GR 1380 1257). These rocks are composed of quartz and biotite and they are poorly segregated unlike the typically banded micaschists. Bedded psammites and metaquartzites occur, which near Quillen (GR 1413 1168), appear to be in faulted contact with the Micaschistes de Penzé. Chauris and Hallégouet (1973) have described metaquartzites within a granodioritic gneiss body (the Gneiss de Brest) which occurs extensively in the Pays de Léon. Chauris (op. cit.) attributes Brioverian, Arenigian (Grés Armoricain?) and Hercynian ages to these metaquartzite bodies.

(b) Petrography of the Micaschistes de Penzé

There are significant mineralogical and textural differences within the Micaschistes de Penzé, and a general description of the lithology will be followed by a N-S traverse through the group.

The semi-pelite Micaschistes de Penzé consist of two alternating types of bands:-

1. Quartz-rich bands that may also contain mica ± plagioclase ± K-feldspar.

2. Biotite ± muscovite ± chlorite-rich bands with minor quartz in association.

Banding occurs on a fine-scale (millimetric or less). There is a strong preferred orientation of the phyllosilicate minerals and the long dimensions of quartz grains. The banding is attributed to a D1/M1 metamorphic segregation episode and has frequently been folded as a result of the D2 episode (Fig. 2:17).

Muscovite and biotite make up between 40 and 70% of the rocks assigned to the Micaschistes de Penzé. The mica generally defines the S1 foliation, but occasional muscovite flakes (up to 1 mm) are developed frequently throughout the series at an oblique angle to the S1 foliation. The muscovite is related to a later metamorphic event.

The quartz-rich bands may possess plagioclase ± K-feldspar. Both feldspar minerals are usually highly altered, up to c. 0.5 mm long and subhedral to anhedral. There is an increase in the feldspar content towards the south of the outcrop.

Quartz is the dominant mineral in these bands forming 65-95%. It occurs with granoblastic texture or as larger elongate grains (with an axial ratio of 2:1) arranged parallel to the S1 fabric.

Minor garnet and cordierite have been recorded in specimens collected from the northern part of the complex at Pointe St. Jean and Reun.

Other minerals noted are haematite, epidote, and chlorite. Their occurrence is given in Table 2:2 and is discussed below.

There are significant variations within the Micaschistes de Penzé which are due to mineralogical changes and differences in the degree of segregation. These variations may be related to:-

AREA	ASSEMBLAGE	BANDING	FOLDS
(N) POINTE St-JEAN	Bio - Qtz - (Gnt) - Olig - K-Felds (Post M2 Gnt ⟶ Bio, growth of musc + chl)	Alignment of mica, qtz. segregation lenses Relatively poor segregation (Fig. 2:7)	Ubiquitous F3 folds and F4 open flexures
PONT DE LA CORDE	Bio - Musc - Qtz - K-felds (K-felds ⟶ Sericite)	Moderate-well developed S1 segregation banding	Occasional F2 isoclines (Fig. 2:17) variable plunge. F3 folds common and S3 crenulation cleavage.
PONT ÉON	Musc - Chl - Bio - Qtz - Alb - K-felds (Green + brown Bio co-exist, Feorich)	Well-developed S1 segregation banding	Ubiquitous F3 folds
PENZÉ	Chl - Musc - Qtz - Epi (Post M2 Plag ⟶ Epi ?)	Well developed S1 segregation banding	F2 folds recoquised on microscopic scale (Fig. 2:15/16) F3 folds ubiquitous.

TABLE 2:2 SUMMARY OF MICASCHISTES DE PENZE FROM NORTH - SOUTH

1. primary sedimentary heterogenity and/or
2. degree of metamorphism.

The principal differences that occur in this group can be examined in four areas in a north to south traverse from Pte. St. Jean to Penzé village. The petrographical details are given in Table 2:2:-

1. Specimens from the Pte. St. Jean show the quartz and segregation to be less clearly defined than to the south. In detail the mica segregation is better developed within hinge areas of late folds where thickening occurs. Biotite and muscovite occur in even distribution throughout the rock. Biotite shows strong pleochroic absorption and is well formed. Muscovite occurs in two forms at this locality, commonly as grains arranged parallel to the foliation with a strong preferred orientation, and as larger plates that overgrow the S1 fabric. The S1 fabric is deformed most commonly by D3 folds and the muscovite plates are sub-parallel to the S3 axial planar crenulation-cleavage. Chlorite grains occur as large (c. 0.4 mm) grains concentrated in the hinge zones of the D3 folds and forms at the expense of biotite. Feldspar does not occur in the semi-pelitic schists but does occur in the semi-psammites which are adjacent at this locality.

Garnet occurs occasionally as irregular grains within biotite-rich aggregates (Fig. 2:7), while cordierite (often altered to pinnite) occurs either as discrete grains or in symplektic growth with biotite and quartz.

2. In the area around Pont de la Corde there is a strong segregation banding. Muscovite and biotite occur in equal proportions forming some 50-60% of the rock. K-feldspar occurs within the quartz-rich bands and is always highly altered. Occasional quartz porphyroblasts occur up to 1 mm in diameter set amongst finer grained, recrystallized quartz (Fig. 2:8). It should be noted that Delattre et al. (1966) mapped these rocks as Schistes Zébrés of Devono-Carboniferous age.

Fig. 2:7 Micaschistes de Penzé, W. Pte. St. Jean

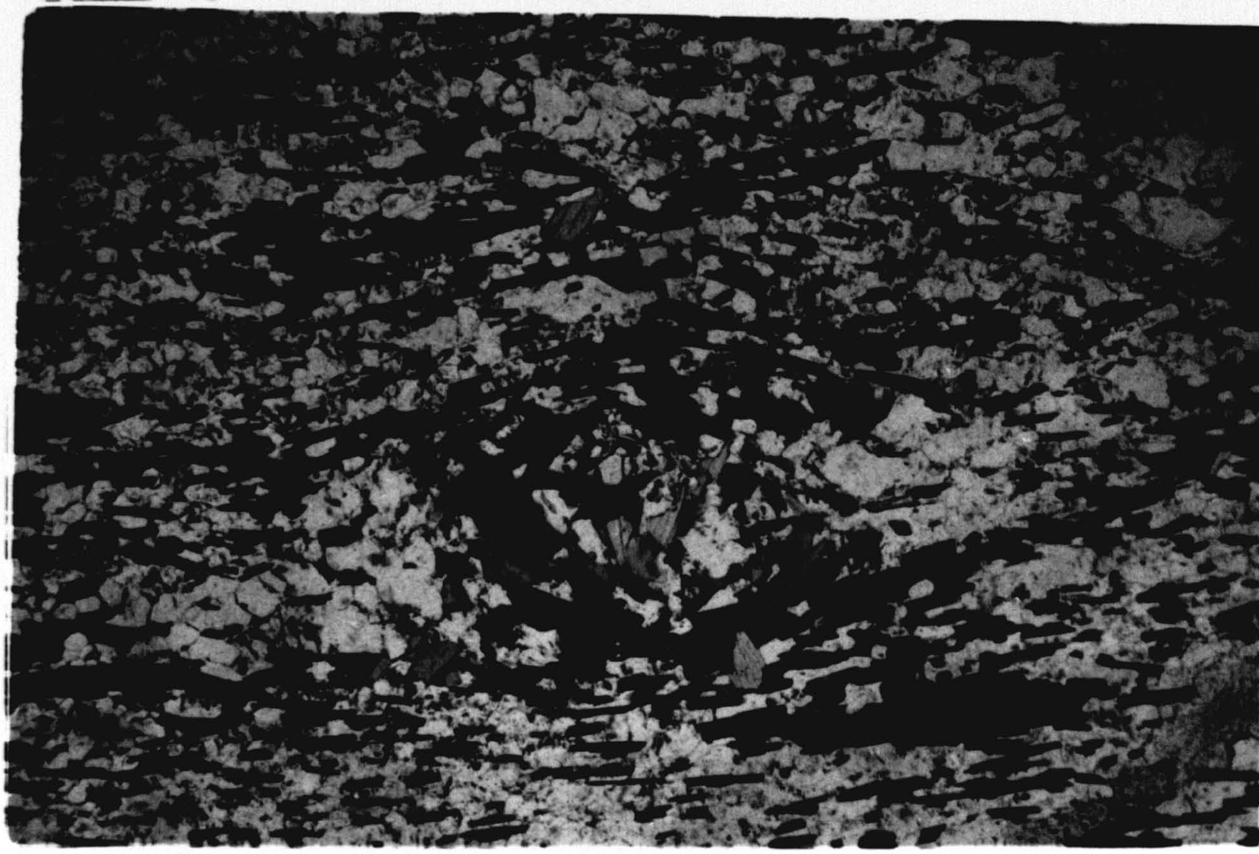
A relic M2 garnet has been largely replaced by biotite and quartz. The quartz - biotite segregation banding, S1, is relatively poorly-developed at this locality. Large (pale coloured) muscovite grains overgrow the foliation.

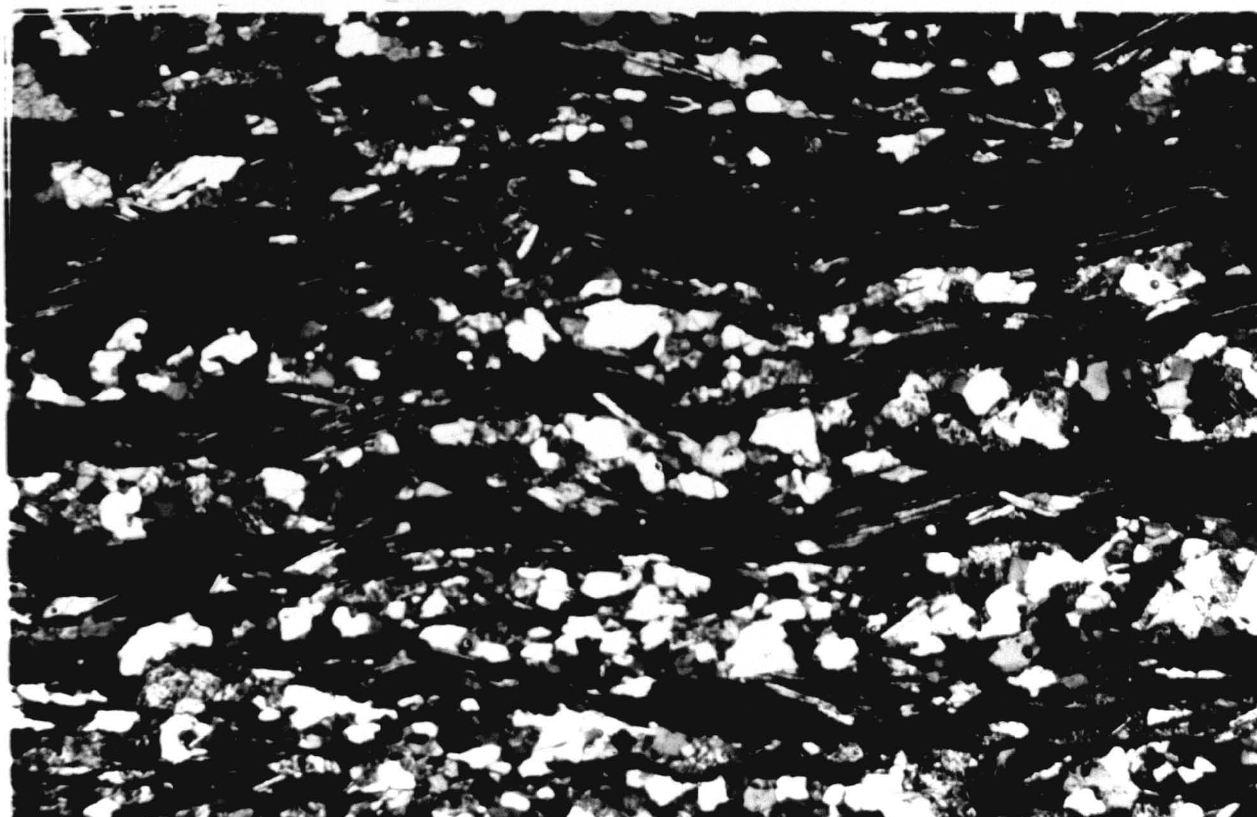
Scale: x16 XPL

Fig. 2:8 Micaschistes de Penzé, Pont Eón

Well-developed S1 segregation banding with phyllosilicate-rich (biotite and muscovite) and quartz + K-feldspar + albite rich layers developed on a millimetric scale. The S1 banding is gently folded at this locality by F3 upright small-scale folds. Muscovite grains overgrow the foliation.

Scale: x16 XPL





3. To the south in the area around Pont Eón segregation banding is very marked and regular. Brown biotite is less common than in the northern outcrop and displays pleochroic absorption. It coexists with green biotite and chlorite rims some of the biotite grains. Muscovite and chlorite are the dominant minerals forming some 60-65% of the rock. Plagioclase (albite) and K-feldspar, both strongly seriticized, are common in the quartz-rich bands where it forms as much as 15% of the mode. Specimens taken from a locality (GR 1352 1123) near Mespaul show a similar structure and mineralogy but with significant amounts of haematite occurring as separate grains.

4. Further outcrops of the Micaschistes de Penzé around the village of Penzé display strong segregation banding. In these rocks biotite is absent and chlorite and muscovite are the dominant mineral phases. Chlorite forms as much as 30-40% of the rock, muscovite some 20-30% and quartz 25-30%. Epidote replaces plagioclase, but is rare. Iron staining is very strong and brown chlorite commonly occurs along late cross-cutting veins.

(3) THE GNEISS GRANITIQUE D'ÎLE CALLOT

(a) Introduction

The third lithological unit recognised in the St. Pol-de-Léon Metamorphic Complex that pre-dates the emplacement of Hercynian granites has been termed the Gneiss Granitique d'Île Callot (cf. Granite ecrasé of Delattre et al. 1966). The gneiss is a distinctive unit whose outcrop is restricted to the Île Callot, north Carantec and La Grand Grève areas (Map 1; Fig. 2:11). The gneiss is cut by a suite of amphibolite sheets that also predates the Hercynian granites and shares the same deformational history as the host granitic gneiss. The amphibolite sheets are described in the next section.

The granitic gneiss is variable in that it is comprised of a number of acid to intermediate phases that were intimately associated prior to deformation. The phases were emplaced on at least two separate occasions and appear to inject a coarser-grained granitic host which makes up the typical lithology and is volumetrically the most important (Figs. 2:9 and 2:10).

The granitic gneiss has been heterogeneously deformed so that within the outcrop of the lithology mapped as the Gneiss Granitique d'Île Callot the following features may be observed:-

1. Various intrusive phases, acid to intermediate in composition, that pre-date the development of the gneissose foliation.
2. Fine-grained horizons arranged parallel to the foliation.
3. Amphibolite sheets which post-date the emplacement of the granitic gneiss but pre-date the development of the gneissose fabric.
4. Quartz-rich segregation pods and veins, thought to be a product of deformation and metamorphism.

The host and typical Gneiss Granitique d'Île Callot lithology is strongly foliated with conspicuous augen of quartz and alkali feldspar (7-15 mm in diameter). The foliation is variable in its spacing from 1-10 mm and is depicted by the strong alignment of biotite grains (Fig. 2:9).

The acid to intermediate phases, intrusive into the granitic host, occasionally display preserved cross-cutting intrusive relationships (Fig. 2:12). The mineralogy of the rocks that can be seen to inject the host is different and grain-size is somewhat finer. Two intrusive phases are recognised, type 1 (Fig. 2:12) is rich in quartz and feldspar. K-feldspar occurs as small augen (<2 mm diameter) and muscovite is the dominant mica. Biotite is of minor importance. Type 2 is somewhat

Fig. 2:9 Gneiss Granitique d'Île Callot, S.E. Île de Callot

Well-developed gneissose banding is depicted by the parallel alignment and segregation of elongate quartz and K-feldspar and biotite grains.

Scale: x16 XPL

Fig. 2:10 Gneiss Granitique d'Île Callot, S.E. Île de Callot

Field photograph of the granitic gneiss showing the nature of the foliation, defined by the segregation of quartz + K-feldspar from biotite. Thin (<1 cm) segregation pure quartz bands are particularly frequent at this locality. Late kink-bands (D3/F3?) deform the gneissose foliation and quartz bands and are commonly developed in conjugate sets.

Scale: Compass-clinometer extended = 18 cm

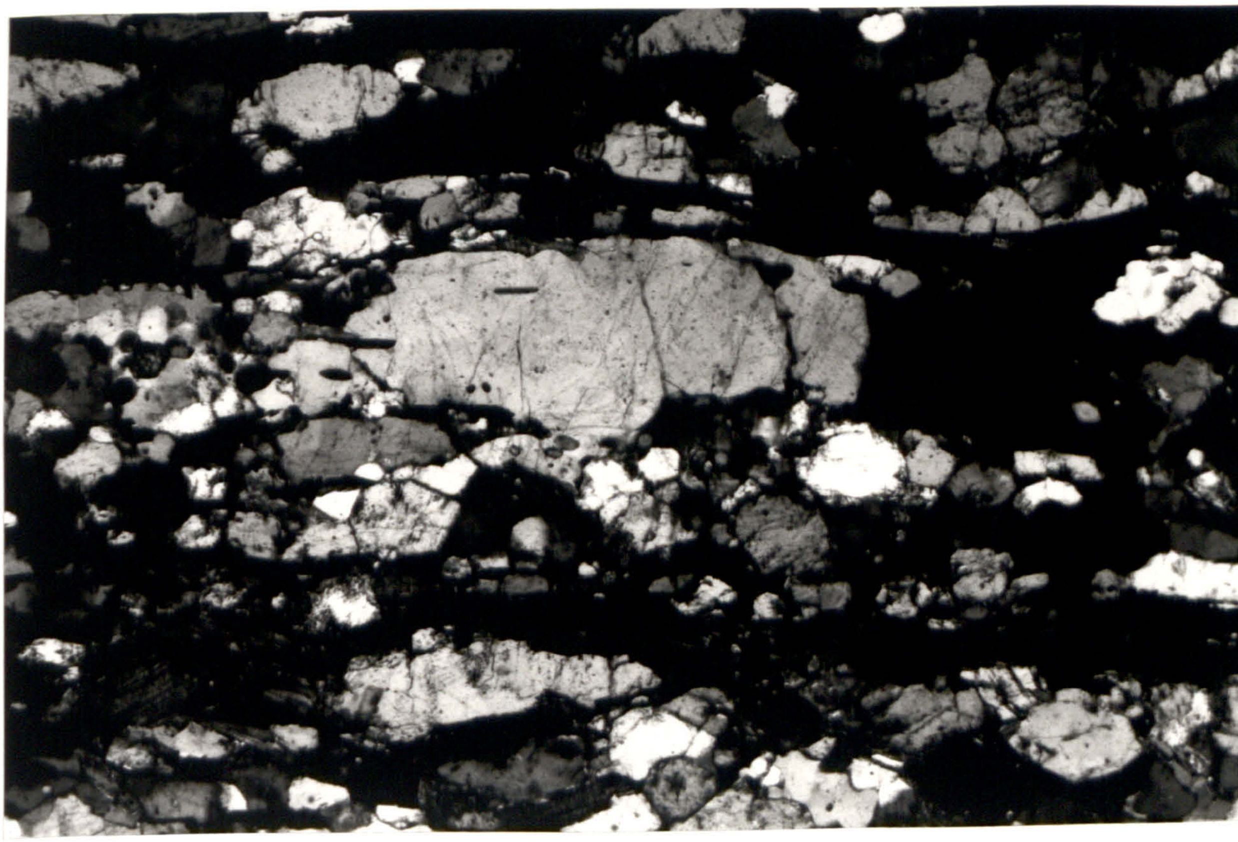


Fig. 2:11 Orientation of structures within the Gneiss Granitique d'Île de Callot

Hercynian Granite de Primel-Carantec

Gneiss Granitique d'Île de Callot

Metasediments

Mylonites (CSB)

Amphibolite sheet

The well-developed planar and linear fabrics of the granitic gneiss have been re-orientated by the emplacement of the Granite de Primel-Carantec. Isolated blocks of the Gneiss Granitique d'Île Callot can be mapped out within the later granite. Lineations and strikes are average readings for the individual gneiss blocks.

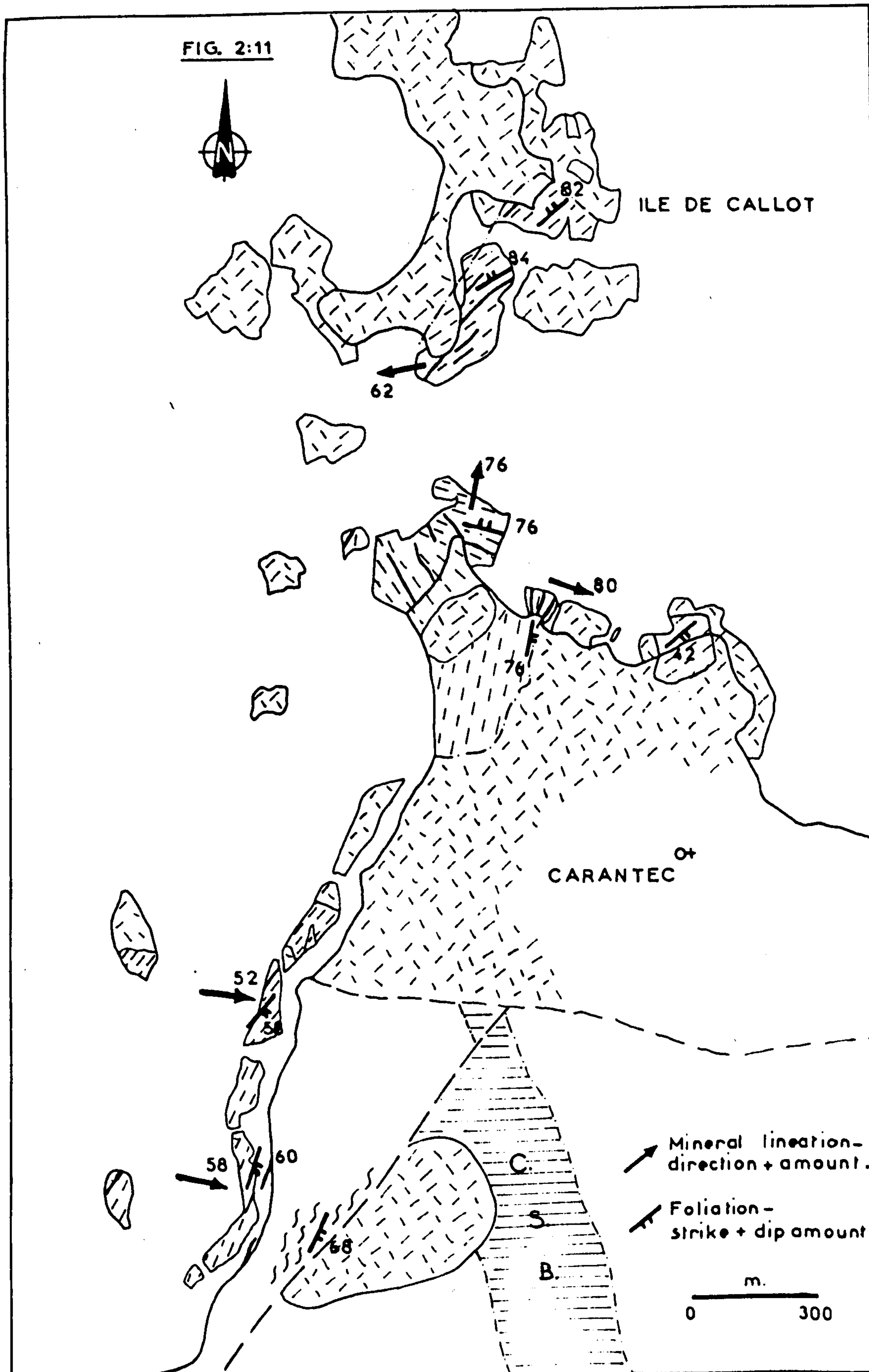


FIG. 2:11
N
ILE DE CALLOT
82
84
62
76
76
80
76
42
CARANTEC
52
58
58
60
68
C
S
B
Mineral lineation-
direction + amount.
Foliation-
strike + dip amount.
m.
0
300

Fig. 2:12 Gneiss Granitique d'Île Callot, N. Carantec

At least three granite types comprise the Gneiss Granitique d'Île Callot. The dominant lithology is the medium-coarse grained variety (1; figured 2:9 and 2:10). This is truncated by a finer-grained variety (2) which is turn truncated by an even finer-grained light coloured (aplite) variety. All three granite types were emplaced prior to the peak D2/M2 fabric producing event.

A thin quartz vein (4) is developed parallel to the gneissose banding and is associated with the nearby Granite de Primel-Carantec.

Scale: Hammer handle 36 cm

4

1 2 3

coarser grained with abundant biotite. The fine-grained domains or bands, that are present within the granitic gneiss, are considered to be different to the recognisable intrusive sheets described above as they are laterally continuous. These bands are arranged parallel to the gneissose fabric and it is considered that these bands represent zones of higher strain in which there has been a grain size reduction. The main mineral constituents of these bands in order of abundance are quartz, K-feldspar, plagioclase (albite), muscovite and biotite. The mineralogy is that of a granite and similar to that of the host granite gneiss. The minerals are inequigranular and quartz and feldspar have a xenoblastic texture whilst biotite and muscovite have a strong preferred orientation. Boundaries between these domains and the coarser host are usually sharp.

Quartz-rich pods and lenses occur throughout the granitic gneiss. These are arranged parallel to the foliation and take on a boudinaged form. They may represent continuous quartz veins formed prior to the deformation, or alternatively, a product of metamorphic segregation forming during the deformation event D2/M2.

Late magmatic white quartz veins associated with Hercynian magmatism cut both the granitic gneiss and the Hercynian granite de Primel-Carantec and are distinct from the quartz lenses.

(b) <u>Petrography of the Gneiss Granitique d'Île Callot</u>

In thin section the granitic character of the host gneiss is borne out with a composition of quartz + K-feldspar + albite (variable in amount) + biotite + muscovite. The K-feldspars may be orthoclase or perthite, both phases occur as augen (<4 mm) and form c. 35-45% of the rock. The development of perthite is variable and the exsolution may be either an original igneous phenomenon or the product of metamorphism. Albite is ubiquitous but varies in abundance, usually 5%, but up to 15% of the mode has been recorded. Microcline is rare and occurs as small grains of less than 1 mm width.

Quartz forms 40-50% of the rock and has two forms; (i) as large (<3 mm) elongated ribbon quartz grains with undulose extinction and arranged parallel to the foliation; (ii) and as small unstrained polygonal grains which appear to form at the expense of the larger grains. Biotite is ubiquitous and forms between 10-20% of the mode; it is generally strongly orientated to produce a strong foliation but some grains lie in the pressure shadows of feldspar augen with random orientation. The colour of the biotite reflects the degree of contact metamorphism to some extent, as biotite from Île Callot and north Carantec is chestnut-red and has high pleochroic absorption, whilst outcrops more distant to the Hercynian granites have biotite with a pale-brown to green colour and low absorption. Muscovite occurs in small amounts within the coarser-grained 'host' lithology as large c. 1 mm grains orientated oblique to the foliation and within the thin biotite/muscovite-rich foliae.

(4) THE AMPHIBOLITE SHEETS

(a) Introduction

The Gneiss Granitique d'Île Callot is cut by a suite of intrusive basic sheets which are now amphibolites. The sheets also occur in isolated outcrops and in association with the Mixed Metasediments and Amphibolites of the Baie de Morlaix within the Granite de Primel-Carantec around Île Callot. The amphibolites are megascopically and microscopically distinct to the Amphibolites de Pte. St. Jean. This is an important observation as this helps to determine the age of the Mixed metasediments and Amphibolites of the Baie de Morlaix, discussed in Chapter 7.

The width of the amphibolite sheets varies from 1-4 m. They are laterally variable, often showing boudinage and occasionally sheets join at low angles. At such contacts the foliation within the host granitic gneiss is broadly parallel to that of the intrusive amphibolite sheets, thus the sheets pre-date the main metamorphic fabric producing episode that is termed D2/M2.

In detail the foliation is depicted by a regular millimetric scale segregation banding formed of alternating amphibole-rich bands and quartzo-felspathic bands (Fig. 2:13). The foliation is more strongly developed of the margins of some of the thicker (3 m plus) sheets, but thinner sheets show a uniform development of the foliation and a regular grain size.

The sheets are particularly frequent within the Gneiss Granitique d'Île Callot where they form between 10 and 15% of the total granitic gneiss outcrop (Fig. 2:14). It is proposed that the amphibolite sheets represent a major phase of basic dyke emplacement that was:-

1. Emplaced into already crystallized granite. All primary relationships eg. margin chilling effects have been destroyed by the high-grade metamorphism.
2. Deformed together with the Gneiss Granitique d'Île Callot and shares the same deformational history.

(b) Petrography of the Amphibolite Sheets

The main minerals in order of abundance are hornblende, plagioclase, quartz and sphene, with secondary epidote and biotite and accessory magnetite. The amphibolites are foliated on a fine scale (c. 1 mm). The foliation is a segregation fabric produced during the D2/M2 event in the evolution of the St. Pol-de-Léon Complex. The foliation is defined by alternation of quartz ± feldspar-rich zones alternating with hornblende-rich zones.

Hornblende makes up c. 65-70% of the rock and occurs in two forms:

1. Grains up to 2-3 mm in diameter, porphyroblastic to poikiloblastic in form, enclosing small rounded inclusions, mainly of quartz and plagioclase.

Fig. 2:13 Amphibolite sheet, SE Île de Callot

In thin-section the segregation banding present within the amphibolite sheets is relatively poorly-developed. Hornblende is dominant as large, partly deformed grains and as small prismatic crystals, granoblastic quartz and andesine also occur.

Scale x16 XPL

Fig. 2:14 Amphibolite sheet, SE Île de Callot

A c. 3 m thick amphibolite sheet truncates the Gneiss Granitique d'Île Callot. Both lithologies are strongly foliated, here orientated NE-SW with a linear fabric orientated WNW at c. 70°.

The late Hercynian Granite de Primel-Carantec truncates the granite gneiss and forms islands within the Baie de Morlaix.

Scale: Tape ≐ 80 cm

2. Idioblastic to sub-idioblastic grains which are prismatic, elongated and are either aligned parallel to the foliation or may be more randomly orientated. These grains are less than 1.5 mm in diameter and have a strong pleochroic absorption.

In some cases the larger grains are aggregated to form augen-like zones around which smaller elongate hornblendes are arranged.

Quartz makes up some 25-30% of the amphibolites. The grains are generally small (<0.5 mm) although larger, elongate ribbon quartz grains occasionally occur. Plagioclase (An_{42}), of a size similar to the smaller hornblendes, occurs as subidioblastic to xenoblastic, slightly elongate grains. Biotite is often concentrated within thin zones which help to define the foliation of these amphibolites. Such zones are also characterized by thin film-like veins of iron oxide concentrates in zones parallel to the foliation. In these samples where the biotite has been altered to chlorite the plagioclase is likewise cloudy. Sphene is common and forms clusters and rhomb-shaped aggregates together with opaque ores, thought to be largely titano-magnetite, the sphene forms the main accessory components in the rock. Apatite occurs as very small prisms or more poorly shaped grains enclosed within plagioclase and hornblende.

Tha amphibolite sheets can be distinguished from the Amphibolites de Pte. St. Jean by their regular millimetric banding and by the relative abundance of quartz, and more diagnostically, sphene.

(C) STRUCTURE AND METAMORPHISM OF THE ST. POL-DE-LÉON METAMORPHIC COMPLEX

(1) INTRODUCTION

The rocks of the St. Pol-de-Léon Metamorphic Complex have undergone several episodes of deformation and metamorphism. The structures and metamorphic assemblages produced by these deformation episodes are described here, while a discussion as to the timing of the deformation is given later in Chapter 8,using stratigraphical and geochronological data from the region.

Major lithological units have responded heterogeneously to imposed stresses during the successive deformation episodes, so that the frequency and tightness of structures varies within single lithological units and between the major units. For example, the metasediments show ubiquitous F3 folds whilst the Amphibolites de Pte. St. Jean only occasionally show folds of this generation.

A summary of the deformational episodes with their respective folds and planar fabrics plus the metamorphic assemblages is given in Table 2:3. This can be compared to the sequence proposed by Roper (1980) for the western Pays de Léon, Table 2:4.

(2) THE D1 STRUCTURES AND ASSOCIATED M1 METAMORPHISM

The most prominent effect of the D1/M1 episode has been to produce a well-developed lithological banding and/or foliation in the earliest components of the St. Pol-de-Léon Metamorphic Complex, namely the amphibolites and metasediments. Folds related to the D1 episode have not been recognised but the strong banding S1 has been folded by later episodes.

The metasediments show variation in the degree of segregation of micaceous and quartz-rich bands, summarised Table 2:3 (see also Fig. 2:7 and 2.8). Likewise, as described earlier, there are within the amphibolite group two types of amphibolite present:-

1. A striped variety which is banded on a millimetric-centimetric scale.
2. A more massive 'dark' variety, in parallelism with the S1 foliation

EVENT	MICASCHISTES DE PENZÉ	AMPHIBOLITES DE PTE. St-JEAN	GNEISS GRANITIQUE D'ÎLE CALLOT
D5	NE - SW and NW - SE Faulting across area		
		Minor faulting	
D4	Open flexuring and some kink-bands	Open flexuring and chevron - folds in hinges	Kink-bands ?
M3	Retrogression (Gnt→ Bio, Plag→Epi)	Retrogression limited	Retrogression (growth of muscovite)
S3	Well-developed crenulation cleavage and pressure solution	Spaced fracture cleavage	-
F3	Widespread development of upright NE plunging folds	Rare development of upright folds	Kink-bands well-developed ?
M2	Peak metamorphism Upper Amphibolite Facies (Cord + Bio + Gnt)	Peak metamorphism Upper Amphibolite Facies (Cpx + Labr + Hnb)	Amphibolite facies
S2	Spaced cleavage, axial planar to folds	Spaced cleavage/ schistosity	Development of gneiss banding
F2	Isoclinal folds (micro-small macroscopic scale) (Figs. 2:15-17)	Isoclinal folds in preferred horizons with congruous folds (Figs. 2:18-18b)	
M1	Nature unknown	Nature unknown	(Emplacement of granite and basic sheets = post-D1, pre-D2)
S1	Well-developed segregation banding (Qtz + mica)	Variable development of amphibolite banding	
F1	Not seen	Not seen	

TABLE 2:3 SUMMARY OF DEFORMATION AND METAMORPHISM ; ST. POL-DE-LÉON METAMORPHIC COMPLEX

METAMORPHIC AND STRUCTURAL EPISODES IN THE LANNILIS METAMORPHIC COMPLEX

D5	LATE FAULTING AND QUARTZ VEINS
D4	MOVEMENTS ASSOCIATED WITH THE PORSPODER LINEAMENT (FRACTURE CLEAVAGE AND LOCAL MYLONITISATION).
D3	'LATE' OROGENIC EPISODE. CHEVRON FOLDS AND OPEN FLEXURES. MINOR RETROGRESSIVE METAMORPHISM
D2/M2	'MAIN' OROGENIC EPISODE. TIGHT/ISOCLINAL FOLDS, OFTEN WITH E-W AXES. ASSOCIATED WITH MEDIUM AND HIGH GRADE METAMORPHISM
D1/M1	'EARLY' OROGENIC EPISODE. ISOCLINAL FOLDS WITH AXES NEAR N-S. ASSOCIATED METAMORPHISM, OF UNCERTAIN GRADE.

TABLE 2:4 EXTRACT FROM ROPER (1980)

The question arises as to whether the banding within both the metasedimentary schists and the amphibolites is a primary lithological variation, enhanced during the D1/M1 episode, or the product of metamorphic segregation with neo-mineralization and complete recrystallization. This second alternative may be achieved by a diffusional transfer mechanism initiated by a deformational episode accompanied by:-

1. Metasomatism, the differential transfer of elements with addition or subtraction of non-volatile constituents.
2. Shearing mechanism, associated with the development of ductile shear zones that leads to a mobility and segregation of elements.
3. Diffusion transfer coupled with circulating hydrothermal fluids, as for example in migmatization.

It is not possible to state the metamorphic conditions and resultant mineral assemblages of the M1 metamorphism as D2/M2 effects have largely destroyed earlier assemblages and any primary igneous or sedimentary structures. It may be argued that there are no reported cases of relict high-grade minerals in those assemblages formed during the M2 metamorphism, and therefore any metamorphism accompanying D1 is unlikely to have been of higher grade than that accompanying the D2 episode.

The segregation mechanism resulted in a strong segregation banding, which in the metasediments is represented by quartz segregation lenses approximately parallel to primary lithological contacts, eg. those between psammite and micaschist units. In the amphibolite group, bands of the dark massive amphibolites are orientated parallel to the striped amphibolites. Thus a mechanism that involved high confining pressures is considered to have occurred during D1/M1 such as ductile shearing. It is interesting to note the development of banding in mylonitic rocks derived from a basic igneous parent in the case of the Moulin de la Rive Orthogneiss Complex, (Chapter 4), and within high strain zones within the basic metavolcanics of the Formation de la Pointe de l'Armorique (Chapter 3).

In the St. Pol-de-Léon Metamorphic Complex a marked change in the orientation of the S1 foliation relative to the western, central and southern Pays de Léon is observed (Chauris 1972). In the St. Pol-de-Léon Metamorphic Complex the dominant S1 trend is approximately N-S while to the southwest, in the area of St. Thegonnec, the trend is approximately ENE-WSW (Chauris op. cit.; Kerrien et al. 1970). This marked swing in the attitude of the S1 fabric is considered to be the product of the D2 deformation episode and related to the formation of the Carantec Shear Belt along the eastern margin of the St. Pol-de-Léon Metamorphic Complex (discussed further in Chapter 6).

In the western Pays de Léon, Roper (1980) has recognized folds that he attributes to the D1/M1 episode. Here, in the Lannilis Metamorphic Complex, the Micaschistes de L'Aber Wrac'h display two types of isoclinal folds to which the schistosity is axial planar. Roper (op. cit. p. 215) states that 'since the trend and direction of plunge of these two sets is quite different (approximately N-S and E-W) it follows that the folding was polyphase'. Shelley (1966) has argued that N-S set is the earlier fold phase.

The lack of F1 folds may be accounted for by the nature of the lithology that was deformed by D1. The amphibolites may have developed a banding and foliation rather than folds, as there were no planar surfaces to fold in a sequence that were possible original massive and pillowed basaltic lavas. F1 folds have not been recognised within the banded metasediments but there is a well-developed S1 foliation.

(3) THE D2 STRUCTURES AND ASSOCIATED M2 METAMORPHISM

The D2/M2 episode resulted in extensive folding and medium-high grade metamorphism of the rocks now represented by the Amphibolites de Pte. St. Jean and the Micaschistes de Penzé, and deformation of the Gneiss Granitique d'Île Callot and the amphibolite sheets. The development of the Carantec Shear Belt (discussed in Chapter 6) is associated with the D2 episode, and this resulted in the major reorientation of the S1 fabric in the eastern Pays de Léon and the St. Pol-de-Léon Metamorphic Complex.

The S1 fabric is approximately parallel to the mylonitic banding developed in the Carantec Shear Belt, and the major outcrop pattern is dominated by the shear belt formation, this is discussed further in Chapter 8.

F2 folds produced during the D2 episode are the first recognisable megascopic folds observed within the metasediments and the amphibolites. They are present as southwest-plunging isoclines which are of microscopic to small megascopic scale (Figs. 2:15-18). The folds are not common in the metasedimentary rocks but are frequently developed within the amphibolites. The F2 axes generally plunge steeply ($50-80^{o}$) towards the SSW.

Within the metasedimentary Micaschistes de Penzé the S1 quartz-rich and mica-rich bands are folded on both microscopic and small megascopic scales. The isoclinal folds have markedly thickened hinge zones and thinned, frequently boudinaged limbs (Fig. 2:17). Microscopic analysis shows that the limbs are commonly transposed and there is a poorly developed spaced S2 crenulation cleavage. S2 is defined by the alignment of muscovite grains, axial planar to the F2 folds and therefore usually sub-parallel to the S1 foliation (Fig. 2:16). F2 folds in the metasediments were ubiquitously refolded during D3.

Fig. 2:15 Micaschistes de Penzé, Pont Éon

Small-scale isoclinal fold with associated spaced cleavage which is developed sub-parallel to the S1 segregation banding. An upright crenulation cleavage, S3, deforms the earlier banding.

Scale: x16 XPL

Fig. 2:16 Micaschistes de Penzé, Pont Éon

Small-scale F2 isoclinal fold which refolds the S1 segregation banding. Large quartz veins developed in the hinge zone are largely unstrained and indicate post-F2 recrystallization.

Scale: x40 XPL

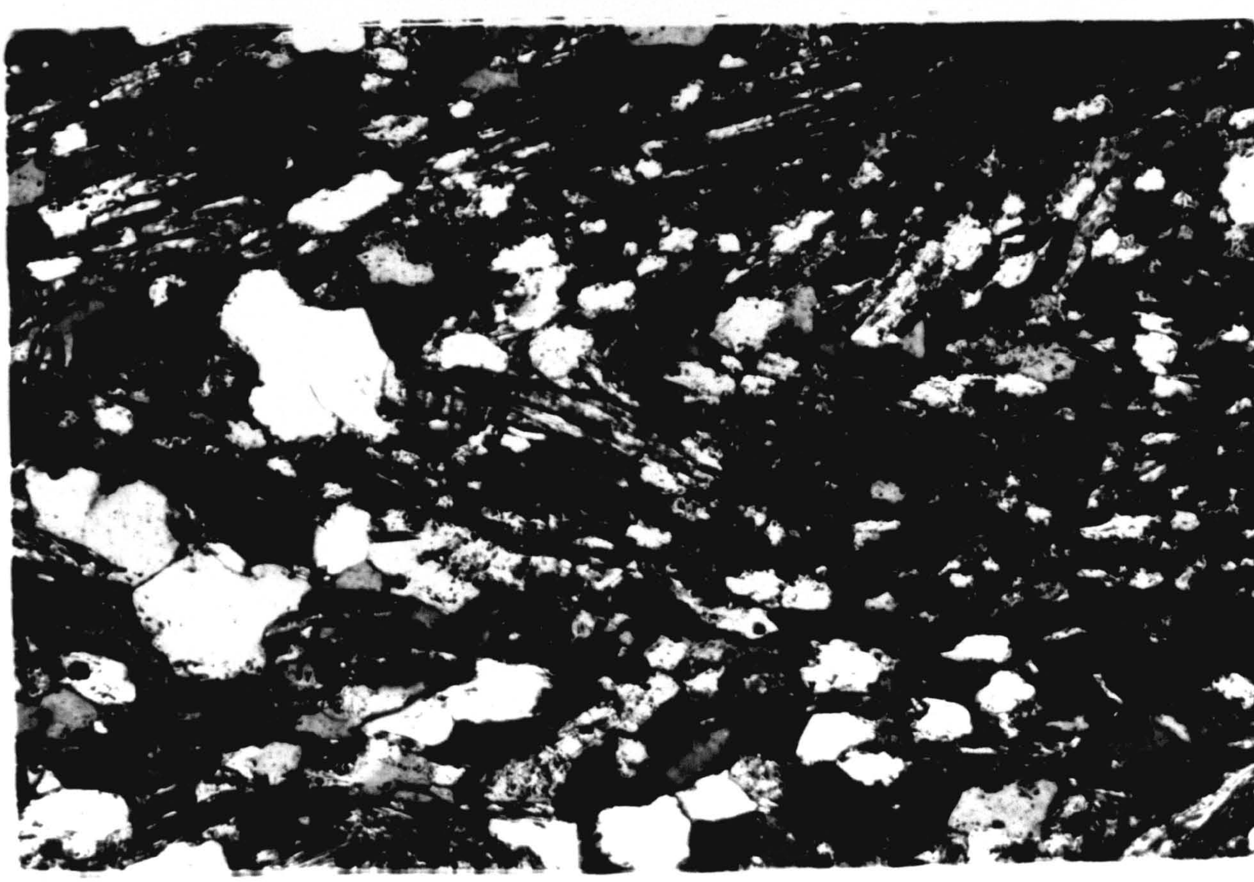


Fig. 2:17 Micaschistes de Penzé, Pont Éon

Rare, small macroscopic F2 isoclines. The quartz-rich bands are commonly laterally impersistant and display marked hinge thickening and limb attenuation.

Scale: Lens cap = 54 mm

Fig. 2:18 Amphibolites de Pte. St. Jean, Île Inizan

An F2 isoclinal fold in the striped amphibolites deforms the S1 segregation banding. The fold plunges steeply (at 74°) to the southwest. The large quartz-segregation lens post-dates D2/M2 and truncates the fold.

Scale: Ruler = 30 cm

Fig. 2:18b Amphibolites de Pte. St. Jean, Pte. St. Jean.

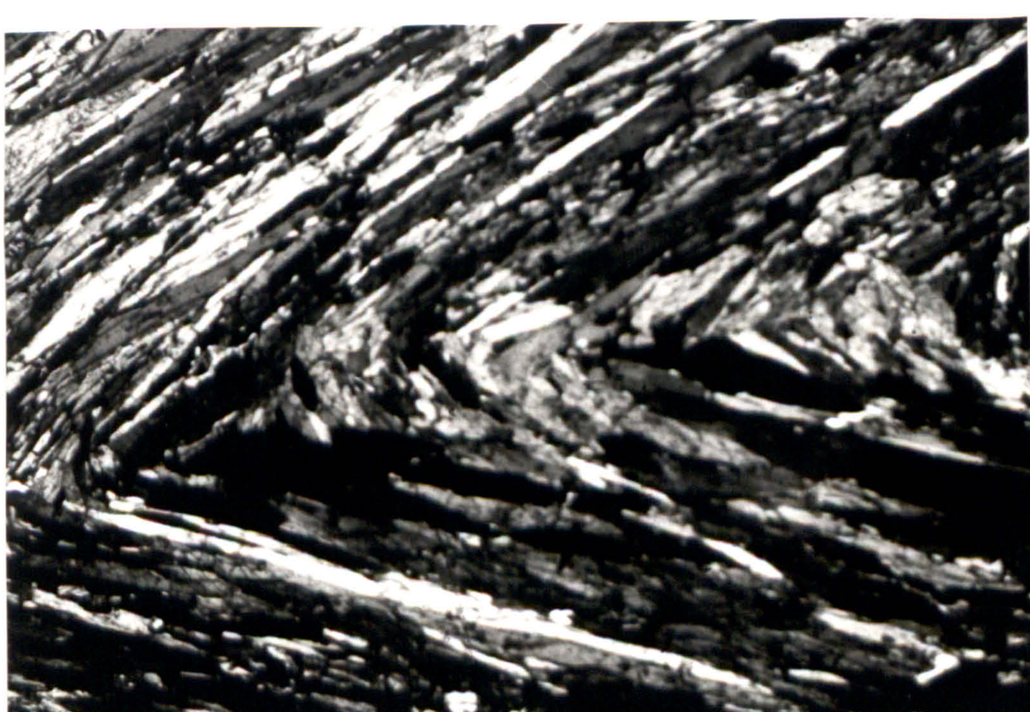
Photomicrograph to show the detail of an F2 hinge zone (as above) in the striped amphibolites. Hornblende prisms are largely mimectic about the hinge indicating that the M2 episode post-dated the D2 fold episode.

Scale: x40 XPL

Fig. 2 : 17

Fig. 2 : 18

Fig. 2 : 18b



The amphibolites have been heterogenously deformed by the D2 episode. Isoclinal to tight folds are developed in preferred horizons where the S1 amphibolite banding is well-developed (Figs. 2:5 and 2:18). Massive dark amphibolites are rarely seen to be folded on outcrop scale. Tight chevron folds occur as accommodation structures within the finely banded amphibolite horizons and are therefore restricted (Fig. 2:5). Good examples may be seen to the SE of the Pte. St. Jean (GR 1386 1287). The folds pre-date peak M2 metamorphism. Hornblendes are mimectic around hinge zones (Fig. 2:18B). The later development of prismatic hornblendes exaggerates the tight angular hinge zones.

A weak spaced S2 cleavage is associated with the development of the F2 folds in both amphibolites and metasediments (Fig. 2:19). An intersection lineation between S1 and S2 is developed, and is approximately parallel to the plunge of the F2 isoclines (ie. usually steep to the SSW).

The metamorphism associated with D2 resulted in the assemblages given in Table 2.1. The assemblages accord with the amphibolite facies of Turner (1981, p. 366). The climactic M2 assemblages have undergone some retrogression during the later M3 or M4 events. Assemblages observed in the Amphibolites de Pte. St. Jean include clinopyroxene. This mineral, thought to be augite, is restricted to quartzo-feldspathic horizons within the banded amphibolites where it has an equigranular form (Fig. 2:4). Its form and relationship to the other minerals present suggests that it is the product of the prograde M2 metamorphism.

Cordierite and garnet (almandine) are restricted to certain horizons within the metasediments and also indicate an M2 prograde assemblage.

A map showing the metamorphic index minerals within the St. Pol-de-Léon Metamorphic Complex (Fig. 2:19) shows a general increase in grade towards the north and west of the sector.

FIG 2:19 M2 METAMORPHIC INDEX MINERALS ACROSS THE CSB

The M2 metamorphic mineral assemblage increases markedly in grade across the CSB as shown by the index minerals present within the different lithologies on either side of the shear belt. The well-developed S1 fabric recognised in the St. Pol-de-Léon Metamorphic Complex, west of the CSB (considered to be of D1/M1 Cadomian age), largely masks any primary structures in both metasedimentary and meta-igneous lithologies. This early fabric has been modified during peak D2/M2 deformation and metamorphism. Primary structures are preserved in the Devono-Carboniferous lithologies of the Morlaix Basin. East of the CSB, the D2/M2 assemblage is within the greenschist facies.

Movement along the CSB, which resulted in the juxtaposition of the two contrasting tectono-metamorphic terrains, was terminated at the end of D2/M2 times. Within the St. Pol-de-Léon Metamorphic Complex a general increase in metamorphic grade is recognised to the north and west, ie. towards the Lannilis Metamorphic Complex and the Plougerneau Migmatite Complex (Roper 1980).

KEY

CSB. Blastomylonites of possible metasedimentary and/or metaigneous origin.

EAST OF THE CSB : MORLAIX BASIN

MSED Metasediments

AMPH Formation de Barnénez

GRST Meta-basic dyke suite, now greenstones.

WEST OF THE CSB : ST. POL-DE-LÉON METAMORPHIC COMPLEX

M. SED Micaschistes de Penzé

AMPH Amphibolites de Pte. St. Jean

GGNS Gneiss Granitique d'Île Callot

Undifferentiated Hercynian Granite

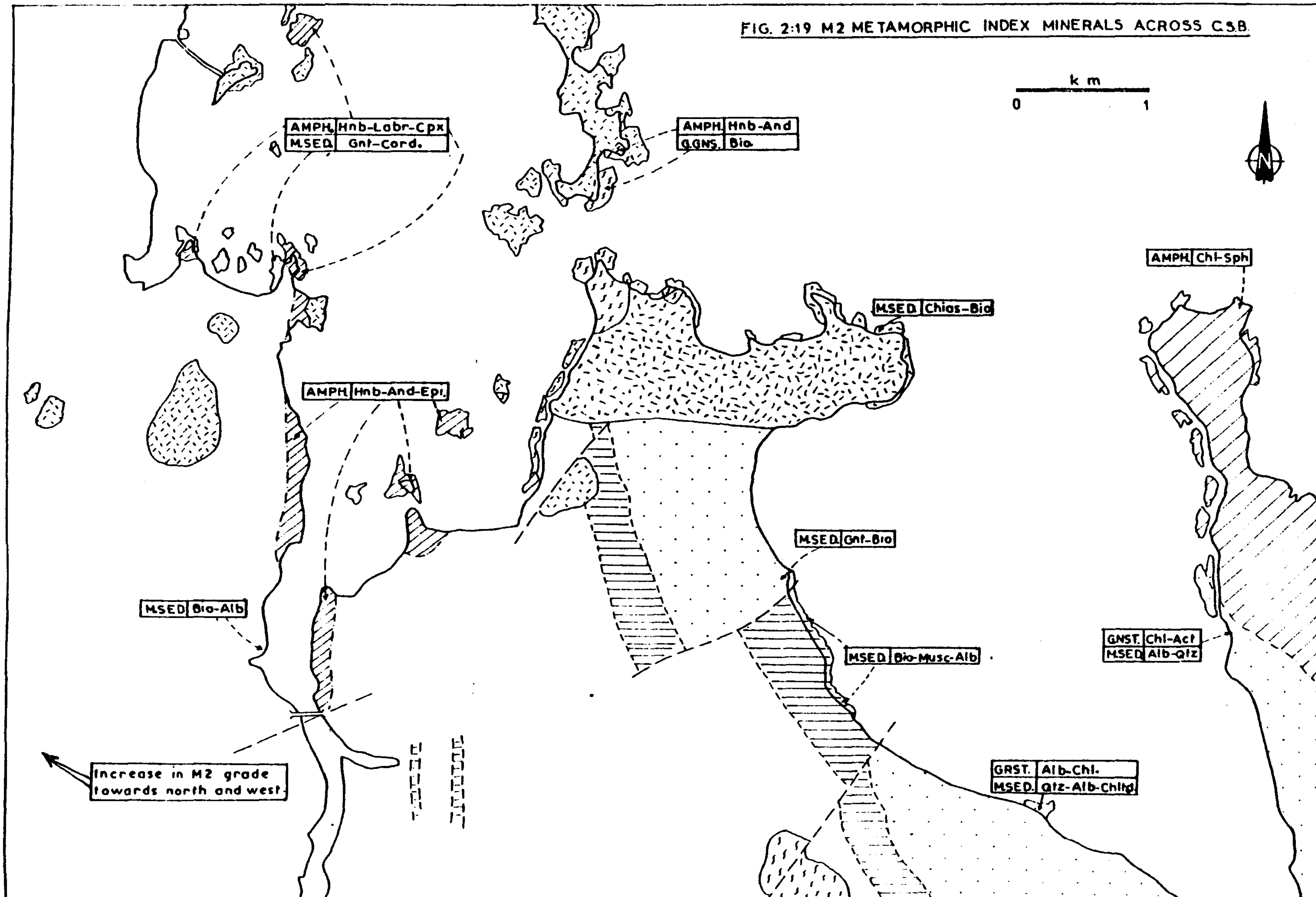


FIG. 2:19 M2 METAMORPHIC INDEX MINERALS ACROSS C.S.B.

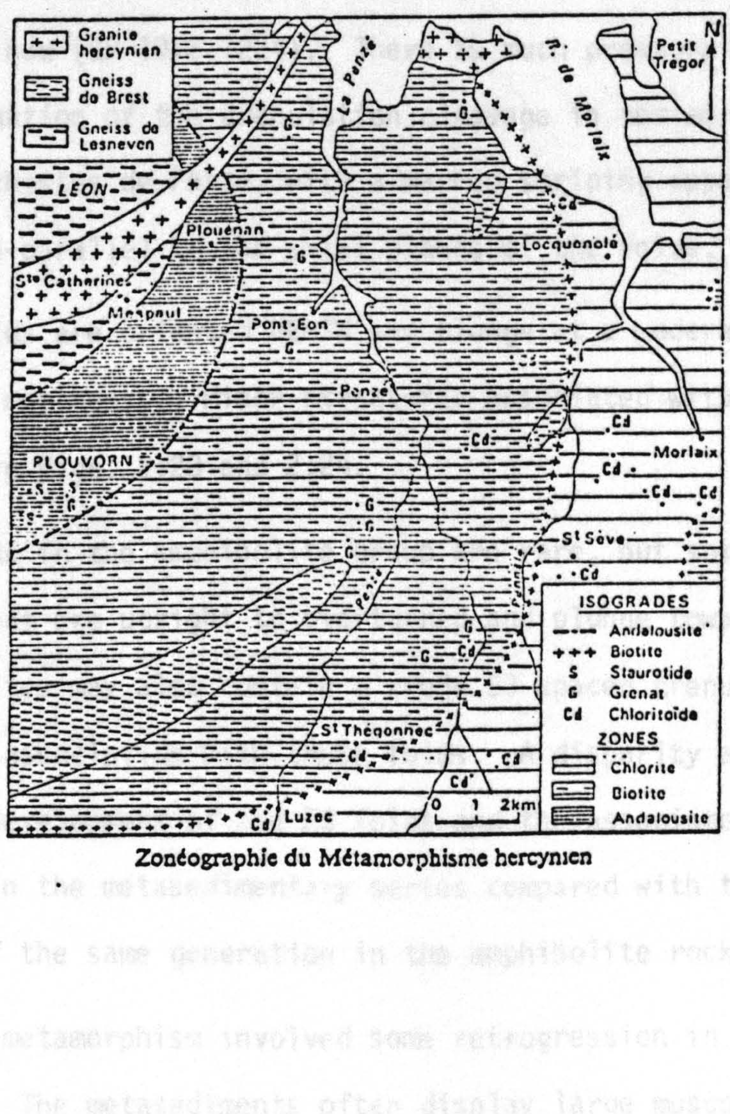
The development of clinopyroxene and labradorite (An_{56}) in the Amphibolites de Pte. St. Jean, and garnet and cordierite in their Micaschistes de Penzé in the area to the northwest of the Rivière de Penzé is indicative of upper amphibolite facies metamorphism.

To the east of the river, epidote and andesine (An_{40}) are indicative of lower amphibolite facies. Cabanis (1975) has produced a metamorphic map of the eastern Pays de Léon (Fig. 2:20) but he does not recognise this important transition. Further to the west, Roper (1980) has described sillimanite-bearing schists and migmatites in the NW Pays de Léon. It may be argued that the regional M2 episode progrades towards the NW of the Pays de Léon, but further studies are required in the Brignogan-Plouescat area in order to validate this argument.

The Gneiss Granitique de'Île Callot intrudes the amphibolites and the metasedimentary schists. The granitic gneiss and the intrusive meta-basic dykes possess a well developed gneissose banding, the regional trend of which is approximately NNW-SSW. Within the main outcrop of the Hercynian Granite de Primel - Carantec individual blocks of this gneiss (containing the dykes) have been reorientated (Fig. 2:11) and doming of the gneiss may have occurred as the granite was emplaced.

An important consideration with regard to the timing and sequence of the deformational episodes is the presence of the metabasic sheet intrusions within the Gneiss Granitique d'Île Callot. It is considered that the amphibolitization of the basic sheets occurred during M2, as they possess a strong fabric (parallel to the host granitic gneiss) and a high-grade assemblage. Therefore, if the age of the metabasic sheets is known some indication as the age of D2/M2 may be given. This is discussed together with the similarity of deformation events in the western Pays de Léon on p. 50.

Fig. 2 : 20 ZONATION OF HERCYNIAN METAMORPHISM IN THE EASTERN PAYS DE LEON
(AFTER CABANIS, 1975)



Zonéographie du Métamorphisme hercynien

(4) THE D3 STRUCTURES AND ASSOCIATED M3 METAMORPHISM

The D3/M3 episode resulted in strong folding of the metasedimentary rocks with little deformation of the amphibolite group. Folds are upright to slightly overturned with an associated well-developed S3 crenulation cleavage (Figs. 2:21 and 2:22). F3 folds reorientate the isoclinal F2 folds and fold the S1 segregation banding. Fig. 2:21 shows good relationships at Milinou (GR 1372 1224). There is much pressure solution associated with the formation of the crenulation cleavage in the more pelitic horizons of the Micaschistes de Penzé, with a marked striping apparent that is developed sub-parallel to the axial planes of the folds.

The folds are oriented NE-SW and plunge at a moderate angle, usually 40-60^{0} to the northeast. Minor structures associated with these folds are illustrated in Figs. 2:23 and 2:24.

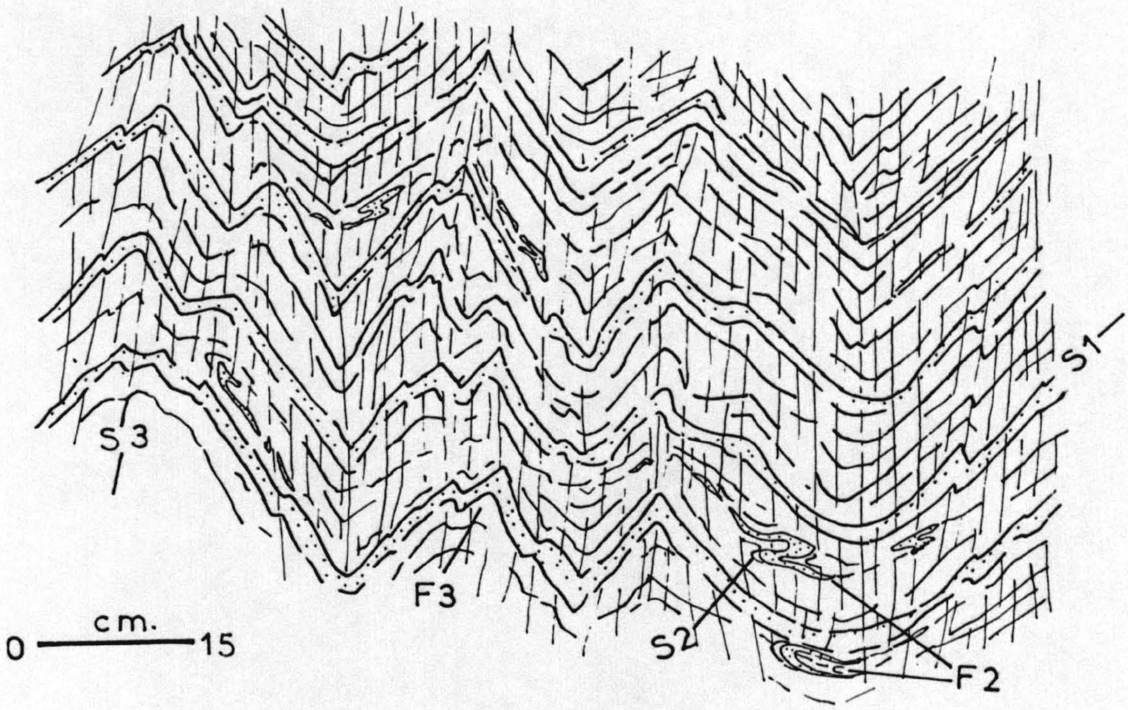
F3 folds in the amphibolite group are rare, but some folds are recognised that are upright to overturned and plunge towards the northeast. The amphibolites may also contain a crude S3 spaced crenulation cleavage developed in association with these folds. A disparity arises as to the ubiquituous development of the F3 folds and the associated S3 cleavage present within the metasedimentary series compared with the rarity of structures of the same generation in the amphibolite rocks.

The M3 metamorphism involved some retrogression in the climatic M2 assemblages. The metasediments often display large muscovite grains approximately parallel to the axial planes of F3 folds. Reactions that may have been involved in the retrogression include:-

Biotite→chlorite, cordierite→pinnite, feldspar→sericite. Muscovite plates are also present within the Gneiss Granitique d'Île Callot, but this lithology appears to be little deformed by the D3 episode.

It may be argued that the granitic gneiss and amphibolites acted as homogeneous 'blocks', with only minor structures forming during the D3 episode. The metasediments may have acted in a ductile manner with well-

Fig. 2:21 Micaschistes de Penzé, Pont Eon



F3 folds with occasional refolded F2 folds. The F2 folds are preserved as transposed recumbent structures that are refolded by dominantly upright F3 structures. The F3 folds plunge NE at a moderate angle. S3 is well-developed and is a crenulation cleavage along which pressure solution striping may develop.

Fig. 2:22 Micaschistes de Penzé, Penzé village

Detail of the S3 crenulation fabric which deforms the S1/S2 mica layering. S1 is the early segregation banding and S2 is recognised as a spaced cleavage associated with isoclinal folds.

Scale: x16 XPL

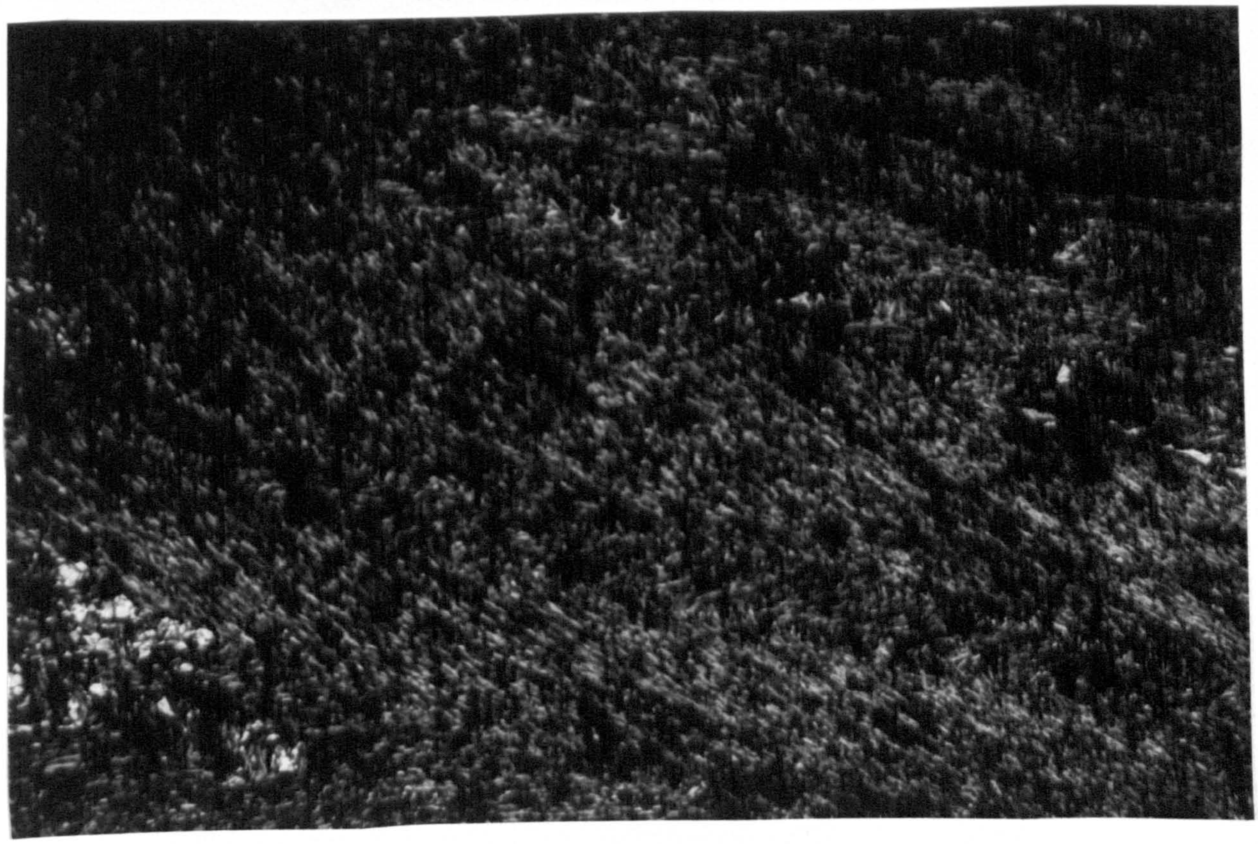


Fig. 2:23 Micaschistes de Penzé, Penzé village

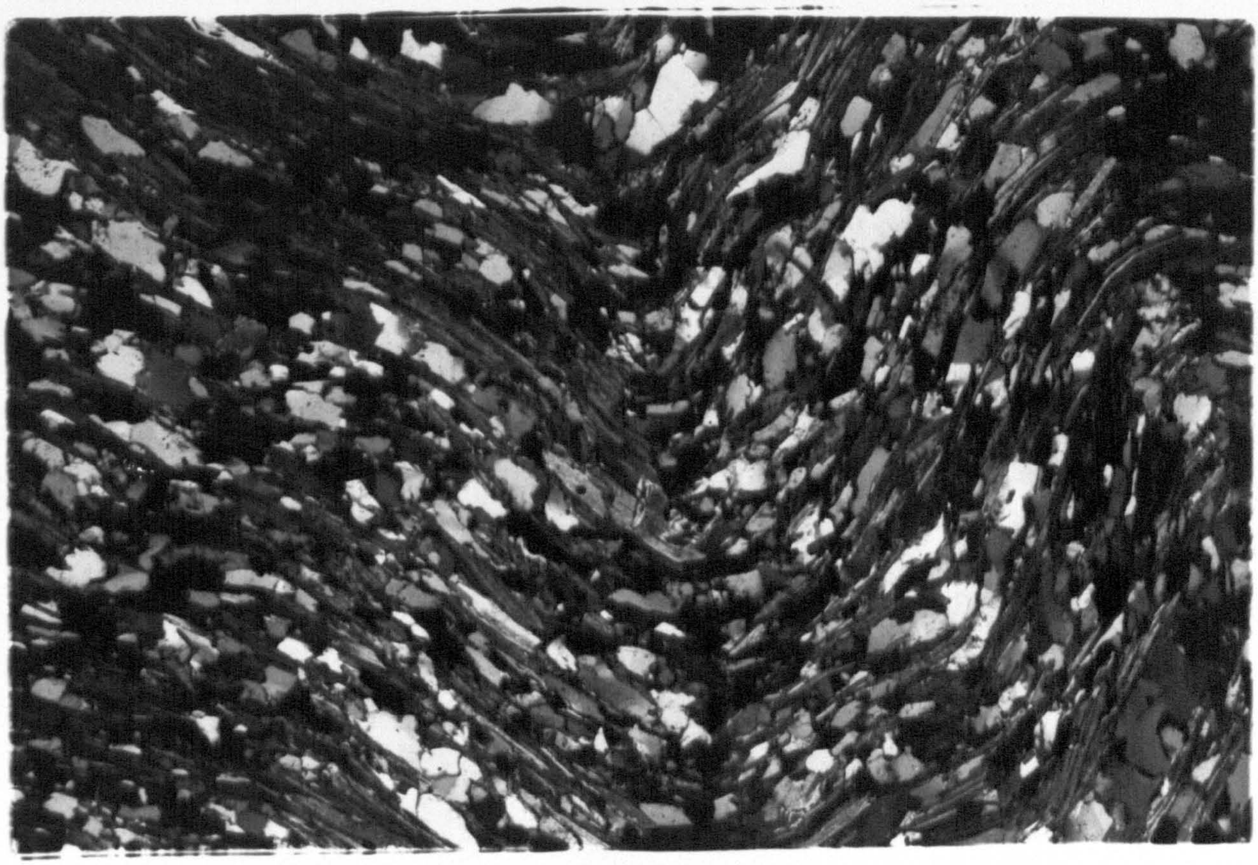
Detail of an F3 hinge zone in which the muscovite grains are gently folded and quartz displays slight undulose extinction.

Scale: x16 XPL

Fig. 2:24 Misaschistes de Penzé, Penzé village

Detail of an F3 hinge zone, the deformation of muscovite and quartz grains indicates that the assemblage is D2/M2.

Scale: x16 XPL



developed slip-surfaces (S1) along which further folding occurred.

(5) THE POST-D3 STRUCTURES

(a) The D4/M4 Episode

The D4/M4 episode resulted in extensive 'flexuring' of the metasediments, amphibolites and the granitic gneiss. The Amphibolites de Pte. St. Jean commonly display these flexures which are characterized by a warping or open folding of the S1 banding (Fig. 2:25). Within the hinge areas of these folds there are commonly small chevron folds that accommodate the overall fold shape. The chevrons are often fractured in their hinge areas and a spaced fracture cleavage is associated with them.

The small-scale chevron folds are lithologically controlled, their distribution being restricted to the finely-striped horizons within the amphibolite group and the finer banded metasedimentary types. Within the Gneiss Granitique d'Île Callot kink-bands/chevron folds are developed in the finer-grained, more schistose horizons, and are thought to correspond to the D4 structures seen elsewhere. The flexures develop in conjugate sets with axial trends at 270-340^{0} and 360-050^{0}. Axes dip steeply to the W or NW (Fig. 2:25).

Associated with the D4 deformation is an element of stretching, in which marker horizons e.g. the banded amphibolites of the Amphibolites de Pte. St. Jean and the amphibolite sheets that truncate the Gneiss Granitique d'Île Callot, can be seen to be boudinaged. In detail, the hinge zones of the F4 folds show some thickening and limbs are attenuated in the direction of stretching. The small chevron folds show the same form.

(b) The D5/M5 Episode

D5 deformation resulted in the minor faulting of the pre-Hercynian metamorphic rocks of the St. Pol-de-Léon Metamorphic Complex. This episode of deformation may be closely related in time to D4 as chevron

Fig. 2:25   Amphibolites de Pte. St. Jean, Pte. St. Jean

A D4 open warp or flexural fold in which minor chevron folds are developed in the hinge area. Small-scale faults are commonly formed in the hinge area of such structures.

Scale: Hammer shaft = 36 cm

structures and kink-bands reflect a brittle/ductile transition and many of the D4 flexural folds and chevron folds display brittle limb-thrust structures (Fig. 2:25).

(D) THE PRIMARY NATURE AND POSSIBLE AGE OF THE ROCKS COMPRISING THE ST. POL-DE-LÉON METAMORPHIC COMPLEX

Some attention has already been drawn as the relationships between the metabasic, metagranite and metasedimentary units that make up the St. Pol-de-Léon Metamorphic Complex. Although much of the primary lithological detail has been lost as a result of deformation and metamorphism there is evidence that:-

1. The Micaschistes de Penzé and Amphibolites de Pte. St. Jean pre-date the D1/M1 episode and are possible in part contemporaneous.
2. The Gneiss Granitique d'Île Callot is younger than the Micaschistes de Penzé and Amphibolites de Pte. St. Jean and is itself cut by a suite of metabasic sheets.

(1) THE AMPHIBOLITES DE PTE. ST. JEAN AND THE MICASCHISTES DE PENZÉ

There is a broad similarity between the Micaschistes de Penzé of the St. Pol-de-Léon Metamorphic Complex and the Micaschistes de L'Aber Wrac'h (Roper 1980) and the Micaschistes de Conquet (Chauris et al. 1972) of the western Pays de Léon. It is suggested that the Micaschistes de Penzé are the eastern equivalent of the above mentioned micaschist units.

The age of the metasedimentary units of the western Pays de Léon has been discussed by Roper (op. cit.). He points out the stratigraphical and lithological evidence used by Cogné and Shelley (1966), Chauris (1966) and his own findings, to show that the metasedimentary units he labels the Micaschistes de l'Aber Wrac'h are the probable equivalents of the Quartophyllades de l'Elorn, a thick meta-greywacke and mudstone sequence that is considered to be Brioverian in age by Darboux (1974) and Bishop et al. (1969). Field observations by the present author on the nature of the Quartzophyllades de l'Elorn in the Rade de Brest, the Micaschistes de Conquet at Le Conquet, the Micaschistes de L'Aber Wrac'h along the Aber Wrac'h view supports this view.

Therefore the Micaschistes de Penzé are considered to be the lateral equivalents of the Brioverian Quartzophyllades de L'Elorn and the Micaschistes de L'Aber Wrac'h.

The amphibolites de Pte. St. Jean shares a common deformational history to the metasedimentary units and have been shown to be in part contemperaneous. The thick amphibolite sequence may represent one of the following:-

1. An intrusive basic igneous suite.
2. An extrusive basic volcanic suite.
3. An extrusive basic pile injected by intrusive basic igneous rocks.
4. A series of paraamphibolites of sedimentary/volcaniclastic origin.

In order to determine the primary nature of the amphibolites it is useful to examine other meta-basic assemblages in northern Brittany which show varying degrees of metamorphic segregation banding.

Within the study area there are two areas in which metabasic rocks are interbanded with metasediments. Within the Baie de Morlaix at the Pte. de Barnénez (GR 1438 1272) a suite of amphibolites are interbanded as sheet-like masses with metasediments. The metasediments show evidence of polyphase deformation and the amphibolites, which were emplaced as basic sheets into unconsolidated sediment, now possess a weak segregation banding (see Chapter 6).

A second example occurs in the area around Pte. de l'Armorique (GR 1609 1268) within the Petit Trégor. At this locality highly folded metasedimentary screens, c. 1 m thick, occur interbanded with a series of recognisable massive and pillowed lavas of basic composition, now metamorphosed to a greenschist assemblage. Primary relationships are preserved to some degree and the recognisable pillow lavas, plus occasional meta-hyaloclastite horizons, point to a volcanic parentage for these rocks. The metavolcanic Formation de Pte. de l'Armorique is assigned to the Brioverian (Verdier 1968; Autran et al. 1979) and is overlain by a thick metagreywacke succession known as the Formation de Plestin. The stratigraphy is based partly on relationships seen elsewhere by this author in northern Brittany, principally within the Baie de St. Brieuc and at Pte. de Guilben, near Paimpol in the Trégor.

Within the western Pays de Léon, Roper (op. cit.) gives some discussion as to the origin of metabasic rocks occurring in association with themetasedimentary Micaschistes de L'Aber Wrac'h. He quotes the options presented by Chauris (op. cit.) that the metabasic rocks may represent:-

1. Contemporaneous (therefore Brioverian) volcanic horizons within the metasediments.

2. Intrusions into the metasediments.

It is interesting to note, in this case, that along the north side of the Baie de Douarnenez, at Plage de Telgrue, a series of pillow lavas can be observed interbanded within the Brioverian metasediments.

With regard to the primary nature of the rocks now represented by the Amphibolites de Pte. St. Jean and the Micaschistes de Penzé it is apparent, therefore, that throughout north and west Brittany there are similar associations preserved at lower metamorphic grades. Nowhere is a sedimentary sequence preserved, of such composition, that would account for a para-amphibolite origin as envisaged by Delattre et al. (1966) for the Amphibolites de Pte. St. Jean.

A Brioverian parentage is therefore considered most likely for the Amphibolites de Pte. St. Jean and the Micaschistes de Penzé, as analogies can be drawn with similar associations preserved at a lower metamorphic grade. Both of these groups have undergone intense polyphase deformation and medium-high grade metamorphism in part of the St. Pol-de-Léon Metamorphic Complex. The deformational history is different to that of the adjacent Devonian-Carboniferous lithologies of the Morlaix Basin.

(2) THE GNEISS GRANITIQUE D'ILE CALLOT AND THE AMPHIBOLITE SHEETS

The amphibolites and the metasediments have been truncated by a third lithological unit, the Gneiss Granitique d'Île Callot. The gneiss, as shown earlier, is a highly deformed body with a well-developed planar and linear fabric. Within the gneiss are amphibolite sheets, indicating that the deformation and metamorphism of both the gneiss and amphibolite sheets was post-D1 and pre-D2 (the peak metamorphic episode).

The Gneiss de Brest of the western Pays de Léon is petrographically similar to the Gneiss Granitique d'Île Callot, and Chauris (1972) has mapped the gneisses at Île Callot as Gneiss de Brest. Roper (1980) has concluded that the Gneiss de Brest is of Cadomian age and Adams (1967) has given a Rb-Sr whole rock date of c. 550 ± 40 m.y. on specimens of what Roper (op. cit.) has identified as a low strain facies of this lithology.

The Perros-Guirec Granitoid Complex of the Trégor and its western extension in the study area (the Moulin de la Rive Orthogneiss Complex of the Petit Trégor, see Chapter 4) both truncate Brioverian lithologies. This forms a similar relationship to that observed in the St. Pol-de-Léon Metamorphic Complex, but is preserved at a lower metamorphic grade. A series of meta-basic sheets truncates the Perros-Guirec Granitoid Complex and they pre-date the peak deformation and metamorphic episode in the

Petit Trégor and Trégor areas. Field and geochronological evidence presented elsewhere in this thesis (Chapters 4, 5 and 6) points to a Cadomian age for the Perros-Guirec Granitoid Complex and an early Carboniferous age for the metabasic sheets.

Evidence drawn from observations in north and west Brittany, therefore, suggests a Cadomian age for the Gneiss Granitique d'Île Callot.

(E) SUMMARY

The amphibolites de Pte. St. Jean and the Micaschistes de Penzé are the oldest rocks present in the St. Pol-de-Léon Metamorphic Complex. They were deformed prior to the emplacement of the Gneiss Granitique d'Île Callot. This granitic gneiss was subsequently invaded by a suite of basic dykes.

Analogies drawn from other lithologies within the research area, and from northern Brittany, point to the amphibolites representing metabasic volcanics associated with metasediments of Brioverian age. The Gneiss Granitique d'Île Callot is considered to be of Cadomian age and may represent part of a much larger granitoid complex (the Gneiss de Brest and/or the Perros-Guirec Granitoid Complex).

Peak metamorphism accompanied the D2/M2 episode and it is considered that the Carantec Shear Belt was initiated at this time. The D2/M2 episode occurred after the emplacement of the metabasic dyke suite, which is of lowermost Carboniferous age and related to major basaltic volcanism in the adjacent Morlaix Basin (discussed in Chapter 6).

The lithologies of the St. Pol-de-Léon Metamorphic Complex were further deformed during the D3/M3 episode, with F3 folds being particularly well-developed in the metasedimentary schists. Two further periods of deformation, D4 and D5 are related to the Hercynian granite plutonism (discussed in Chapter 7 and 8).

The lithologies present within the St. Pol-de-Léon Metamorphic Complex and the sequence of structural and metamorphic episodes are similar to those present within the Lannilis Metamorphic Complex (Roper 1980). Roper (op. cit.) attributes peak metamorphism (D2/M2) in the Lannilis Metamorphic Complex to the latest Devonian-earliest Carboniferous Bretonic earth-movements. In Chapter 8 however, attention is drawn to the problem of correlating the timing of the deformation episodes in NW Brittany, as stratigraphical evidence from the Morlaix Basin (Chapter 6) points to a slightly later, Lower Carboniferous age for the D2/M2 episode (the Bretonic in Stille's terminology, Fig. 1:8). There is agreement that the peak metamorphism occurred at around 345-350 m.y., based on the available geochronological data.

The extensive Hercynian granites and the Mixed Metasediments and Amphibolites of the Baie de Morlaix which are contained within the granites are discussed in Chapter 7. The geological evolution of the St. Pol-de-Léon Metamorphic Complex and its relationship in a regional context is discussed in Chapter 8.

It is concluded here that the Lannilis and St. Pol-de-Léon Metamorphic Complexes are essentially part of the same complex that comprises the major part of the Pays de Léon.

CHAPTER THREE

THE BRIOVERIAN ROCKS OF THE PETIT TRÉGOR

CHAPTER THREE

THE BRIOVERIAN ROCKS OF THE PETIT TRÉGOR

(A) INTRODUCTION

(1) PRELIMINARY STATEMENT

This chapter is concerned with rocks assigned to the Brioverian Supergroup which crop out along the coast between the Baie de Locquirec and the eastern side of the Grève-de-St. Michel and which extend inland southwestwards towards the Morlaix Basin area. Rocks of possible Brioverian age belonging to the St. Pol-de-Léon Metamorphic Complex are not included within this chapter.

The Brioverian, as discussed in this thesis, commenced with a thick sequence of basic eruptive rocks (pillowed and non-pillowed lavas and sills) with some thin sedimentary horizons and both concordant and cross-cutting acid intrusive sheets. Together these constitute the Formation de Pte. de l'Armorique. This formation is overlain by a thick sequence of epiclastic sediments with minor basic and acid intrusive sheets which constitutes the Formation de Plestin. This stratigraphy for rocks assigned to the Brioverian in the study area is radically different to that proposed by previous workers. The major differences of the local stratigraphy compared to previous interpretations are summarised both in Table 3:1 and here:-

1. The Moulin de la Rive Orthogneiss Complex (discussed in Chapter 4) is interpreted as a Cadomian igneous complex which was intruded into the Brioverian supracrustal rocks. This igneous complex represents the westerly continuation of the major Perros-Guirec Granitoid Complex of the Trégor. The Moulin de la Rive Orthogneiss Complex has been previously assigned to the Pentevrian, (Verdier 1968; Auvray et al. 1980a) and it has been given different names by previous authors (Table 4:1).

2. The dominantly granitic mylonites that constitute the Locquirec Shear Belt (LSB), discussed in Chapter 5, are interpreted as having formed within a major ductile shear zone. The LSB is located along the southeastern marginal zone of the Moulin de la Rive Orthogneiss Complex. Cadomian and Hercynian earth movements contributed to the formation of the mylonitic rocks which have been previously interpreted as supracrustal rocks forming the basal part of the Brioverian sequence. These have been described as a sequence of quartzo-feldspathic grits and arkoses followed by acidic pyroclastics with epiclastic (particularly conglomeratic) interbeds, all labelled the Series de Locquirec by Verdier (1968), the Formation de Locquirec by Autran et al. (1979) and the Tuffs de Tréguier and Locquirec by Auvray (1979). According to these authors this mixed epiclastic-pyroclastic sequence was deposited with major unconformity upon the crystalline rocks in the Moulin de la Rive area and was conformably overlain by the basic extrusives and sediments of the succeeding Brioverian (the Formation de Pte. de l'Armorique and Formation de Plestin respectively of this thesis).

The relationships proposed here imply, that since the LSB rocks were produced from the strong deformation of the marginal facies of the Moulin de la Rive Orthogneiss Complex, the northwest boundary of the shear belt (Fig. 5:15) marks the boundary from a relatively low to a high strain regime. It does not mark an unconformable junction between Brioverian supracrustal rocks and a Pentevrian basement complex. It will be demonstrated that the south-southeastern boundary of the LSB represents the original, albeit highly deformed, intrusive junction between the Brioverian Formation de Pte. de l'Armorique and the marginal (now mylonitized) components of the younger Cadomian Moulin de la Rive Orthogneiss Complex.

(2) PREVIOUS RESEARCH IN THE AREA OF STUDY

The stratigraphy of the Brioverian Supergroup has for a long time been the subject of discussion (eg. Barrois and Pruvost 1929; Graindor 1957, 1965; Le Corre 1976, 1977). This has been largely due to the fact that correlation between different parts of the Brioverian outcrop is difficult because of the lack of fossils, the monotonous nature of the sediments and lack of distinctive lithostratigraphic markers. All the above authors agree with the subdivision of the Brioverian into three major groups:-

1. The Lower (Inferieur, Xa on maps)
2. The Middle (Moyen, Xb)
3. The Upper (Superieur, Xc)

Each of these divisions has been further divided into "stages" which have been summarised by Le Corre (1977).

Within the northern part of the Armoricain Massif the Lower Brioverian is largely represented by a thick sequence of basic volcanic rocks with thin intercalated bands of metasediment that, either conformably overlies a thin basal epiclastic sequence, the Serie de Cesson near Cesson at the head of the Baie de St. Brieuc (Cogné 1962), or rests upon supposed mixed epiclastic sediments and pyroclastic rocks in the Locquirec area (Autran et al. 1979). The name given to the Lower Brioverian basic volcanic sequence varies between authors (Table 3:1). Around the Baie de St. Brieuc, it is generally referred to as the Amphibolites and Schistes de Lanvollon (Cogné 1962). In the present study area the local name used in this thesis is the Formation de Pte. de l'Armorique (c.f. Formation de L'Armorique of Autran et al. 1979). Auvray (1979) has outlined the arguments given by various workers regarding the relative age of the Lower Brioverian basic volcanic and sedimentary sequences in Northern Brittany.

This author	Formation de Pte de l'Armorique	Formation de Plestin
Barrois 1909	Schistes cristallins à Epidiorite de Lannion	Schistes briovériens
Sandréa 1958	Series epimetamorphique à chlorite, amphibole, epidote	Series epimetamorphique à chlorite, amphibole, epidote
Delattre et al. 1966	Epidiorite de Plestin	Quartzophyllades de St-Martin-des-Champs
Verdier 1968	Sèries de la Pointe de l'Armorique	Grès feldspathiques de St-Efflam
Autran et al. 1979	Formation de Rugunay and Formation de l'Armorique	Formation de Plestin
Auvray 1979	Formation volcano-sedimentaire de l'Armorique-Trédrez (= Lanvollon)	Formation greywackeuse de Saint-Efflam

TABLE 3 : 1 NOMENCLATURE APPLIED TO THE BRIOVERIAN SUCCESSION IN THE PETIT TRÉGOR

As already indicated,a major difference of opinion exists regarding the interpretation of the nature and age of the Formation de Moulin de la Rive and the Formation de Locquirec sensu Autran et al. (1979) between the present author on the one side and Verdier (1968), Autran et al. (op. cit.) and Auvray (op. cit.) on the other. These differences are highlighted in a table showing the stratigraphic sequences proposed for this area by these authors (Table 3:2).

All the authors cited above recognise a Pentevrian basement represented by the orthogneisses of the Series/Formation de Moulin de la Rive (the Moulin de la Rive Orthogneiss Complex of this thesis) on which the Brioverian is said to rest unconformably. Autran et al. (op. cit.) provide the most detailed map of this area, which is based largely on the previous work of Verdier (op. cit.). The Moulin de la Rive Orthogneiss Complex has been dated by Auvray et al. (1980) as having been formed at c.1800 M.y. (Lower Proterozoic) and is compared to the Icart Gneisses on Guernsey . The age date obtained is based on U-Pb zircon concordia-discordia methods and will be discussed in more detail in Chapter 4, part (F).

Cogné (1972) has correlated the problematical poudingues (conglomerates) at Locquirec with the Poudingue de Cesson, of the Baie de St. Brieuc (Barrois 1895b), and he proposed that these marked the base of the Brioverian. Verdier (1968) had previously recognised a series of poudingues, arkoses, keratophyric tuffs, argilites, siltites and basic tuffs, that overlay the basement in a similar manner to that observed at Pentevrian/Brioverian boundary at Jospinet (Cogné 1959a). Verdier (op. cit.) assigned these rocks, which he labelled the Serie de Locquirec, to the Lower Brioverian. Auvray (1972) correlates the Tufs de Tréguier with the tuffs at Locquirec and places these within the Middle Brioverian.

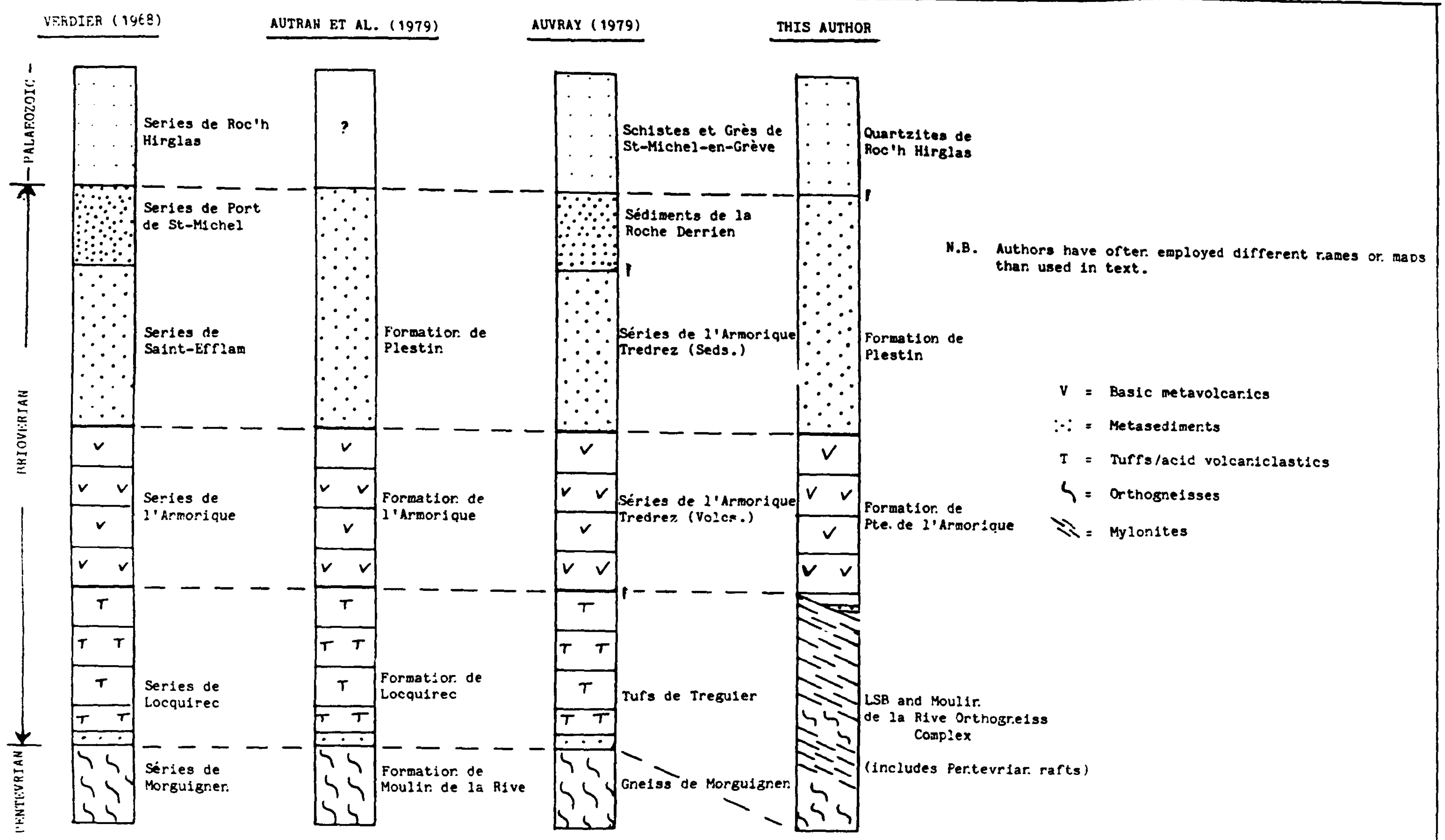


TABLE 3:2 COMPARATIVE LITHOLOGICAL SECTIONS ; PTE DU CORBEAU - St-MICHEL-EN-GREVE

It will be shown in Chapter 5 that this supposed epiclastic-pyroclastic sequence occurs within the Locquirec Shear Belt and that the rocks are mylonitic rocks derived from igneous rocks of the Moulin de la Rive Orthogneiss Complex as described in Chapter 4. Overlying the Formation de Locquirec according to Autran et al. (op. cit.) are "lavas et tufs keratophyrique" and "tufs keratophyrique en lentilles" known as the Formation de Rugunay. The Formation de Rugunay is not recognised in the present work and has not been mapped by other workers.

The basic extrusive Formation de L'Armorique overlies the Formation de Rugunay according to Autran et al (op. cit.), and is assigned to the Lower Brioverian. In this thesis the two formations are considered together within the Formation de Pte. de l'Armorique. Verdier (1968), Auvray (1979) and Autran et al. (op. cit.) have described the nature of the basic volcanic series.

These authors consider the sedimentary Formation de Plestin (this thesis) to overlie the metavolcanic rocks . Auvray (op. cit.) considered both the Tufs de Tréguier and the Formation greywackeuse de Saint Efflam (c.f. Formation de Plestin of this thesis) to be contemporaneous and deposited in two "sillons palaeogeographiques" in Middle Brioverian times, the tuffs and the felspathic grits now being in tectonic contact. Autran et al. (op. cit.) attributes the Formation de Plestin to an Upper Brioverian age, the whole Brioverian succession being represented, they believe, in the Baie de Lannion area. Delattre et al. (1966) attached a Devonian age (Emsian) to these rocks,which they termed the Quartzophyllades de St. Martin-des-Champs, and which were correlated with the Schistes Zébrés of the Morlaix area.

In geochemical studies Autran et al. (op. cit.) argue that the Brioverian acidic and basic formations (de Locquirec and de l'Armorique) represent a calc-alkaline association. Auvray (op. cit.) points to the similarity of the Granite de Beg ar Forn to the Granite de Talberg of the Cadomian Perros-Guirec Granitoid Complex of the Trégor which he demonstrates to be intrusive into the Brioverian rocks.

(3) AN OUTLINE OF THE DEFORMATION AND METAMORPHIC EVENTS

The Brioverian Supergroup in the Baie de Lannion area has a general trend that varies from NE-SW in the west to E-W in the east, (Map 2). The Formation de Pte. de l'Armorique and the Formation de Plestin have been subject to polyphase deformation. Their present distribution and trend is largely controlled by the D1 episode which was responsible for the mylonitization in the adjacent Locquirec Shear Belt (LSB).

The formations have been regionally metamorphosed within the lower greenschist facies. Significant hornfelsing has occurred along the northeast of the Grève de St. Michel within the contact aureole of the Hercynian Granite de Trédrez (Leutwein 1968).

The imposed strain is markedly heterogeneous and in high strain zones there are some fine examples of greenschists, with strong metamorphic segregation banding. The structural and metamorphic sequence is discussed in more detail, part (E) and summarised in Table 3:4.

The thin metasedimentary horizons within the Formation de Pte. de l'Armorique exhibit only minor folds while the dominantly metasedimentary Formation de Plestin is deformed by two fold phases.

(B) THE FORMATION DE PTE.DE L'ARMORIQUE

(1) INTRODUCTION

This formation is poorly exposed in the coastal area between Toul Ar Goué (GR 1588 1263) and l'Île Blanche (GR 1596 1255) but to the east of this locality, to the boundary with the Formation de Plestin, the coastal exposure is excellent. Inland exposure is generally poor (Map 3). Along the northeast Baie de Lannion within the contact aureole of the

Trédrez Granite the exposure is also good (Map 2).

The Formation de Pte. de l'Armorique is now approximately 2 km thick. Deformation and metamorphism has often erased many of the primary features within the metabasic rocks and interbedded sedimentary horizons (adinoles in French terminology). Way-up evidence is rare, but primary structures such as drape structures within the pillow lavas can sometimes be used to determine that the sequence youngs towards the southeast. Structural younging is inconsistent, major folds may be present but are not recognised due to lack of suitable marker horizons. Minor folds are readily developed within the sedimentary interbands and within these bands the asymmetry of the folds is inconsistent with 'primary' evidence given by pillow shapes.

A number of different lithologies showing distinctive morphological features have been mapped. These comprise medium-grained massive greenstones, fine-grained greenstones (greenschists), pillowed basic lavas, brecciated beds (pillow breccias), metasedimentary bands, and later concordant and cross-cutting acidic dykes. The occurrence and distribution of these units is shown on Map 3. Their morphology and petrography are described below.

(2) THE MEDIUM-GRAINED MASSIVE GREENSTONES

Much of the Formation de Pte. de l'Armorique has been mapped as massive greenstone. Greenstone is taken here to mean a metamorphosed basic igneous rock and is used as a field term. The greenstones form thick (up to 20 m) units with the thickest units displaying coarse centres relative to their margins. Grain-size is consistent across the thinner, more typical 1-2 m thick units. The greenschist metamorphic assemblage has replaced the primary basic igneous assemblage, but grain-size reflects the initial thickness of the units (Figs. 3:1, 3:3 and 3:4).

The medium-grained greenstones are strongly foliated with a well-developed schistosity parallel to their dominantly NE-SW strike. Where the schistosity is very closely spaced the greenschists are developed in part from the medium-grained greenstones. Such greenschists are developed in zones of high strain within which there is significant grain-size reduction and metamorphic segregation.

In hand-specimen infrequent epidote-rich pods occur that reflect an initial primary variation, possibly represent sites of original pillows or pillow fragments. These pods are common within the fine-grained greenstones and are discussed below.

In thin section the massive greenstones are medium-grained with euhedral amphiboles up to 3 mm in length while plagioclase, epidote and biotite are in the size range c. 0.5-2 mm. Mineralogy in order of importance is amphibole (hornblende + actinolite) + plagioclase + epidote + quartz + chlorite ± calcite ± biotite ± sphene. The hornblende commonly forms porphyroblasts which are commonly altered or replaced by actinolite. The foliated massive greenstones possess thin foliae, rich in chlorite + epidote + actinolite + quartz which anastomose around the hornblende + actinolite + calcite porphyroblastic aggregates and shadows (Fig. 3:3).

Plagioclase varies in importance according to the metamorphism. It is commonly replaced by epidote and quartz in the stronger foliated greenstones. Elsewhere, plagioclase An_{15} may form 20-25% of the mode. Calcite is common in the massive greenstones and forms euhedral crystals and aggregates within the foliated varieties. Epidote may be pistacite, zoisite or clinozoisite and commonly occurs in possible vesicle infills and throughout the formation. Hornblende may have developed at the expense of primary pyroxene (of smaller size). Verdier (1968) suggests

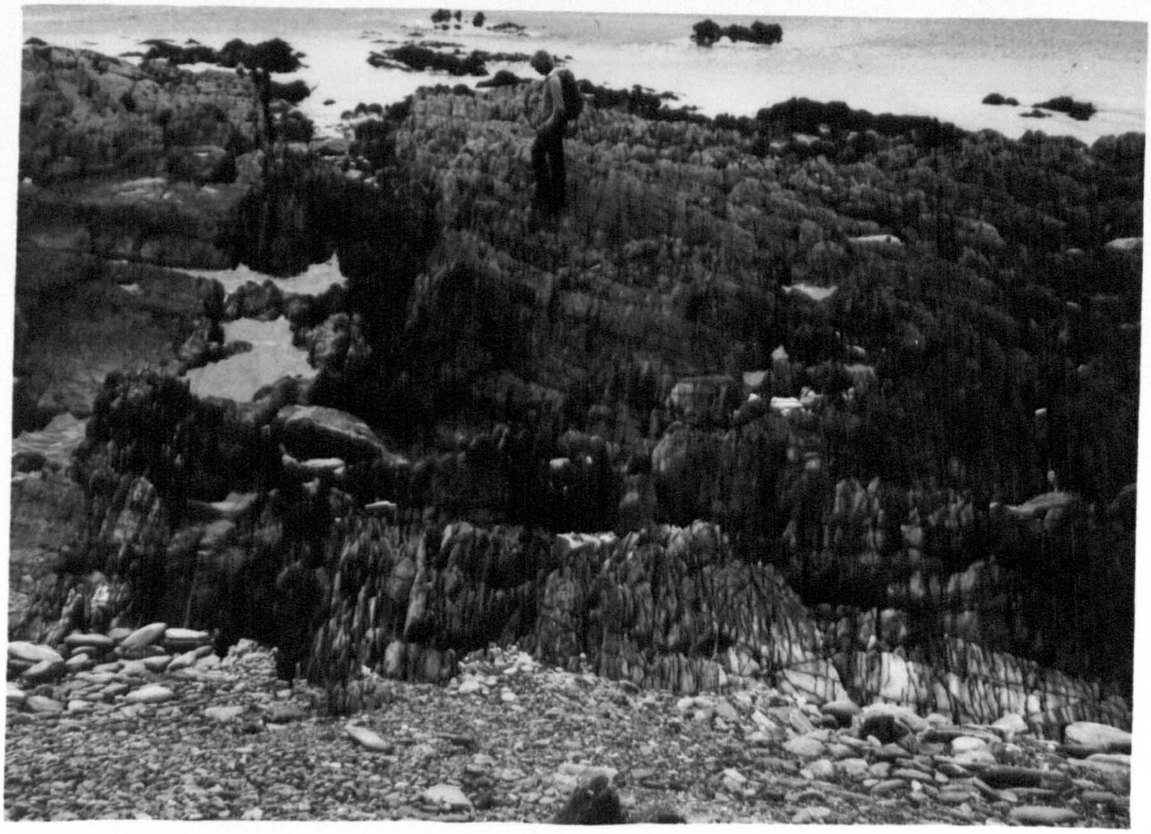
Fig. 3:1 Formation de Pte. de l'Armorique, Toul Ar Goué

At this locality massive greenstones are the dominant lithology, dark pelites are present as a single c. 2 m thick screen. The prominent S1 foliation is orientated 048/82°W at this locality.

Fig. 3:2 Formation de Pte. de l'Armorique, SW Pte de L'Armorique

Metasiltstone present as a c. 1 m thick screen within the metabasic lithologies. A banding is present which may reflect primary bedding. The banding is folded into a series of isoclinal folds which may be highly non-cylindrical. A single spaced cleavage is parallel to the axial planes of the folds.

Scale: Hammer head 18 cm



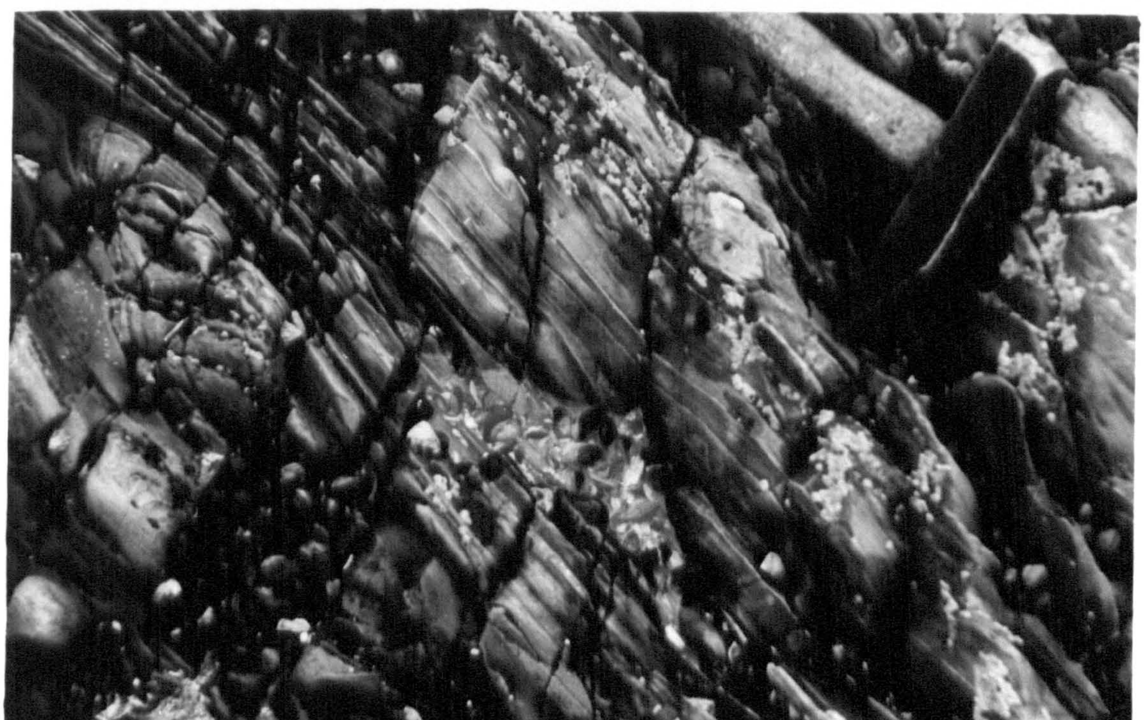


Fig. 3:3 Formation de Pte. de l'Armorique, Pte. de l'Armorique

Typical foliated medium-grained massive greenstone. The mineralogy is epidote + chlorite + quartz ± albite. The S1 foliation is well-developed in this example and is defined by the alignment of chlorite grains that surrounds larger epidote grains.

Scale: x15 XPL

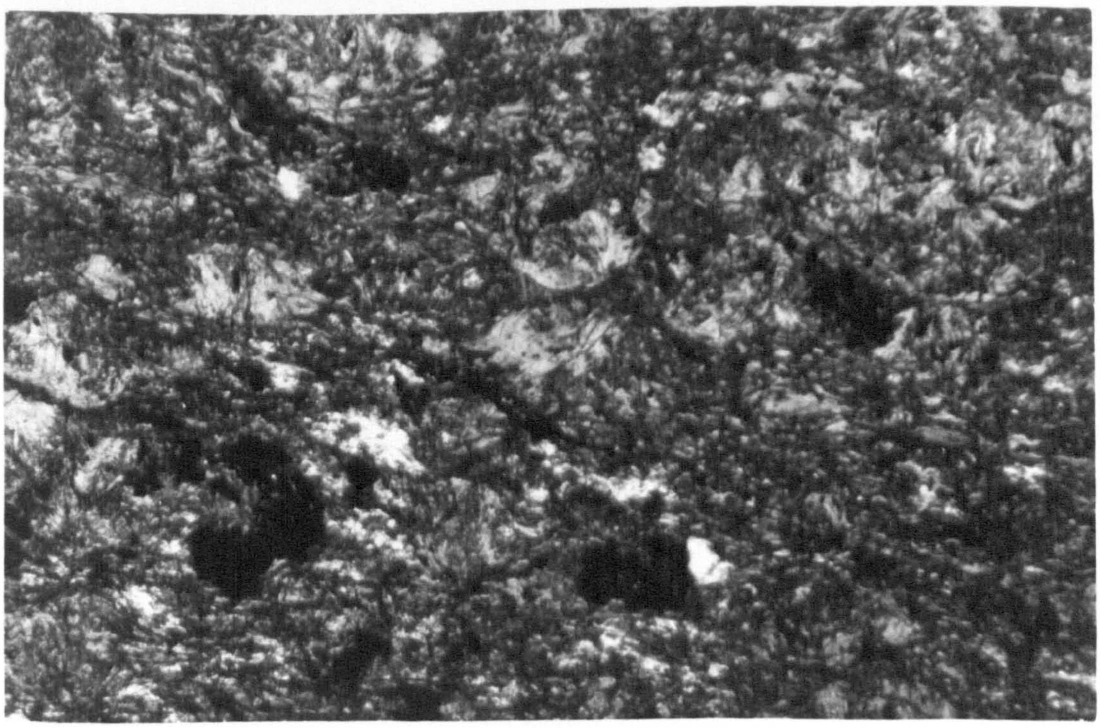


Fig. 3:4 Formation de Pte. de l'Armorique, Porz Mellec

Medium-grained massive greenstone with poorly developed S1 foliation. The grain-size is coarser than in foliated varieties and albite is common.

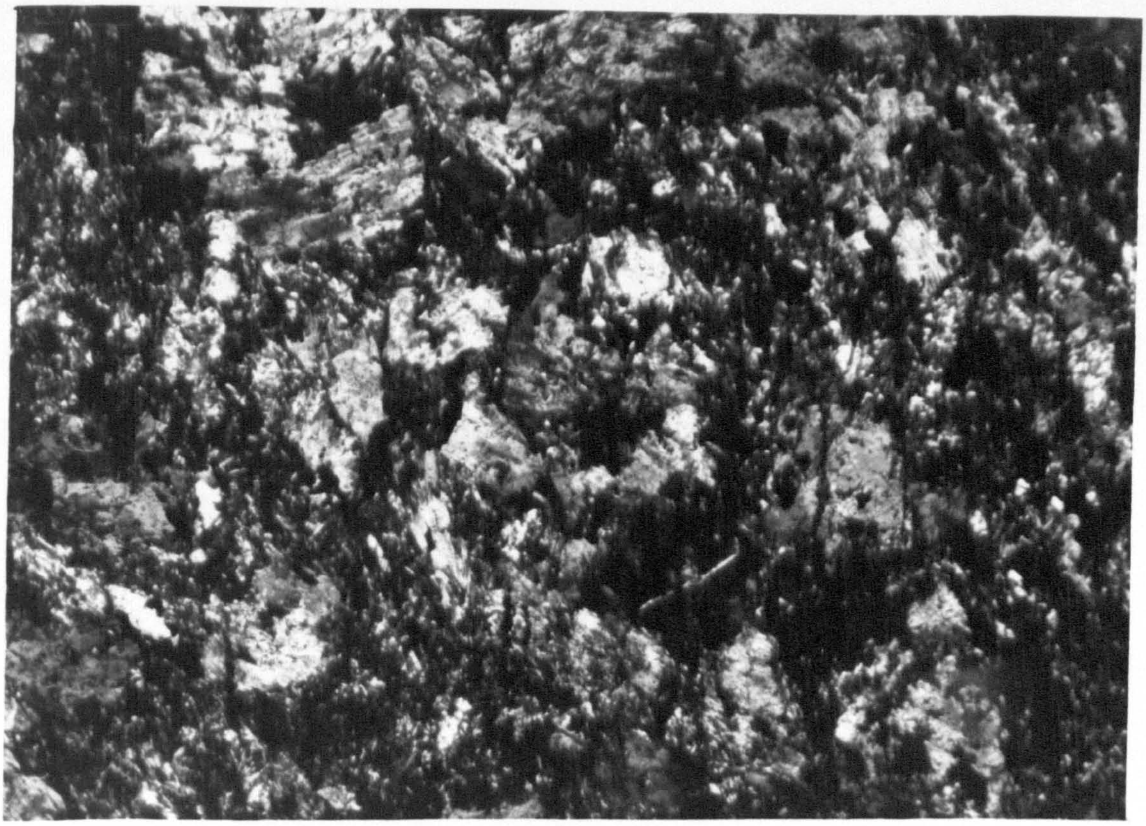
Scale: x15 XPL

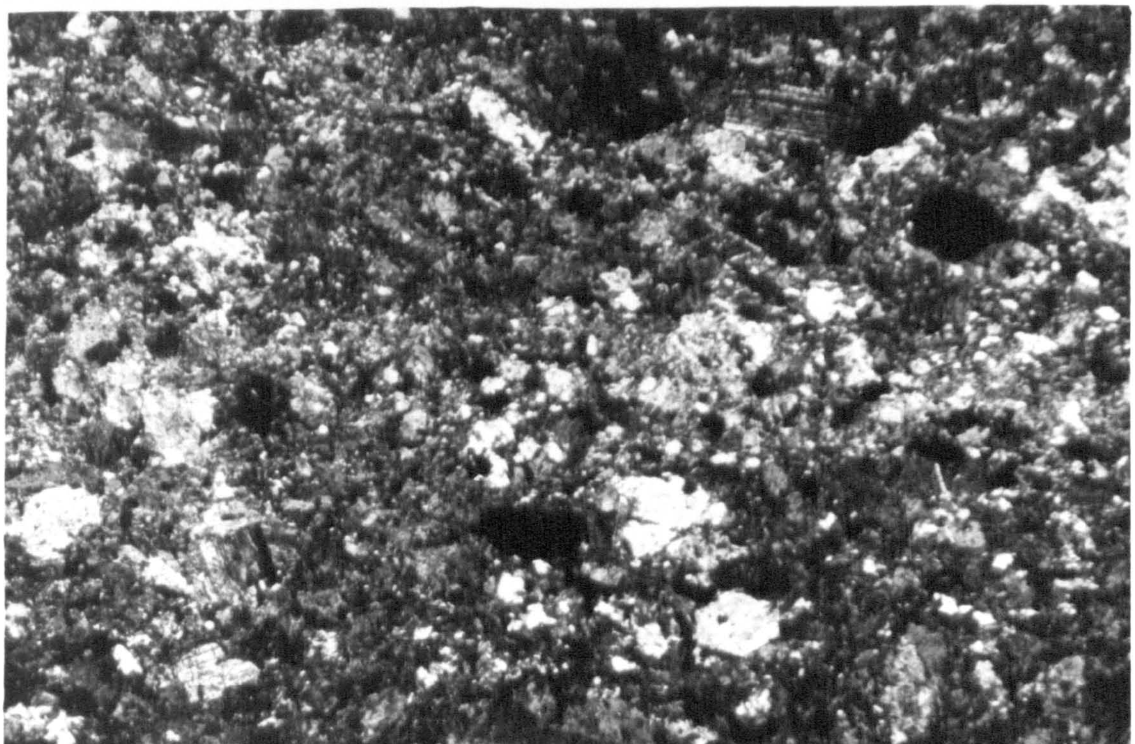
Fig. 3:5 Formation de Pte. de l'Armorique, Plage de l'Argent

Epidote-rich pod within fine-grained poorly foliated greenstone. Mineralogy is epidote + albite + chlorite + white mica ± quartz.

The pods may represent primary fragments (pillow fragments?) or may be the result of metamorphic segregation.

Scale: x15 XPL





that aggregates of chlorite, epidote, zoisite and sphene may represent the site of primary pyroxene grains. The mineralogy of the massive greenstones is summarised in Table 3:3.

The question arises as to the primary nature of these greenstones. They may represent non-pillowed individual flows, individual flow units within compound flows, or intrusive sheets. The following observations suggest an intrusive origin for these massive greenstones:-

1. Thickness of units; units up to 20 m occur with no internal individual flow units observed.
2. Discordance of massive greenstone where two units have joined obliquely.
3. Pillow lavas are readily formed in material of similar composition (no lateral transition into a pillowed flow front has been observed).

Epidote pods are recorded within some units, and the massive greenstones may represent intrusive basic sills together with thick, non-pillowed, lava flows. The strong deformation and metamorphism mask primary details and, therefore, neither possibility can be discounted.

(3) THE FINE-GRAINED MASSIVE GREENSTONES

Fine-grained greenstones occur throughout the Formation de Pte. de l'Armorique. The mineralogy and mode of occurrence of these rocks is similar to the medium-grained greenstones (Table 3:3). The grain-size, however, is in the range c. 0.2-0.4 mm. Fine-grained varieties show no evidence of increased deformation, and whilst some mylonitic greenschists do occur in shear zones these display marked mylonitic textures. The finer grain size may, therefore, be attributed to a primary variation. There are no observed primary grain-size variations within single units and no chilled margins have been observed.

LITHOLOGY	MINERALOGY	TEXTURES
MEDIUM-GRAINED MASSIVE GREENSTONES	Hnb + act + plag (AN12) + clino + chl + qtz + pist + calc ± biot.	Hnb forms porphyroblasts, actin may form at hnb expense in high strain areas. Foliation is depicted by chl + actin. Qtz and calcite may be segregated parallel to the foliation on millimetric scale. Xenomorphic epidote overgrows the foliation.
FINE-GRAINED GREENSTONES	Pist + calc + act + chl ± qtz ± alb.	Epidote is xenomorphic and overgrows fibrous actinolite and chlorite aggregates. Some varieties show quartz + calcite segregation.
PILLOW LAVAS	Core Pist + clino + plag (An 12) + qtz + calc + chl.	Largely unfoliated, some zonation of qtz + epi bands. Plagioclase variably orientated. Clinozoisite and quartz occur as possible vesicle infill
	Rim Pist + chl + Alb + Calc ± qtz.	Plagioclase aligned parallel to foliation in association with parallel orientated chlorite. Occasional possible vesicles preserved. Foliation and segregation variable.
METAHYALOCLASTITES	Epidote-rich fragments Pist + calc + alb ± act ± chl. Rim Pist + chl + alb + calc + qtz.	Fragments are composed of poorly foliated epidote and calcite with occasional plagioclase grains. Host or rim material is often segregated with chlorite + epidote-rich bands and quartz + calcite rich bands

TABLE 3:3 ; SUMMARY OF PETROGRAPHY ; PRINCIPAL LITHOLOGIES FORMATION DE PTE DE L'ARMORIQUE

Within this lithology there are commonly elongate epidote-rich pods, from 6-20 cm in length. These are composed of epidote, largely pistacite (60%) + calcite (30%) + albite + actinolite + chlorite (Fig. 3:5). The pods can form up to 15% of the greenstone.

The original nature of the fine-grained greenstones is uncertain. The epidote pods within the fine-grained greenstones may represent modified brecciated pillow fragments within the fine-grained greenstone matrix (Furnes, 1974 has recorded a similar lithology) but this necessarily invokes an extrusive origin. Alternatively, the pods could be an initial inhomogeneity within the greenstone host that has acted as a focus for metamorphic differentation during the greenschist facies metamorphism and these beds could, therefore, still be either intrusive or extrusive in origin. The epidote-rich pods occur less frequently within the medium-grained greenstones for which there is some evidence of an intrusive origin.

(4) THE PILLOW LAVAS

Greenstones with well preserved pillow structures form a significant part of the Formation de Pte. de l'Armorique (Map 3). Spectacular outcrops occur at the Pte. de l'Armorique (Fig. 3:6 and 3:7). It is difficult to comment on the original variation in the shapes of individual pillows as they have been strongly flattened and metamorphosed. In some horizons it is possible to determine primary younging direction evidence from the pillow shape. Schrock (1948) indicated that the shape of an upper part of one or more pillows controls the shape of the lower part of an overlying pillow, so that the 'V-shaped' sag of the younger pillow points towards older rocks. Pillow drapes indicate lithological younging to the southeast.

Fig. 3:6 Formation de Pte. de l'Armorique, Pte. de l'Armorique

Deformed pillow lavas with variably developed S1 foliation. The pillows show marked flattening and extension in a NE-SW plane. The pillows are typically segregated with a medium-grained core and fine-grained foliated greenschist anastomosing matrix. Pillow size varies, and this is considered to reflect a primary difference.

Scale: Hammer handle 36 cm

Fig. 3:7 Formation de Pte. de l'Armorique, Pte. de l'Armorique

Deformed pillow lavas showing the variation in shape of the pillows and the development of the greenschist matrix. Tension cracks are developed at a high angle to the S1 foliation which is parallel to the length of the pillows.

Scale: Hammer handle 36 cm

Fig. 3 : 6

Fig. 3 : 7

Strong metamorphic segregation has occurred, and is particularly obvious within individual pillows where there is often a marked compositional difference between cores of pillows and their rims. The cores of pillows are characterised by the following mineralogy; pistacite + clinozoisite + plagioclase + quartz ± calcite + ore minerals ± chlorite (Fig. 3:8). There is a segregation commonly developed between quartz + epidote-rich areas and plagioclase (An_{12})-rich areas within the poorly foliated cores. Some cores are rich in clinozoisite and calcite that appear to replace primary vesicle infill material. These possible vesicles are up to c. 5 mm in diameter.

The pillow rims are characterised by an epidote + chlorite + plagioclase + calcite ± quartz assemblage (Fig. 3:9). The grain size is significantly decreased compared to the core area. It is interesting to note that within the centres of pillows the plagioclase grains are large and randomnly orientated, while at the pillow edge they are smaller and show strong preferred orientation. The grain size of the secondary assemblage would appear to mimic the primary magmatic assemblage, as the cores of pillows are coarser than the rims and thick massive greenstone units show coarser centres compared to their margins.

The pillows contain possible vesicles (cited above) in the size range 1-5.5 mm. The pillow centres contain the largest vesicles but they also occur in the pillow margins. Jones (1969) has shown that there is a relationship between volume per cent vesicles, diameter of vesicles and the depth of eruption under water. However, the degree of deformation and metamorphism have made such structures difficult to interpret in terms of eruption depth and no attempt has been made to estimate the depth of eruption. The subaqueous environment necessary for the formation of such pillow lavas has been well documented (Jones 1968; Furnes 1972 amongst others).

Fig. 3:8 Formation de Pte. de l'Armorique, Porz Mellec

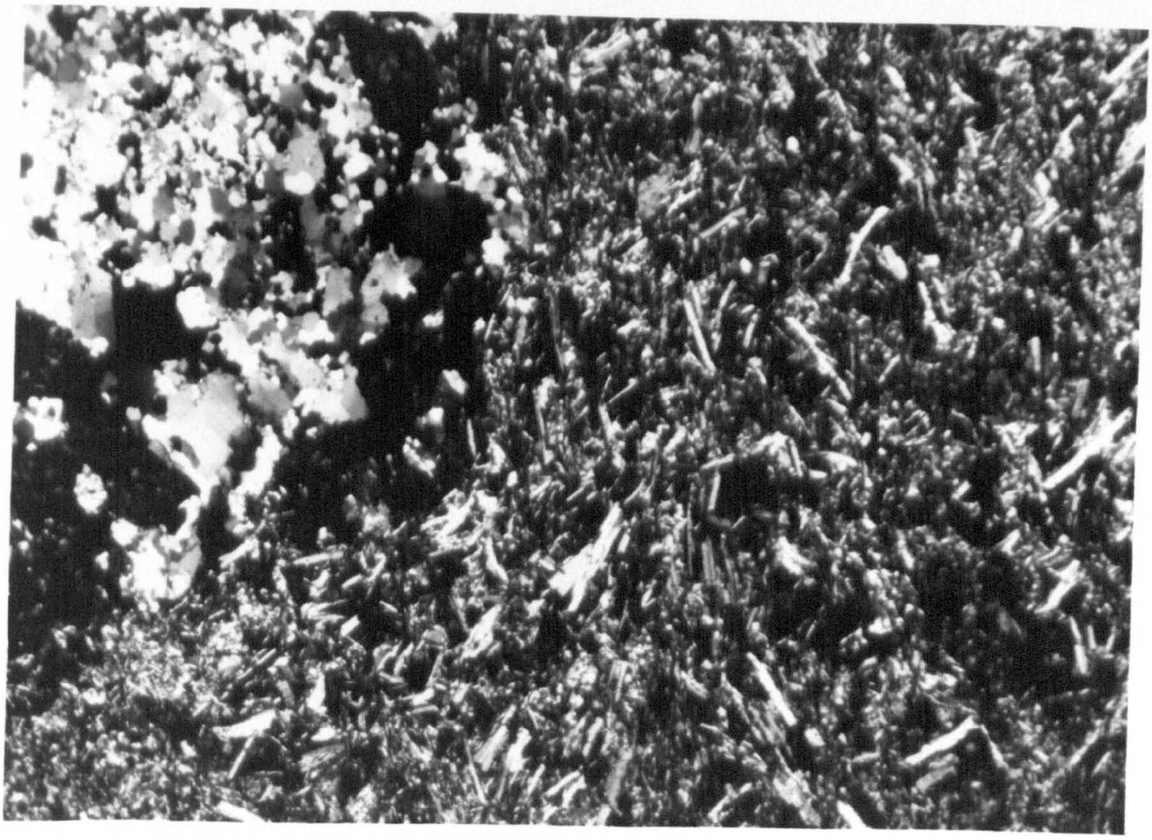
Pillow-core with randomnly orientated albite grains. Epidote is also present. A possible vesicle is infilled with quartz.

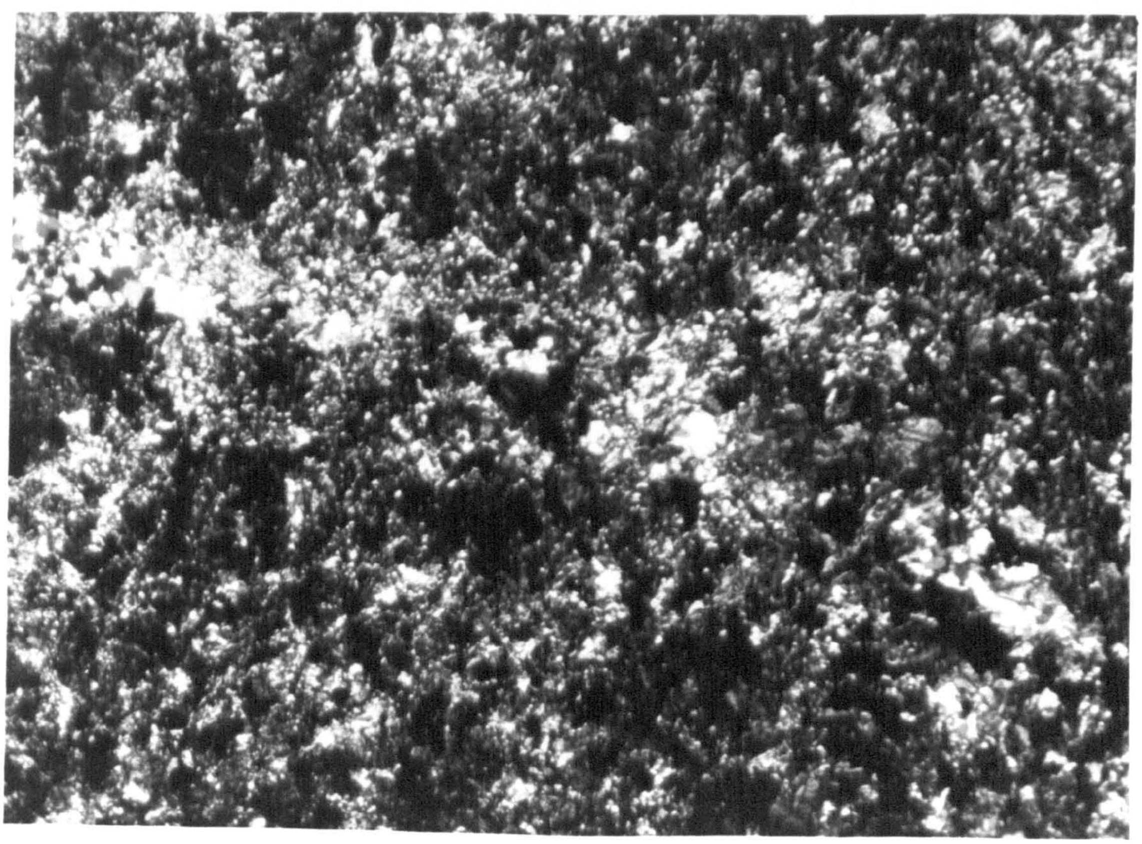
Scale: x15 XPL

Fig. 3:9 Formation de Pte. de l'Armorique, Porz Mellec

Fine-grained, poorly orientated epidote + quartz + chlorite from pillow rim (as Fig. 3:8). Areas rich in quartz and calcite may be present.

Scale: x15 XPL





Some of the pillows horizons contain siliceous material within the pillow interstices (Fig. 3:7). This interpillow material is made up of highly deformed quartz displaying ribbon structure and may either represent true interpillow siliceous sediment or it may be a product of metamorphic segregation.

(5) BRECCIATED BEDS

Brecciated beds that are interpreted as whole or broken pillowed breccias (metahyaloclastites) occur within the Formation de Pte. de l'Armorique. Two bands both c. 2 m thick are depicted on Map 4 but two others c. 1 m thick exist at the Pte. de Plestin (GR 1615 1266). The metahyaloclastites are strongly foliated with the foliation anastomosing the irregular-shaped, epidote-rich, pillow fragments. The size of fragments is in the range 4-16 cm (Fig. 3:10). The fragments are composed of xenoblastic epidote (c. 60%) + calcite (20-30% ± plagioclase (An_{10}) ± actinolite ± chlorite. The matrix 'host' is composed of strongly segregated, fine-grained, epidote + calcite + quartz. The epidote concentration reflects an initial variation due to the presence of the pillow fragments within a finer matrix.

(6) METASEDIMENTARY BANDS

Thin metasedimentary bands occur at several horizons within the basaltic pile that forms the Formation de la Pte. de l'Armorique. These horizons vary from 1-5 m in thickness and are composed of clastic sediments which are pelitic to psammitic in character (Figs. 3:1 and 3:2).

In the Pte. de l'Armorique area the most common association is the interbanding of poorly laminated, grey-green, metasiltstones with more siliceous, coarser, cream-coloured layers (Fig. 3:2). In the Toul Ar Goué area dark pelites occur with interbedded, thin (less than 1 cm thick) silty laminae. Occasionally, grey-green metasiltstones occur with red-brown quartz-rich interbeds which may be up to 12 cm thick.

Fig. 3:10 Formation de Pte. de l'Armorique, Pte. de l'Armorique

Metahyaloclastite breccia. Pillow fragments are held within a variably foliated greenschist matrix. The fragments are up to c. 15 cm and are rounded to sub-angular in shape.

Scale: Hammer handle 36 cm

In thin-section the metasiltstones are very fine grained, composed of quartz + chlorite ± epidote + ore minerals. The quartz is largely recrystallised. The dark-pelitic and metasiltstone interbedded association is a fine-grained assemblage of quartz + chlorite + ore minerals + epidote. These rocks possess a strong crenulation cleavage.

The sedimentary bedding within these horizons is broadly parallel to their contacts with the enclosing metabasic lavas. Small-scale non-cylindrical folds are common within the horizons and the quartz-rich bands denote tight isoclinal folds when seen in profile. The geometry of these folds is discussed in part (D).

(7) THE LATER ACID SHEETS

A series of acid sheets truncate both the Formation de la Pte. de Armorique and the Formation de Plestin. They have a distinctive cream-orange colour, are foliated and range in thickness from c. 50-250 cm. The sheets are generally orientated sub-parallel to the lithological banding within the formation, but occasionally they cross-cut the banding at a high angle and are sometimes tightly folded.

The mineralogy is, in order of importance, K-feldspar (orthoclase, sometimes perthitic) + plagioclase (An_{10}) + quartz + mica ± chlorite ± epidote. The K-feldspar and plagioclase, together with occasional quartz grains, may form phenocrysts (up to 3 mm) which are held in a quartz-rich, usually foliated matrix. Grain size decreases towards the sheet margins. This is considered to be a relic primary chilling effect rather than a metamorphic effect.

Verdier (1968) has discussed these sheets as "filons keratophyrique". He recognises two phases of ketatophyric or albitophyric intrusion within the Baie de Lannion area. He believed that an early phase cut the rocks of the "sôcle" (basement complex), here called the Moulin de la Rive

Orthogneiss Complex, while a later phase cut the Formation de Pte. de l'Armorique and the Formation de Plestin. The acid sheets are considered to be of the same generation, as they possess an identical mineralogy and vary only in their degree of deformation, which is heterogeneous across the area.

Within the Formation de Pte. de l'Armorique, pillow-lavas and metahyaloclastites indicate a submarine extrusive origin. The massive and fine-grained greenstones may be non-pillowed flows or contemporaneous intrusive sheets within the extrusive pile. The presence of laterally consistent metasedimentary bands is considered to be indicative of intermittent periods of relative volcanic quiescence in the submarine environment, during which laminated epiclastic sediments accumulated.

The passage into the overlying Formation de Plestin is gradual and marked by an increase in the frequency and thickness of sedimentary layers.

(C) THE FORMATION DE PLESTIN

(1) INTRODUCTION

A thick succession of metasediments overlying the formation de Pte. de l'Armorique crops out to the south of the Pte. de Plestin (from which the formation is named) and Beg Ar Naon (GR 1646 1290), and southwards for a considerable distance inland (Map. 2). The west side of the Grève de St. Michel affords good exposure of the metasediments and their contact with the older metavolcanic formation. The contact on the east side of the Baie de Lannion with the same formation is well exposed, but is more difficult to interpret due to strong hornfelsing by the Hercynian Granite de Trédrez.

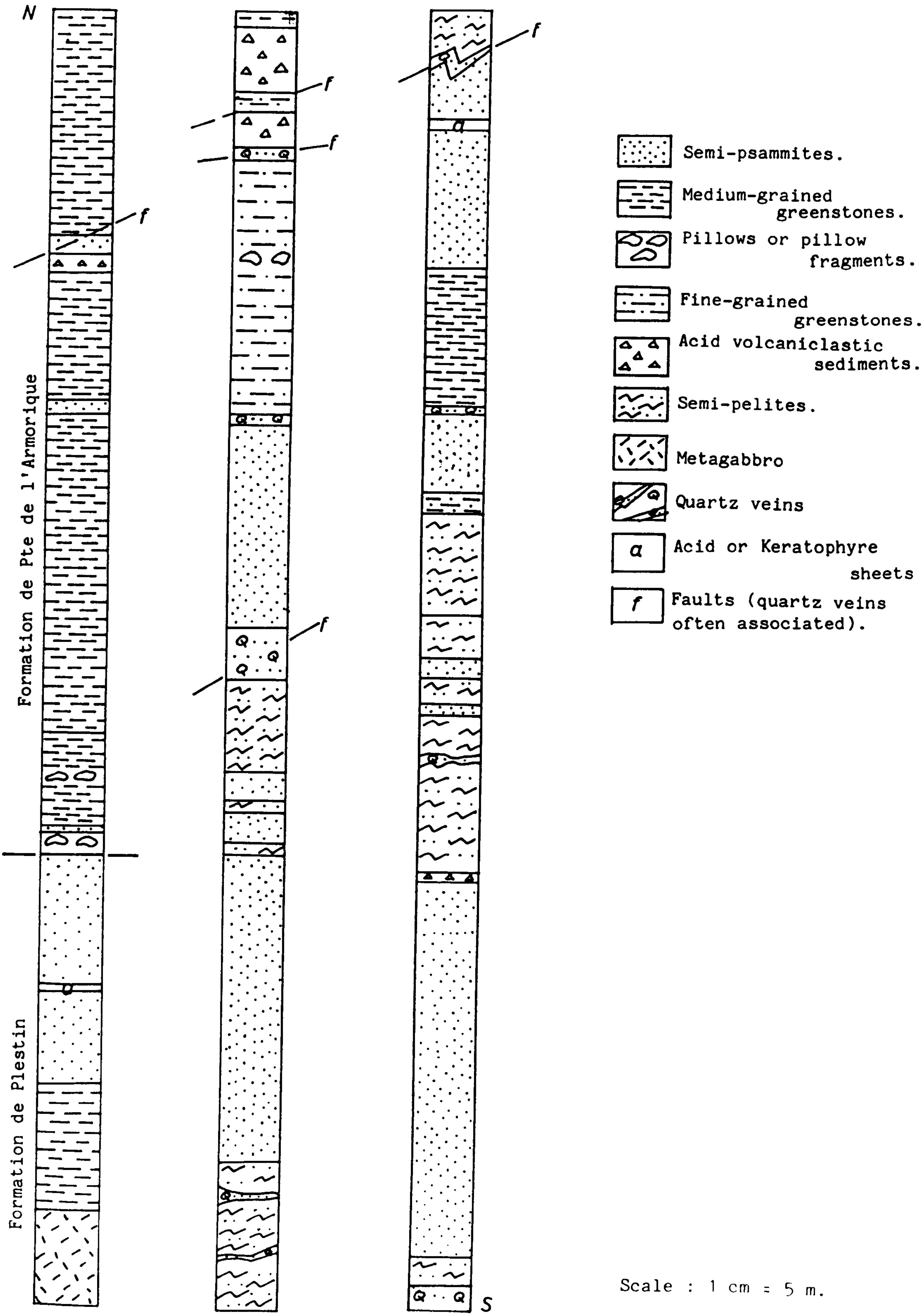
The boundary of the Formation de Plestin with the Formation de Pte. de l'Armorique is taken, in the Pte. de Plestin area, by the occurrence of a pillow lava which is overlain by a 20 m thick metasedimentary sequence. The boundary is, however, strictly gradational as metasedimentary horizons occur throughout the metavolcanic formation and they increase in frequency towards the top of the succession. The stratigraphy of the boundary area is represented in Fig. 3:11. Massive medium-grained greenstones, interpreted as intrusive basic sheets, occur at the base of the Formation de Plestin and are considered to be penecontemporaneous with the sediments, rather than representing later intrusions. Massive greenstones are more frequent at the base of the Formation de Plestin and are of similar mineralogical composition to those of the Formation de Pte. de l'Armorique.

The sediments that comprises the Formation de Plestin are a monotonous series of semi-psammites and semi-pelites. Detailed stratigraphical work has not been attempted and is difficult because of the lack of suitable marker horizons, the strong deformation, and the poor inland exposure. Within the study area four sub-divisions are made which are based on the gross morphological characteristics and the relative amounts of coarse to fine-grained material (psammite to pelite).

(2) SEMI-PSAMMITES OF THE PTE. DE PLESTIN AREA

Semi-psammites are the dominant lithology in the basal part of the Formation de Plestin, which crops out in the Pte. de Plestin to St. Efflam area on west side of the Grève de St. Michel. Other lithologies are encountered in the succession, principally massive greenstones, greenschists, possible acid volcaniclastic bands and semi-pelites (Fig. 3:11). An association of similar lithologies is encountered inland in the Bois de la Roche area (GR 1505 1198) and the Pont Menou area (GR 1580 1224) and is considered as belonging to the same sub-division

Fig. 3:11 Logged section; boundary of the Formation de Pte de l'Armorique and Formation de Plestin



of the Formation de Plestin.

The semi-psammites are well-bedded. Individual beds are in the range 20-40 cms and these tend to occur in packets up to 20 m thick separated by thin semi-pelite or pelite beds. Commonly the individual beds show grading so that coarse-grained beds pass gradationally into a fine-grained semi-pelitic top. A cleavage is formed in the semi-pelitic part of the graded beds and bedding/cleavage relationships combined with the graded-bedding can be used in determining the structure of these rocks. Several generations of thin quartz veins are developed in this formation with one set parallel to the lithological bedding (S0). Grain-size within the semi-psammites is in the range 0.5-2 mm. Mineralogy is (in order of importance) quartz + chlorite + albite ± white mica + ore minerals.

Close to the boundary between the Formation de Plestin and the Formation Pte. de l'Armorique are two light-coloured bands, 2 m and 6 m thick that may possibly be acidic volcaniclastic metasediments. A third band 1 m thick is present higher in the succession. In hand-specimen the lithology is 'flinty' with a marked schistosity. Bands rich in epidote + chlorite and quartz + calcite occur on a 1-2 mm scale. These envelope occasional quartz-rich clasts. Small fragmented albite phenocrysts are visible in thin-section.

Semi-pelitic to pelitic sediments occur as distinct beds within the succession. They are dark grey in colour, laminated and have both sharp and gradational boundaries with the semi-psammites. The semi-pelites and pelites increase in importance towards the south and west of the Grève-de-St. Michel section, and indicate a general fining-up within the basal part of the Formation de Plestin. In this area the semi-pelites are more regularly interbedded with the semi-psammites and beds range in thickness from c. 6-15 cm (Fig. 3:12).

A single greenschist band similar to bands within the Formation de Pte. de l'Armorique occurs near the base of Formation de Plestin. The greenschist band is c. 25 m thick and is strongly schistose. Rare epidote-rich pods (up to 10 cms) occur which may represent original pillow fragments. The rocks are highly deformed and there is some degree of segregation between epidote-rich bands and quartz + chlorite-rich bands.

The greenschists are considered to be extrusive rocks similar to the greenschists encountered within the underlying Formation de Pte. de l'Armorique.

(3) INTERBEDDED SEMI-PSAMMITES AND SEMI-PELITES IN THE ST. MICHEL-EN-GRÈVE AREA

In the St. Michel-en-Grève area the Brioverian Formation de Plestin is characterised by a thick succession of interbedded semi-psammites and semi-pelites. Buff-coloured semi-psammites are the dominant lithology, but there is an increased amount of grey semi-pelites compared with the basal succession which crops out in the Pte. de Plestin area (Fig. 3:13). There are no other primary lithologies, eg. massive greenstones, in the interbedded succession in the St. Michel-en-Grève area, although later acid dykes (keratophyres in Verdier's 1968 terminology) truncate the metasediments. The semi-pelites and semi-psammites display sharp contacts and the occasional presence of 'rip-up' clasts in the latter indicates some erosive contacts. The coarser-grained units sometimes display graded-bedding, but generally the beds are massive and poorly-sorted. Beds are generally in the thickness range 12-25 cms, the semi-psammites being generally thicker than the semi-pelites.

Towards the faulted boundary with the Palaeozoic quartzites at St. Michel-en-Grève (Fig. 3:16) the Formation de Plestin is characterised by thinly bedded (1-2 cm thick) pelitic and semi-psammitic interbands.

Fig. 3:12 Formation de Plestin, St. Efflam

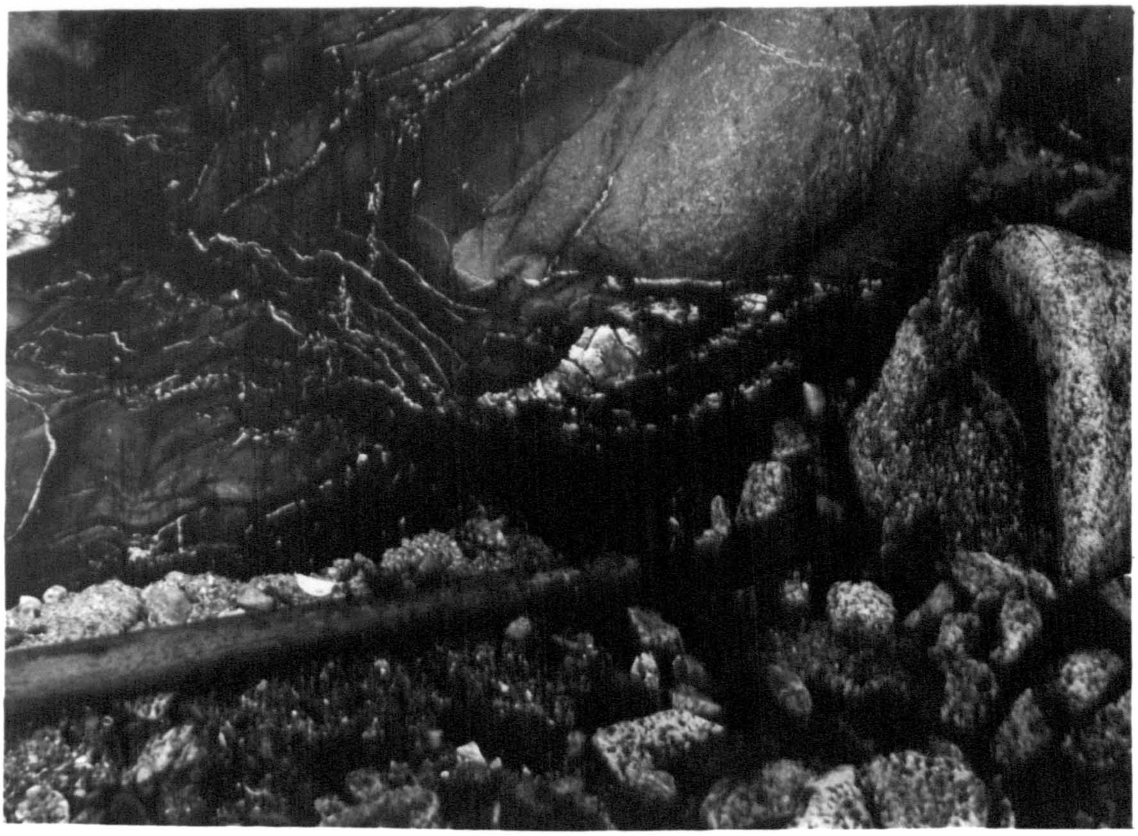
Interbedded semi-psammites and semi-pelites. The semi-psammites show a crude internal banding and may show graded-bedding. A prominent upright S2 crenulation cleavage is well-developed in the semi-pelitic bands which is present as a spaced cleavage in the coarser unit.

Scale: Hammer head 18 cm

Fig. 3:13 Formation de Plestin, St. Michel-en-Grève

Interbedded semi-psammites and semi-pelites with an F1 hinge zone. An S1 cleavage is developed sub-parallel to the axial plane of the F1 recumbent fold, which is modified by the prominent upright S2 crenulation cleavage.

Scale: Hammer head 18 cm



Within the Granodiorite de Beg Ar Forn (GR 1646 1274) there are hornfelsed rafts of metasediment attributed to the Formation de Plestin. The metasediments are interbedded pelites and semi-psammites. This granodiorite and its intrusive contact with the Brioverian rocks is discussed in part (D).

(4) DARK PELITES OF SAINT-EFFLAM

At St. Efflam (GR 1618 1249) dark pelites occur with occasional psammitic beds. The psammitic beds are c. 12-20 cm thick and display 'rip-up' clasts of pelitic material. This sub-division is restricted to one outcrop, but is quite different to other sub-divisions recognised in the Formation de Plestin because of the dark-coloured pelites. There is a single folded acid dyke at this locality. The presence of this dyke and the nature of the psammitic beds distinguishes this lithology from a hornfelsed dark pelitic assemblage at St. Michel-en-Grève which is considered to be of Palaeozoic age.

(5) PELITES OF THE GARLAN-LANLEYA TO PLOUÉGAT GUÉRAND AREA

In the Garlan-Lanleya to Plouegát Guérand area the fine-grained pale green pelites dominate the Brioverian Formation de Plestin. This succession of pelites is considered here as a sub-division of the Formation de Plestin and is distinct from the semi-psammite, semi-pelitic and greenstone association that extends from the Pte. de Plestin area south-westwards towards Bois de la Roche (Map 2).

The pelites in this area are monotonous, chlorite-rich and pale-coloured. In some areas, e.g. at Pen Ar C'hra (GR 1571 1204) thin (<1 mm) coarser-grained bands alternate with pelites. The metasediments possess a strong schistosity which is sub-parallel to the banding. The banding may represent a metamorphic segregation banding rather than true lithological lamination. The mineralogy of the pelites is quartz +

chlorite + white mica ± albite + ore minerals.

Cabanis et al. (1979a) discuss a series of "grés volcano-clastiques et arkosiques" and "argilites et siltites feldspathiques" collectively called the Formation de Garlen-Lanleya which are equated with formations in the St. Michel-en-Grève area. It is considered that the formation recognised here has no direct equivalent in the St. Michel area and is quite a distinct sub-division of the Formation de Plestin.

(6) CONCLUSIONS

Sedimentary structures and lithological associations within the subdivisions of the Formation de Plestin encountered in the Pointe de Plestin, St. Michel-en-Grève and St. Efflam sections indicate that two sedimentation processes were operative. In simple terms, the bed forms of the semi-psammites (massive bedding, poor sorting and rip-up clasts) point to the relatively rapid transportation and deposition of material by a sediment gravity-flow mechanism (possibly turbidite flows) into an environment in which fine-grained sediments were slowly accumulating. Much of the fine-grained material could have been removed during the transport of the coarser sediment and re-deposited elsewhere, or could have subsequently settled out of suspension as a co-turbidite lag fall deposit. The immature (arkosic) nature of the semi-psammites also indicates a rapid transport rate of material.

Many authors (Cogné 1962; Graindor 1959; Le Corre 1977) have described the Brioverian sediments as a metagreywacke assemblage. The dominantly semi-pelitic and semi-psammitic association in the Grève-de-St Michel area is considered to represent a metagreywacke assemblage in which high energy flow (turbidity currents) deposited the semi-psammite lithology. Such a mechanism could account for fairly rapid lateral and vertical changes in the succession and the sedimentary structures observed.

The pelites of the Garlan-Lanleya to Plouégat-Guérand area are considered to overlie mixed metasediments and greenstones of the Bois de la Roche area (which may represent the lateral equivalents of the Pte. de Plestin sub-division). The pelitic sediments may represent relatively stable conditions within the receiving basin. Autran et al. (1979) describe a volcaniclastic origin for rocks occurring in the Garlan-Lanleya area.

(D) THE STRATIGRAPHICAL IMPLICATIONS OF GRANODIORITE INTRUSIONS INTO THE BRIOVERIAN FORMATIONS OF THE BAIE DE LANNION

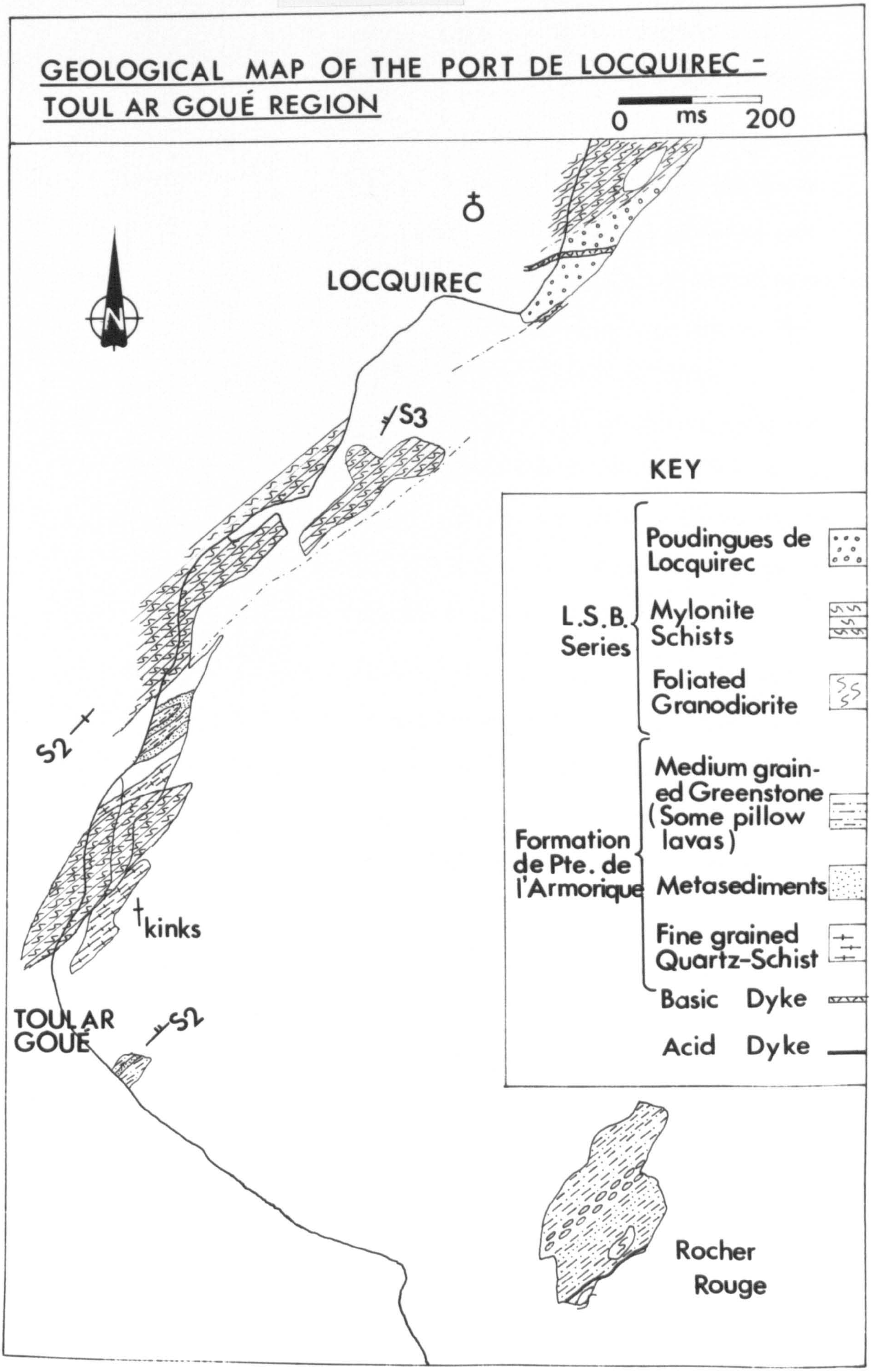
Three areas are examined in this section in which the dominantly metavolcanic Formation de Pte. de l'Armorique has been intruded by granodioritic rocks. A study of the lithologies and their contacts provides evidence as to the true nature of the Formation de Locquirec (sensu Autran et al. 1979), and the age of the intrusive bodies in the Baie de Lannion area.

(1) THE BOUNDARY BETWEEN THE LOCQUIREC SHEAR BELT (LSB) AND THE FORMATION DE PTE DE L'ARMORIQUE

The boundary between the largely basic eruptive lithologies that form the Formation de Pte. de l'Armorique and the mylonitized granitoid rocks of the Locquirec Shear Belt (Formation de Locquirec sensu Autran et al. 1979) is exposed in the reefs at Toul Ar Goué (GR 1588 1263), in the southwest corner of the Baie de Locquirec (Fig. 3:14).

A small reef (GR 1589 1261) at Toul Ar Goué is composed of lithologies characteristic of the Formation de Pte. de l'Armorique. These lithologies are finely foliated massive greenstones containing a single c. 2 m thick horizon of black pelitic and semi-pelitic schist (Fig. 3:1).

FIG. 3:14



GEOLOGICAL MAP OF THE PORT DE LOCQUIREC - TOUL AR GOUÉ REGION
0 ms 200
N
LOCQUIREC
S3
S2
kinks
TOULAR GOUÉ
S2
Rocher Rouge
KEY
L.S.B. Series
Poudingues de Locquirec
Mylonite Schists
Foliated Granodiorite
Formation de Pte. de l'Armorique
Medium grained Greenstone (Some pillow lavas)
Metasediments
Fine grained Quartz-Schist
Basic Dyke
Acid Dyke

The contact zone is exposed in the NE-SW trending rock platform approximately 100 m due west of the massive greenstone outcrop cited above (Fig. 3:15). In this zone three lithological groups are present:-

1. Mylonitic schists: These are interpreted as sheared intrusive rocks which represent the southeastern marginal facies of the Moulin de la Rive Orthogneiss Complex. The granitoid mylonites are foliated and often schistose in aspect. In thin section mylonitic textures indicating grain-size reduction, neomineralization, recrystallization etc., occur. The mineralogy in order of importance is quartz + albite + feldspar (microcline) + chlorite ± white mica. A variety enriched in quartz and with a smaller grain size occurs on the easternmost margin of the shear belt. Kink-bands and a late, post-D1 crenulation fabric are observed in some of the granitoid mylonites in this area. The development of these mylonitic granitoid rocks is discussed in detail in Chapter 5.

2. Metasediments: These are bedded rocks composed of interlaminated dark semi-pelites and lighter coloured metasiltstone bands. These may be 1 mm-1 cm thick. The metasediments exhibit microfolds and there is a well developed crenulation-cleavage present which is both axial-planar to these small mesoscopic folds and parallel to the mylonitic banding in the granitoid rocks.

3. Greenstones: Massive greenstones occur within the contact zone, which are foliated and schistose in part. Epidote-rich pods occur and there is some degree of metamorphic segregation associated with the shearing deformation.

Granitic to granodioritic rocks are considered to have been injected into a mixed volcanic and sedimentary sequence, the Formation de Pte. de l'Armorique. The contact is not sharp and pods of granitic material occur within the mixed host. Subsequent deformation has affected all the rock types present in the contact zone with mylonitization the prominent

Fig. 3:15 Contact zone between the Formation de Pte. de l'Armorique and the granitoid mylonites of the LSB, Toul Ar Goué

Two deformed dark green screens of metasediment are seen within buff-weathering granitoid mylonite. The two metasediment bands have been deformed into a tight fold. Lithological banding (S0) in the metasediment is parallel to the margins of the screens. A pronounced axial-planar foliation is present within both the screens and granitoid mylonite.

Scale: Hammer handle 36 cm

process in the granitoid rocks of the Locquirec Shear Belt (LSB).

(2) THE GRANODIORITE DE BEG AR FORN

The Granodiorite de Beg Ar Forn (also known as Beg An Fourm) forms a prominent headland on the northeast side of the Grève de St. Michel (GR 1660 1263). The outcrop and distribution of the granodiorite is more complicated than represented on previous maps (Barrois 1909; Delattre et al. 1966) as a variety of rock types are present in the headland area. The northern margin of the granodiorite is intrusive into metasediments of the Formation de Plestin. Fig. 3:16 illustrates the relationships present in this area, with rafts of sediment present within the granodiorite and veins of granodiorite cutting the Formation de Plestin. The southern margin of the granodiorite is in faulted contact with Brioverian metasediments (the interbedded semi-pelites and semi-psammites of the St. Michel-en-Grève area). Rafts of hornfelsed metasediment occur within the granodiorite.

The granodiorite is itself metamorphosed, with chlorite forming at the expense of biotite and would appear to be affected by the nearby Granite de Trédrez.

The granodiorite has been previously considered as part of the Hercynian Granite de Trédrez (Barrois 1908c; Delattre et al. 1966; Verdier 1968). Auvray (1979) pointed out the intrusive relationship and the enclaves of metasediment within the granodiorite, and considered it to be separate from the Granite de Trédrez. Auvray (op. cit.) indicated the similarity of the Granodiorite de Beg ar Forn with a component of the Cadomian Perros-Guirec Granitoid Complex called the Granodiorite de Talberg (Fig. 3:17) on the basis of petrographic and geochemical similarity. Auvray (op. cit. p332) writes "la granodiorite de Beg An Fourm presente tous les caractères petrographiques et chimiques des granodiorites du domaine nord-trégorrois, en particulier des granodiorites à texture

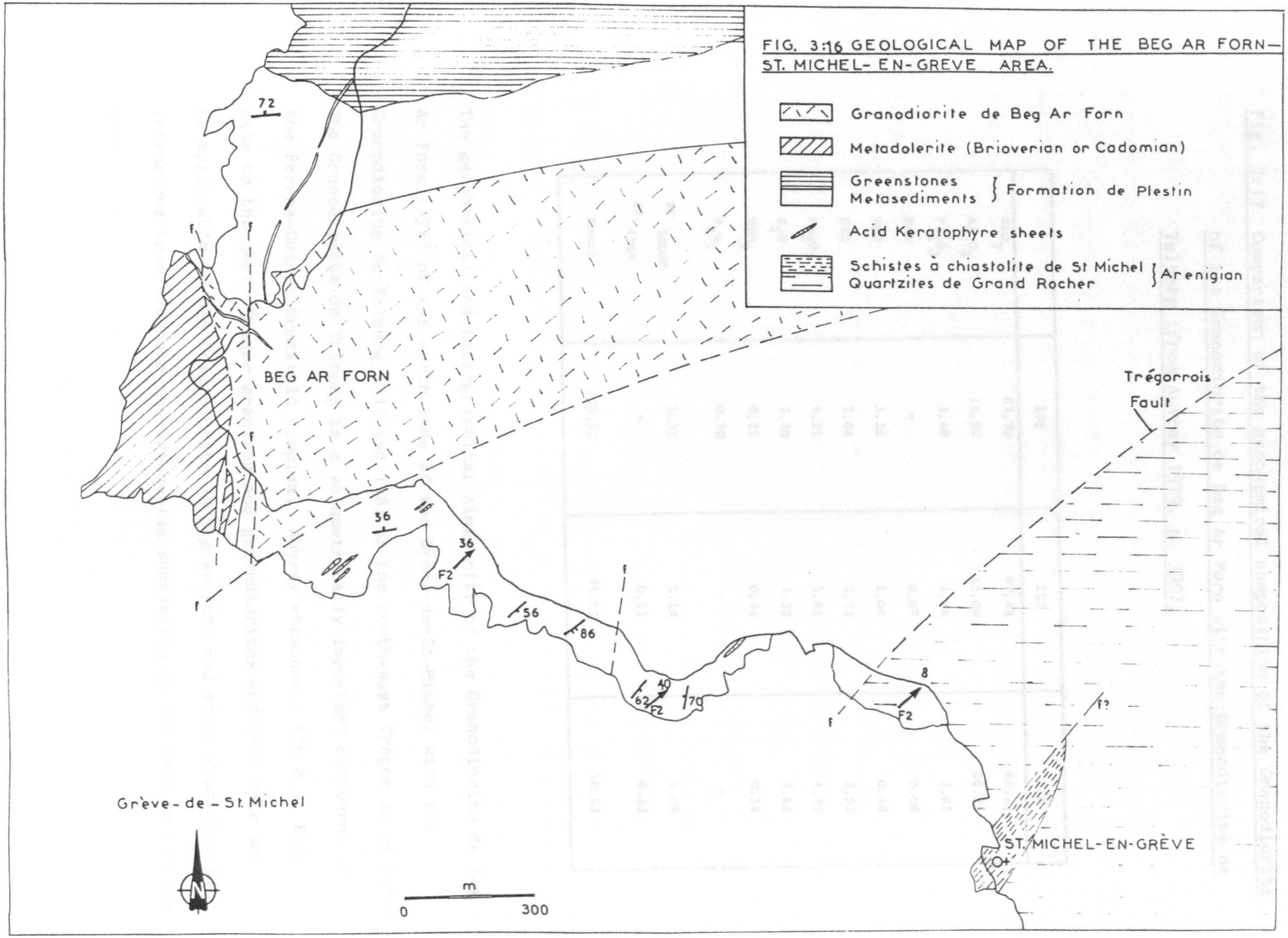


FIG. 3:16 GEOLOGICAL MAP OF THE BEG AR FORN–ST. MICHEL-EN-GREVE AREA.

Fig. 3:17 Comparison of the geochemical composition of the Granodiorite of the Granodiorite de Beg Ar Forn with the Granodiorite de Talberg (from Auvray 1979, p. 330).

	176	117	118
SiO_2	67,70	67,43	68,23
Al_2O_3	16,57	15,08	16,31
Fe_2O_3	3,49	3,94	3,62
MnO	-	0,07	0,06
MgO	1,16	1,04	0,68
CaO	2,84	2,72	2,53
Na_2O	4,21	3,81	4,22
K_2O	2,20	3,32	2,65
TiO_2	0,35	0,44	0,34
P_2O_5	0,30	-	-
PF 1000°	1,31	1,14	1,06
PF 110°	-	0,13	0,13
Total	100,13	99,12	99,83

The geochemical and petrographical similarity of the Granodiorite de Beg Ar Forn (176) of the north side of the Grève-de-St-Michel with the Granodiorite de Talberg (117 and 118) of the north-east Trégor is of note. The Granodiorite de Talberg is a volumetrically important component of the Perros-Guirec Granitoid Complex. Auvray attaches a 670 M.y. K/Ar date to the north Trégor granites and granodiorites and this date may be applicable to the Granodiorite de Beg Ar Forn and other granodioritic intrusions that truncate the Brioverian succession in the Baie de Lannion area.

grenue du type Talberg". Observations by the present author in the Trégor support this view.

The correlation of these two granodiorite bodies is critical in determining the stratigraphy of the Brioverian in the Baie de Lannion area. Auvray having established a Cadomian age for the Granodiorite de Beg Ar Forn envisages the following stratigraphy, in which two separate volcano-sedimentary successions are separated by the emplacement of the Perros-Guirec Granitoid Complex:-

Auvray (1979)

4) Tufs keratophyriques de Tréguier-Locquirec

3) Emplacement of the Granodiorite de Beg Ar Forn (Batholithe de Perros-Guirec-Bréhat)

2) Formation greywackeuse de St. Efflam

1) Formation volcano-sedimentaire (interclations phtanitiques) de l'Armorique - Trédrez (= amphibolites et schistes de Lanvollon).

The contact between the Tufs de Tréguier and the Formation de l'Armorique (sensu Auvray op. cit.) is, according to Auvray, faulted. This has been shown to be incorrect. The comparison between the Granodiorite de Beg Ar Forn and the Granodiorite de Talberg is considered to be valid, but there is no need for the complicated stratigraphy as envisaged by Auvray.

A simpler stratigraphy based on field observations in the Locquirec-St. Michel-en-Grève area is proposed here and summarised in Table 3:2.

3) Emplacement of the Cadomian Igneous Complex of Moulin de la Rive (now the Moulin de la Rive Orthogneiss Complex and the equivalent mylonitic rocks of the Locquirec Shear Belt). Emplacement of the Granodiorite de Beg Ar Forn.

2) Formation de Plestin (dominantly metasediments)

1) Formation de Pte. de l'Armorique (dominantly basic metavolcanics)

A comparable stratigraphy is observed elsewhere in northern Brittany, as discussed in part (G).

(3) GRANODIORITE INTRUSIONS IN THE ROCHES D'ARGENT AREA

Two small granodiorite intrusions have been mapped in reefs in the Roches d'Argent area (GR 1600 1264) and at RocherRouge (GR 1595 1259) in the Baie de Locquirec (Map 3). The granodiorite possesses a gneissose foliation which trends NE-SW parallel to the schistosity in adjacent greenstones into which the granodiorite has been injected. The mineralogy is albite + K-feldspar (perthite) + quartz + chlorite + epidote.

The granodiorite is considered to be part of the nearby Moulin de la Rive Orthogneiss Complex. The outcrop of the granodiorite lies outside of the Locquirec Shear Belt and has therefore escaped mylonitization.

The recognition of the intrusive nature of a number of granodiorite bodies in the Baie de Lannion area provides evidence as to the lithostratigraphy of the Brioverian Supergroup. A simple stratigraphy has been erected that is different to other models proposed for this region, but is the same as that present in other parts of the Armoricain Massif (Cogné 1962; Le Corre 1977), whereby the lower part of the Brioverian Supergroup is composed of basic metavolcanics overlain by a thick series of metasediments.

(E) DEFORMATION AND METAMORPHISM OF THE BRIOVERIAN SUPERGROUP

(1) INTRODUCTION

The Formation de Pte. de l'Armorique and the Formation de Plestin have been subjected to at least two major episodes of deformation. The two formations have responded differently during the imposed strain and the strain was markedly heterogeneous (Table 3:4).

In the Formation de Pte. de l'Armorique a major deformation episode, termed D1, led to the development of a foliation, termed S1, that is broadly parallel to the lithological banding and the S1 foliation developed in the adjacent Moulin de la Rive Orthogneiss Complex. The foliation swings from a NE-SW trend in the Pte. de l'Armorique area to an E-W trend in the eastern Baie de Lannion area (Map 2). Mylonitic greenschists derived from the basic metavolcanic lithologies are developed in restricted shear zones.

In the Formation de Plestin two fold phases are recognised. The F1 folds are considered to be related to the D1 episode recognised in the Formation de Pte de l'Armorique and also to F1 folds developed in the Palaeozoic formations in the St. Michel-en-Grève area (discussed in Chapter 6). F2 folds possess a well-developed crenulation cleavage which is parallel to the foliation in the metabasic formation.

The timing of the deformation episodes is discussed in part (E:3) and Chapter 8. Evidence from adjacent areas points to the presence of an early deformation episode (pre-D1) that is masked by the D1 and later episodes in the Petit Trégor. Deformation of the Brioverian Supergroup may be largely related to the development of the Locquirec Shear Belt.

In this section the Brioverian formations are described separately as they have acted heterogeneously to the imposed polyphase deformation. It should be noted that the deformational and metamorphic episodes apply to the localised sequence and may not necessarily extend to a regional status. The regional sequence of events is discussed in Chapter 8.

(2) THE FORMATION DE PTE. DE L'ARMORIQUE

The structures and metamorphism of this formation are described here, but a discussion as to the timing of the deformational and metamorphic episodes is given later. No major folds have been observed in this sequence of massive greenstones, pillow-lavas, pillow-breccias, greenschists and metasedimentary horizons. The major effects of the deformation and metamorphism have been; a) to rotate the sequence into an approximately vertical plane, b) to produce a well-developed schistosity, c) to shorten the thickness of the sequence (which is indicated by the flattening of pillowed horizons), d) to produce small-scale folds within the metasedimentary horizons and e) to produce greenschist facies metamorphic rocks and, in narrow bands, greenschists with marked segregation banding. Minor effects include the development of kink-bands and late faults. The most important structural feature of the Formation de l'Armorique is the vertical to sub-vertical attitude of the lithological banding and the schistosity. Both the banding and the schistosity are parallel to the S2 foliation of the Locquirec Shear Belt (LSB).

In the Pte. de l'Armorique area the schistosity trends 050°-230° NE-SW. This rotates to a 080°-260° E-W trend in the eastern Baie de Lannion. The schistosity is defined by the parallel alignment of chlorite and white mica. The schistosity is best developed in the fine-grained lithologies.

Pillow-lavas in the Formation de l'Armorique are strongly deformed. They are flattened to varying degrees with eliptical profiles (Figs. 3:6 and 3:7). They provide useful strain markers and indicate significant shortening, estimated at 100% across the succession. This indicates, that whilst shearing processes are considered to be an important mechanism in the deformation of this formation and throughout the area, there is an important degree of flattening deformation associated with the shearing episode.

The pillows often have strongly deformed margins, so that pillowed horizons have relict pillow centres that are intact and define an eliptical form which is enveloped by a foliated greenschist matrix. This matrix is a segregated greenschist and of markedly different mineralogy to the pillow centres (Table 3:3). The size of the preserved pillows is in the range 30-120 cms x 10-70 cms with an average length : width ratio of 2:1. Larger pillows tend to possess higher length : width ratios. This may reflect some degree of shape fabric, other than broadly primary spherical, rather than a purely tectonic effect.

An important consideration is that of relative competency of the pillow-lavas in comparison to the more abundant massive greenstones. A shortening estimate of 100% (based on the L:W ratio of 2:1) may only be valid for the pillows horizons.

A common feature of the pillow-lavas is the presence of tension-cracks within the relict cores (Fig. 3:7). These are useful in that they provide evidence as to the nature of the deformation mechanism. The tension cracks are also present in the epidote-rich pillow fragments that have been mapped as hyaloclastite breccias. The cracks may be perpendicular to the pillow elongation direction and foliation, or slightly sigmoidal, denoting a poorly developed 'Z'-shaped crack defining a dextral sense of movement. Tension gashes also occur within the Moulin de la Rive Orthogneiss Complex where they are particularly well-developed in epidote-rich pods. The tension gashes may have formed during the D1/M1 deformation episode in response to shearing deformation, or more probably as a brittle accommodation structure developed during the D2 episode.

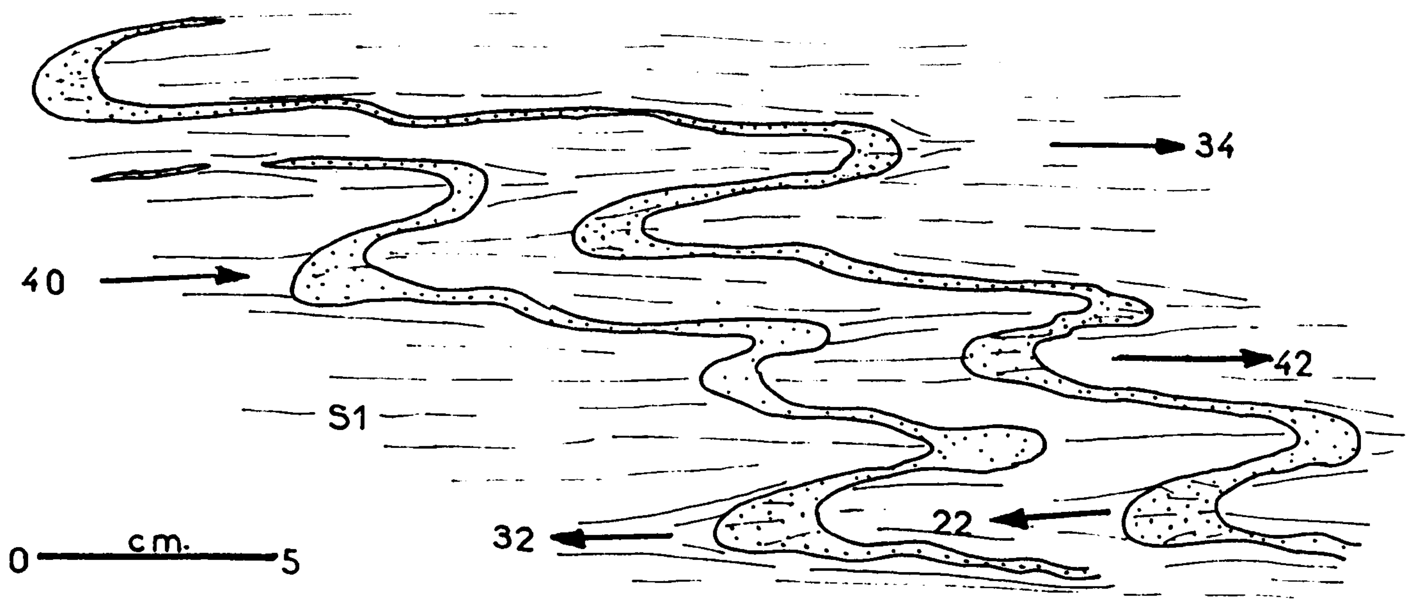
The metasedimentary horizons within the Formation de Pte. de l'Armorique commonly display minor folds (Fig. 3:2). Two types of metasedimentary horizons are recognised which have different observed structures. Dark pelitic sediments with thin metasiltstone laminae occur in the Toul Ar Goué area, at the boundary of the formation with the L S B mylonitic rocks. In this zone the metasiltstones are folded into small-scale tight upright folds, with a well-developed sub-vertical axial-planar cleavage that is parallel to the mylonitic fabric (locally called S2) in the adjacent granitoid mylonites (see Chapter 5, part (C)). The cleavage observed here, crenulates an early fabric which is developed sub-parallel to the lithological banding (Fig. 3:13).

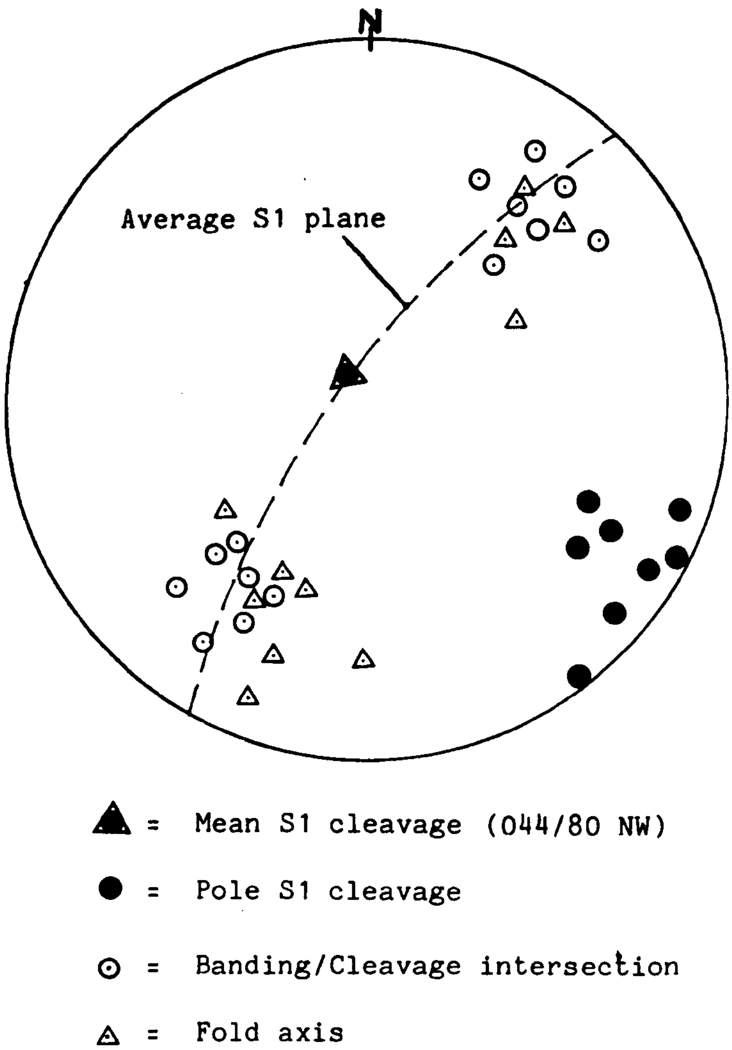
The second type of metasedimentary horizon recognised is volumetrically more important than the pelitic type cited above. These horizons (c. 1-2 m thick) are more siliceous and are made up of grey-green metasiltstones with occasional quartz-rich (semi-psammitic) beds which may be 1-8 cm thick. These beds depict isoclinal folds that are different in form to the tight folds described in the pelitic horizons. The isoclinal folds are non-cylindrical within the plane of the 045^{0} schistosity trend (Fig. 3:18) and folds plunge both SW and NE. The folds display hinge thickening, and some folds display transposition of the limbs so that the hinge areas are preserved and the limbs absent.

An axial planar cleavage is developed which displays marked refraction in the hinge areas, reflecting a degree of competency contrast between the quartz-rich beds and the laminated metasiltstone host.

Greenschists with a well-developed segregation banding are present throughout the formation. They occur in narrow planar zones (1-3 m thick) and within the pillowed horizons. The greenschists possess a sub-vertical schistosity which trends NE-SW parallel to the S1 fabric. In detail, the segregation is developed on a millimetric to centimetric scale (more commonly on the finer scale) with the alternation of green (chlorite-rich) bands and cream-white (calcite-rich) bands (Fig. 3:19).

Fig. 3:18 Non-cylindrical folds in metasedimentary horizons, Porz Mellec





Isoclinal folds with highly non-cylindrical fold axes are commonly developed within the Formation de Pte de l'Armorique. Axes plunge at various angles to the NE and SW within the plane of the S1 cleavage. There is no evidence of refolding and they may form as sheath type folds in a shear regime (Sanderson 1971, Cobbold and Quinquis 1980) or possibly as the result of folding of an irregular primary surface. Such folds are also recorded in the Formation de Barnenez (Chapter 6).

The green-coloured bands are composed of chlorite + epidote + white mica ± quartz, while the cream-white coloured bands are composed of calcite + quartz. Sphene commonly occurs at the interface of the two bands. Epidote appears to have formed at the expense of plagioclase, and commonly forms large porphyroclasts which are anastomosed by chlorite and white mica which is preferentially orientated (Fig. 3:20).

In thin-section mylonitic textures are apparent in which fairly continuous bands (Fig. 3:21) or pods (Fig. 3:22) rich in calcite and quartz are enveloped by fine-grained minerals, principally chlorite. Quartz may display ribbon structure or core and mantle structure (White 1977).

The segregation bands may display small isoclinal folds (Fig. 3:19) and these may be related to a later separate deformation episode, or may have developed sequentially to the segregation producing episode. A late cross-cutting fabric crenulates the S1 foliation and may be related to a D2 episode. The fabric labelled S2 is developed at c. 030^{o} (NNE-SSW) and is best developed in fine-grained greenstones and the foliated greenschists.

(3) THE FORMATION DE PLESTIN

In the dominantly metasedimentary Formation de Plestin two major fold - producing deformation episodes can be distinguished, which also provide evidence as to the deformation sequence in the underlying Formation de Pte. de l'Armorique. The first episode D1 is characterised by isoclinal folds with an associated S1 cleavage which is considered to be developed sub-parallel to the axial planes of the F1 folds. These folds have been refolded by dominantly upright folds which possess an associated well-developed crenulation and pressure solution cleavage. The widespread development of the second folds has frequently masked all evidence of the F1 fold closures, which are only occasionally recognised.

Fig. 3:19 Formation de Pte. de l'Armorique, Porz Mellec

Segregated greenschists are developed in shear zones within the metabasic lithologies. Banding is millimetric to centimetric in scale and is defined by the segregation of light coloured calcite + quartz-rich bands with dark coloured epidote + chlorite rich-bands. The banding is apparently isoclinally folded in this example.

Scale: Key 6 cm

Fig. 3:20 Formation de Pte. de l'Armorique, Porz Mellec

Typical finely foliated segregated greenschists. The greenschists are developed in shear zones up to 2 m wide.

Scale: Hammer handle 36 cm

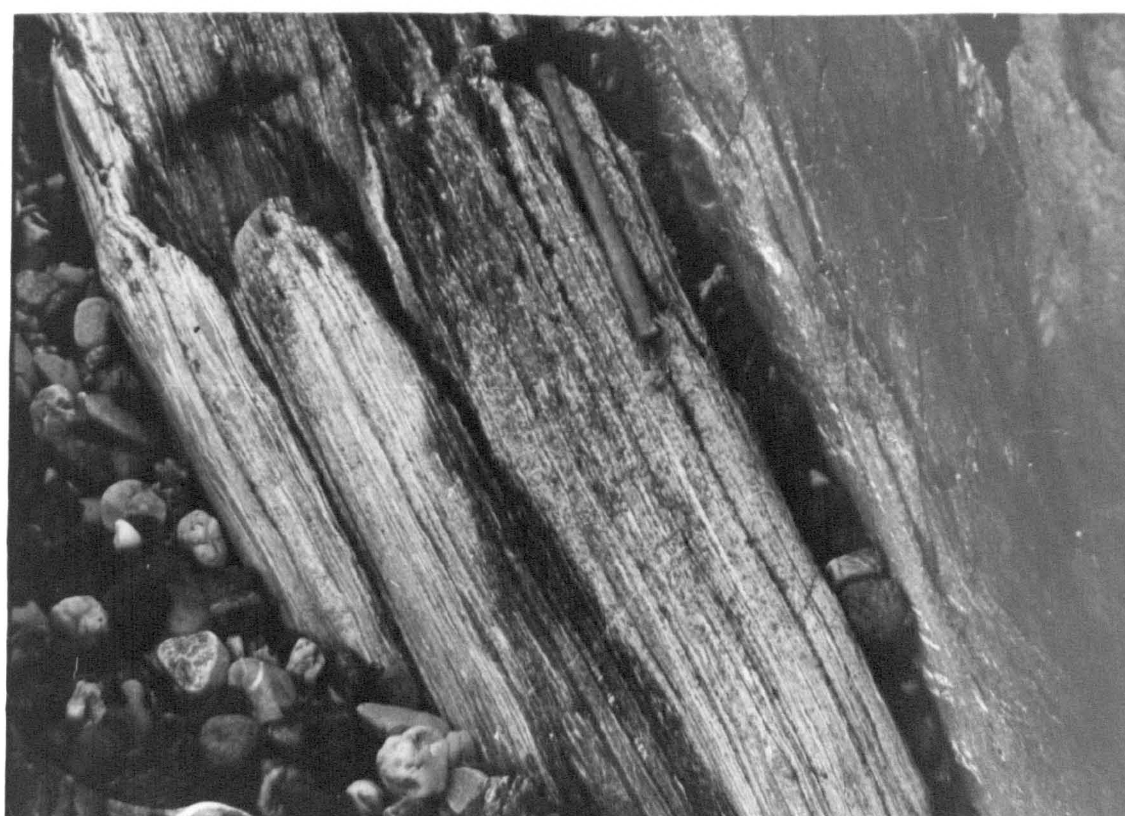


Fig. 3:21 Formation de Pte. de l'Armorique, Plage de l'Argent

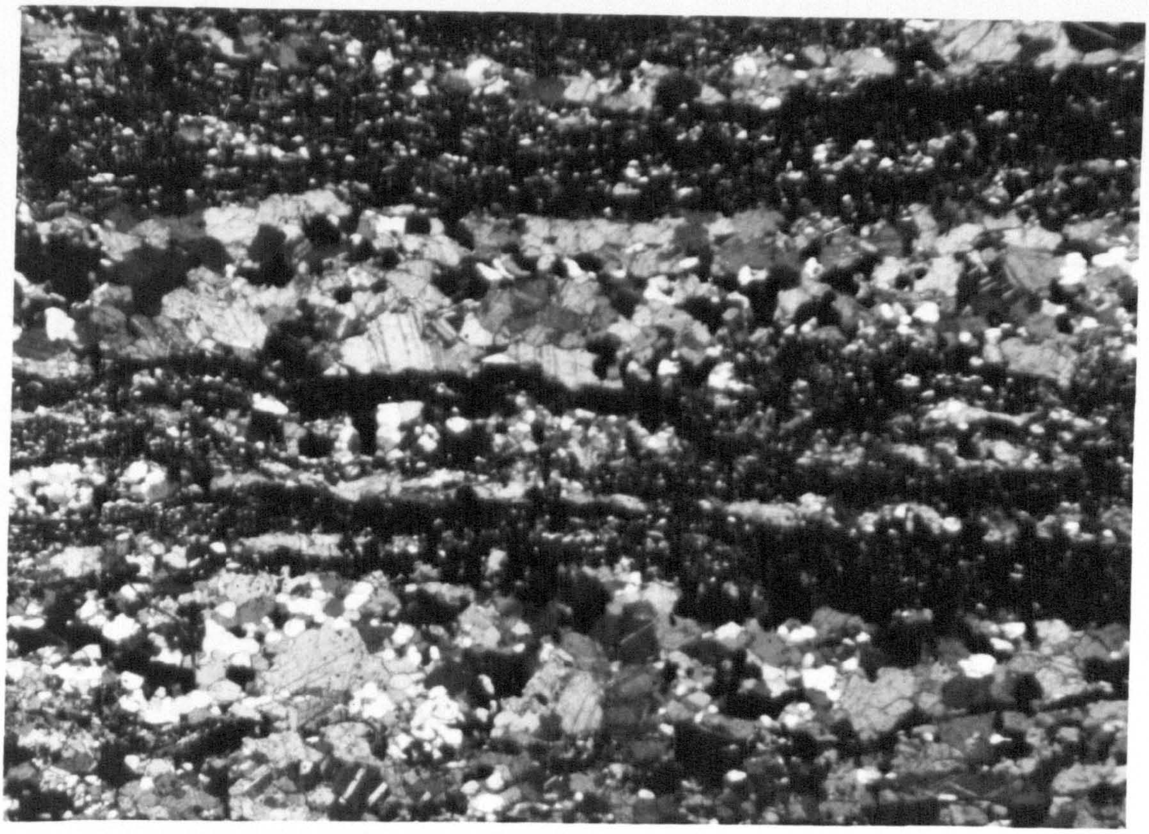
Segregation banding is a common feature of the greenschists in shear zones. The banding is defined by the segregation of calcite + quartz and epidote + chlorite-rich bands parallel to the S1 foliation.

Scale: x15 XPL

Fig. 3:22 Formation de Pte. de l'Armorique, Plage de l'Argent

Mylonitic fabric in greenschists in which quartz-rich lenticular pods are enveloped by chlorite + epidote more continuous rich foliae. The quartz commonly develop core and mantle structure.

Scale: x15 XPL



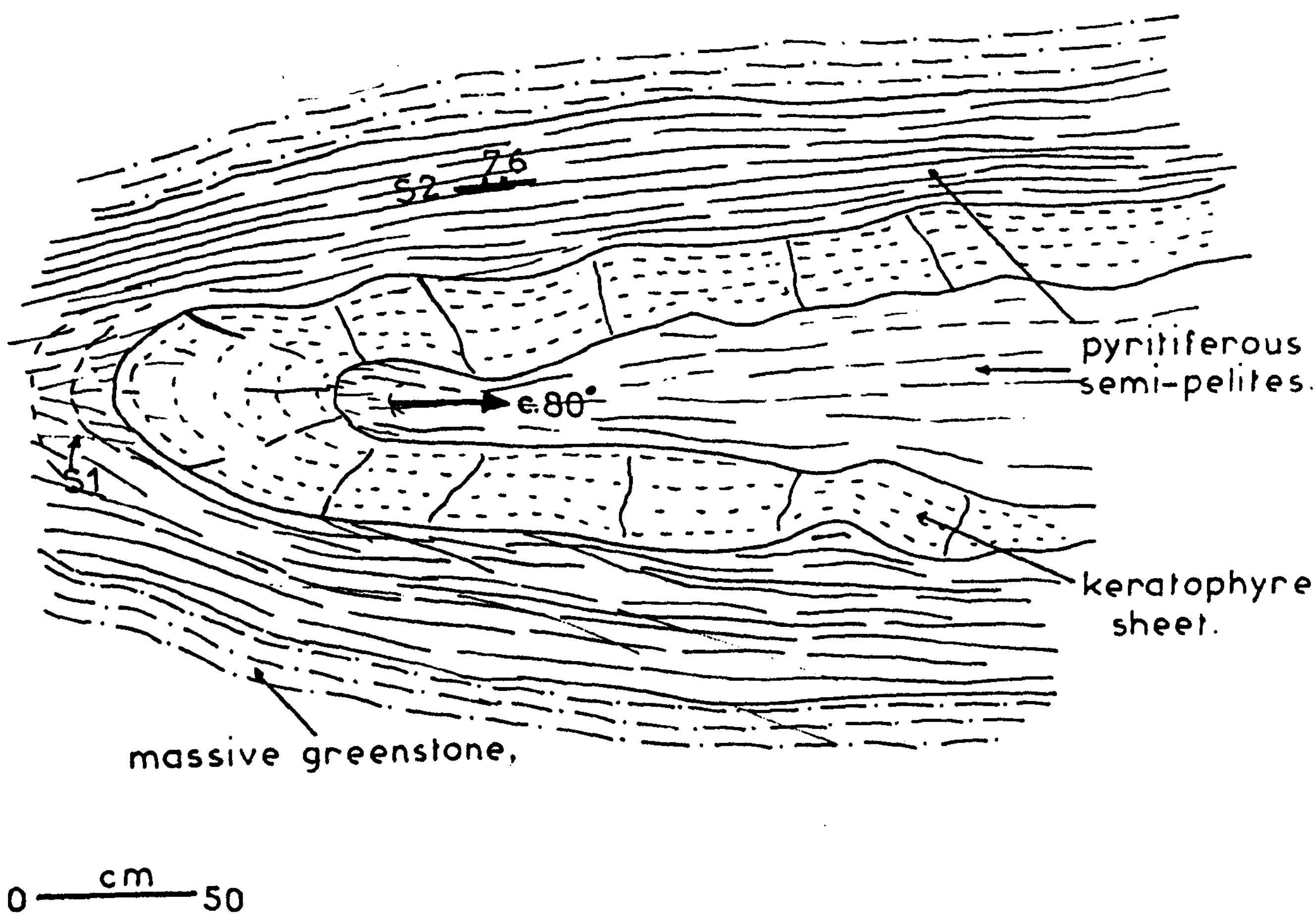
In the St. Michel-en-Grève area folds which face northwest may be attributed to the D1 episode. Several examples of folds were observed which are overturned to the west and commonly faulted parallel to their lower limbs. These F1 folds are further modified by the F2 folds (Fig. 3:13).

Elsewhere, the presence of F1 folds is inferred on the basis of bed inversion as defined by the primary younging direction present. The semi-psammitic beds commonly display graded bedding which may face downwards or may be traced as inverted bedding around the limbs of later F2 folds.

In the Beg Ar Naon area (GR 1646 1290) a single poorly exposed keratophyre dyke is isoclinally folded. This truncates metasedimentary rocks within the Formation de Pte. de l'Armorique, and is considered to be an F1 fold that has been reorientated into the plane of the S2 schistosity, so that both limbs and the hinge of the early fold are now exposed at the current erosion level (Fig. 3:23). Small-scale isoclinal folds have been observed in one locality at St. Michel-en-Grève (GR 1668 1258). These are considered to be F1 folds, they possess an axial-planar cleavage which is crenulated by an oblique S2 crenulation cleavage. The folds are formed in thinly-bedded laminated pelites with occasional siliceous beds.

F2 folds are developed throughout the sedimentary formation. They are generally upright, but may be slightly overturned towards the southeast and the northwest. The folds vary in size from microscopic crenulations to folds of amplitude up to 15 m, the largest of which are exposed in the low cliffs at St. Michel-en-Grève. The folds plunge consistently at a moderate angle towards the northeast (average plunge is 36°).

Fig. 3:23 F1 isoclinal fold, Beg Ar Naon



A single keratophyre sheet, is isoclinally folded by F1. S1 is parallel to S2 and S1 is best-developed in the F1 hinge zone. S2 is orientated approximately 052/76^{0} NW, the F1 fold plunges steeply (c. 80^{0}) to the NE.

Locality. Beg ar Naon. G.R. 1646 1290

The small-scale folds commonly show significant variation in thickness within single beds. Hinge zones and limbs may show asymmetric development with one limb of the fold markedly thicker than the opposing limb (Fig. 3:24). Quartz saddles may develop in hinge zones and transposition of fold structures is indicative of solution-transfer.

The transposition of the quartz-rich layers appears to be related to the development of pressure solution cleavage that is associated with the F2 fold phase. Pressure-solution cleavage is distinguished from the crenulation cleavage by the distinctive striping present in both semi-pelite and semi-psammite beds. The striping reflects a mineralogical difference between quartz-rich light-coloured bands and quartz-depleted dark-coloured bands. The pressure solution appears to be closely related to the development of the crenulation cleavage and the striping is parallel to the S2 crenulation micro-folds. The stripes are not strictly axial planar to the F2 folds and only approximate this direction (Fig. 3:24).

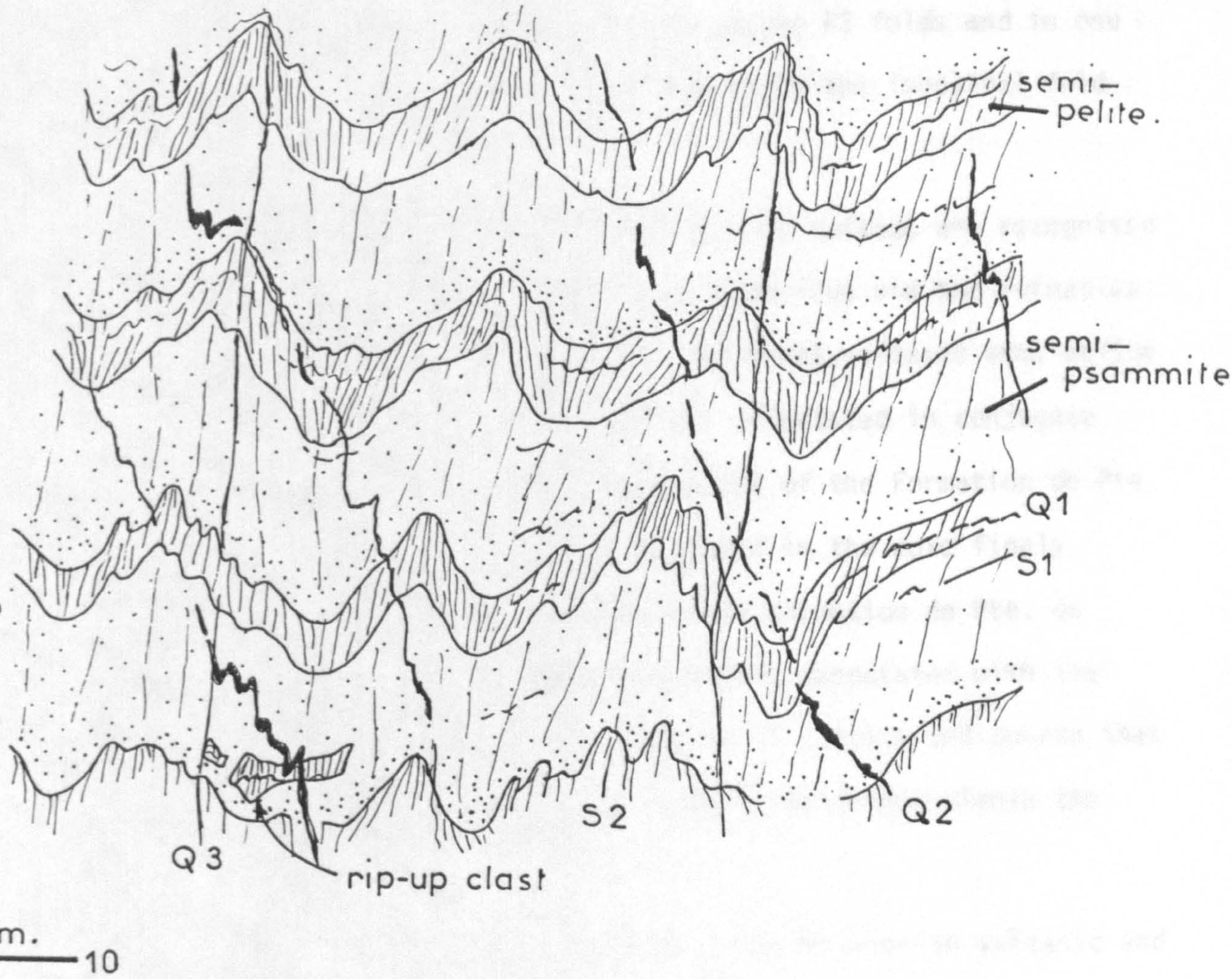
Throughout the metasedimentary succession quartz veins occur. Three sets can be recognised; 1) set (Q1) lies sub-parallel to both the S1 cleavage and the S0 lithological bedding, the veins are c. 1 mm thick and are folded and transposed by later cleavages/foliations;
2) set (Q2) clearly truncates the Q1 set, the S1 cleavage and the S0 lithological bedding, they can be up to 4 cm thick and are folded by the F2 phase; 3) A final set (Q3) lies parallel to the S2 crenulation/pressure solution cleavage, the veins are planar and truncate both Q2 and Q1 vein sets. Fig. 3:25 illustrates the three quartz vein sets. There is evidence that there were some minor earth-movements post-D1 and pre-D2/F2 that resulted in the production of a set of quartz veins. Where this set is folded by the D2 episode they may be boudinaged,with the the axes of the rods lying parallel to the F2 fold axes.

Fig. 3:24 Formation de Plestin, St. Michel-en-Grève

Interbedded semi-psammites and semi-pelites with well-developed F2 folds and S2 crenulation/pressure-solution cleavage. Three generations of quartz veins are recognised, Q1 is parallel to the S0 lithological banding, Q2 is at a high angle to S0 and Q1 is ubiquitously folded and Q3 is parallel to the upright S2 cleavage, (see Fig. 5:25).

Scale: Lens cap 54 mm

Fig. 3:25 Quartz vein sets



Three sets of quartz veins are recognised, Q1 is developed sub-parallel to the lithological banding and is parallel to S1, Q2 truncates Q1 and are folded and Q3 are developed parallel to the prominent S2 cleavage. The upright folds are F2 structures, sedimentary structures include rip-up clasts and graded semi-psammite units.

Location : W. Grève de St-Michel.

The acid sheets are commonly deformed by the F2 folds and in one area, previously cited p. 85, they are deformed by the isoclinal fold phase.

Late structures that may be related to a D3 episode are recognised that affect both the Formation de Pte. de l'Armorique and the Formation de Plestin. Kink-bands are common within the finely-cleaved semi-pelite bands in the Formation de Plestin. They are orientated in conjugate arrays at c. 060-310^{0}. Within the greenschists of the Formation de Pte. de l'Armorique similar kink-bands are developed in the more finely foliated lithologies. Also present within the Formation de Pte. de l'Armorique are late small faults and drag-folds associated with the fault movement. Fault breccias with a matrix of calcite and quartz that surround angular greenstone blocks are commonly developed within the fault zones cutting this formation.

The greenschist facies metamorphism of the Brioverian volcanic and sedimentary succession is the product of a regional metamorphic episode considered to be D1/M1. Greenschists with a well-developed segregation banding formed in narrow ductile shear zones. Contact metamorphism up to hornblende hornfels facies has subsequently affected the Brioverian formations between Beq Ar Forn and Pte. de Séhar within the aureole of the Hercynian Granite de Trédrez.

The foliation present within the Formation de Pte. de l'Armorique is considered to be developed during the D1 episode which also led to the development of the S1 and S2 foliations in the adjacent LSB and Moulin de la Rive Orthogneiss Complex. The shear zones may have developed simultaneously or sequentially to the dominant S1 foliation in a heterogeneous shear regime.

The D1 structures may have been superimposed on earlier structures and, although there is little direct evidence for this in the study area, other areas in NW Brittany indicate an early deformation that is pre-D1 in this scheme.

In the Pte. de Guilben area, near Paimpol, in the Trégor (Fig. 5:36) Brioverian metavolcanics, the Spilites de Paimpol (sensu Auvray 1979), are correlated with the Formation de Pte. de l'Armorique by this author (see discussion p.104). At the Pte. de Guilben there is a steeply southwards dipping sequence of deformed metavolcanic rocks that has undergone marked metamorphic segregation and some degree of flattening. The succession is composed of pillow-lavas, massive-greenstones and pillow-breccias which are truncated by a series of acidic dykes, and are therefore very similar to the lithologies and relationships observed within the Formation de Pte. de l'Armorique. Metasedimentary horizons have not been observed, but jasper occurs in the interpillow triple junctions and may be of sedimentary origin. Greenschists with a well-developed segregation banding have not been observed, and this is significant, as in the Pte. de l'Armorique area, where the greenschists are well-developed and are considered to be formed by shearing, the deformation and recrystallisation is associated within the D1 movements. At the Pte. de Guilben it may be argued that the lithologies have escaped the effects of the D1/M1 episode (that has led to the development of the S1 foliation and shear zones) recognised in the Petit Trégor and the current deformed assemblage observed in the Trégor is that of a pre-D1/M1 episode.

Evidence for the age of a single major deformation affecting the Brioverian Spilites de Paimpol comes from the conformably overlying Brioverian metasediments which crop out south of Paimpol. The metasediments possess simple upright folds and an associated axial planar cleavage. The deformation episode that affects the metavolcanic and metasedimentary formations can be shown to predate the deposition of the Plourivo-Bréhec red beds which are of Lower Palaeozoic age (Auvray et al. 1980b) and unconformably overly the Brioverian. This suggests that the deformation episode recognised in the Pte. de Guilben-Paimpol area is of Cadomian age.

In further support of this argument Brioverian lithologies have been examined in the Baie de St. Brieuc which can be tentatively correlated with the Formation de Pte. de l'Armorique and the Formation de Plestin. It should be stressed that Auvray (1979) and Autran et al. (1979) do not agree with the stratigraphical correlations drawn here, see discussion part (B). Around the southern margin of the Baie de St. Brieuc steeply-dipping Brioverian basic lavas have been metamorphosed in the middle-upper greenschist facies. Although varying from massive to foliated amphibolites these rocks show little of the strong shearing deformation and associated segregation that was an important process in the production of greenschists within the Formation de Pte. de l'Armorique. The Baie de St. Brieuc rocks, like those present within the Pte. de Guilben area, have undergone one major deformation and metamorphic episode that is thought occurred prior to the major episode recognised in the Petit Trégor. It may be argued that the Brioverian formations in the Petit Trégor have been more highly deformed than in areas to the east, the Trégor and Baie de St. Brieuc. This may have occurred during a single episode or during two separate deformation episodes so that the D1 episode recognised in the study area is superposed upon earlier simple structures.

Autran et al. (1979) attribute the major deformation in the Baie de Lannion area to the Hercynian Orogeny. This conclusion is based largely on the comparison with structures in the Morlaix Basin area (Cabanis et al. 1979a). In this thesis two major deformation episodes are recognised.

The D1/M1 episode is considered to have occurred post-emplacement of the Moulin de la Rive Orthogneiss Complex as an early penetrative fabric and S1 is present in both this complex and in the Brioverian lithologies. In Chapter 4, a Cadomian age is argued for the orthogneiss complex. The D2/M2 episode occurred before the emplacement of the Granite de Trédrez which has been dated at 320 ± 10 Ma (Leutwein 1968).

There is a similar structural sequence between the Brioverian metasediments and the Palaeozoic metasediments in the Petit Trégor. Evidence presented in Chapter 6, and discussed further in Chapter 8, indicates that the D1/M1 episode recognised in the Petit Trégor and Baie de Lannion areas is of Hercynian age and Hercynian structures may superpose any earlier Cadomian structures.

(4) SUMMARY

Table 3:4 summarizes the deformation and metamorphic episodes that have affected the Formation de Pte. de l'Armorique and Formation de Plestin.

The metavolcanic and metasedimentary formations have acted heterogeneously to the imposed strain. Greenschists with a well-developed segregation banding were developed in ductile shear zones, that are considered to have developed simultaneously to the S1 foliation during heterogeneous deformation or they may have developed sequentially during a late deformation episode.

The age of the deformation is somewhat problematical as evidence points to a major D1/M1 episode of Hercynian age which may, by analogy with other areas, have superposed and masked earlier, simple structures produced during the Cadomian episode.

Contact metamorphism associated with the emplacement of the late Hercynian Granite de Trédrez is restricted to the northeastern Baie de Lannion.

EVENT	FORMATION DE PTE DE L'ARMORIQUE	FORMATION DE PLESTIN
D3/M3	Kink-bands and drag faults and folds	Kink-bands developed
	Contact metamorphism of Brioverian succession by Granite de Trédrez	
D2/M2	Folding of segregation banding and possible further movement along shear zones. Development of S2 crenulation foliation in restricted lithologies.	Widespread development of upright NE plunging folds with S2 crenulation and /or a pressure-solution cleavage.
D1/M1	Development of S1 foliation parallel to the lithological banding, S1 close-spaced in shear zones in which segregation banding variably developed. Isoclinal folds developed in metasedimentary bands. Regional greenschist facies metamorphism.	Production of medium-small scale isoclinal folds, associated S1 axial planar cleavage.
Pre-D1 ?	Possible tilting of succession as seen at Pte de Guilben and simple structures (Cadomian age ?)	

TABLE 3 : 4 DEFORMATION AND METAMORPHIC EVENTS AFFECTING THE BRIOVERIAN SUPERGROUP

(F) GEOCHEMISTRY OF THE FORMATION DE PTE DE L'ARMORIQUE

(1) INTRODUCTION

Fourteen samples from the Formation de Pte de l'Armorique have been analysed chemically in order to give some indication as to:

(1) their major and trace element contents;

(2) the behaviour of mobile elements within the metavolcanic formation;

(3) the geotectonic environment in which they were erupted.

All the analyses have been made by X-ray fluorescence spectrometry, except for Loss on Ignition (L.O.I.) and FeO,which have been determined by gravimetry and titrimetry respectively. The concentrations of major and trace elements in the analysed samples are given in Appendix 3, the methods of sample preparation and analysis are given in Appendix 1, and the lithological types and localities in Appendix 2.

In view of the limited extent of the data set, discussion of its features will be integrated with that of the results of Autran et al. (1979), who published 24 major element analyses of the Formation de Pte de l'Armorique. It is also relevent to include in the discussion, where necessary, the work of Auvray (1979) on the Spilites de Paimpol in the Trégor, considered to be contemporary with the Formation de Pte de l'Armorique. Auvray has published 50 analyses of samples taken from locations between the Pte de Guilben near Paimpol in the east of the Trégor and the environs of Lannion in the west of the Trégor. The analyses are mostly for major elements only, but selected samples have been analysed for a few trace elements.

The major element analyses of both Autran et al. and Auvray are incomplete. The former authors determined neither CO_2 nor L.O.I.. In these highly strained rocks, where there is much evidence for the mobility of $CaCO_3$ and a high CO_2 partial pressure, which has led to the formation of calcite, it would have been highly desirable to have been able to correct for the presence of significant quantities of calcite. At least three of their analyses (302, 305, 306) show abnormally high CaO contents (indicated by the occurrence of Wo (wollastanite) in the C.I.P.W. norm), suggesting the presence of significant amounts of calcite in the mode. The presence of calcite, usually distributed in a non-uniform manner, particularly in high strain zones, can have a marked dilution effect on the concentration of other elements in such metabasic rocks (c.f. Floyd and Lees 1973).

Auvray determined neither CO_2 nor P_2O_5. The absence of the latter oxide prevents the use of the Spilites de Paimpol data in certain discrimination diagrams for comparative purposes.

Of the rock samples analysed by the present author, NG 002, NG 004, NG 067, PA 033, all show considerable concentration of CO_2, whilst NG 1589, PA 035 and PA 036 show lesser but significant CO_2%. Petrographic studies show that samples NG 002, NG 004, NG 067, PA 033 and PA 034 are either greenschists with well-developed metamorphic segregation banding or contain vesicles with secondary infilling. They must therefore be treated with caution.

(2) MAJOR ELEMENT GEOCHEMISTRY

The samples from the Formation de Pte de l'Armorique used in this study (n = 13) possess the major element characteristics shown in section A of Table 3:5. However, because of the high degree of alteration of some of the samples, six have been rejected in order to gain some idea of the igneous composition of the rocks. A subset of seven samples, considered from their petrographic characteristics to be the least altered of the specimens (NG 1589, NG 0593, PA 029, PA 032, PA 035, PA 036, PA 037), has the major element characteristics shown in section B of Table 3:5. This subset can be shown to plot much more tightly than the overall sample field.

The major element character shown in section B of table 3:5 indicates that this rock suite would pass through the basalt screen of Manson (1968). The total alkali content would indicate that it is a subalkaline suite, while the low TiO_2, K_2O and P_2O_5 contents might indicate a tholeiitic character. Such conclusions are reinforced by two variation diagrams: the total alkalies vs. SiO_2 plot of McDonald and Katsura (1964) (Fig. 3:26), which shows that the majority of the points falls below the alkaline-subalkaline divide; the AFM ternary plot (Fig. 3:27; i.e. total alkalies - total iron as FeO-MgO) which shows a clearly defined iron-enrichment trend, characteristic of tholeiitic suites. In addition, the low Al_2O_3 content argues against a high-alumina basalt, confirmed by the total alkalies vs. Al_2O_3 plots of Kuno (1960, 1968) (Fig. 3:28 (a) and (b)). Much more information can be obtained from other various variation and discrimination diagrams.

Fig. 3:29 (a) and (b) shows the simple bivariate variation diagrams using MgO as a differentiation index. The tight grouping of the seven 'best' samples is apparent. Not too much variation which could be ascribed to fractionation can be seen. SiO_2 shows an inverse relation with MgO, as do P_2O_5, TiO_2 and to a lesser degree total alkalies.

Plotting the data on variation and discrimination diagrams and comparing the plotted fields with those of the data of Autran et al. (1979), shows good agreement between the two data sets, so further discussion will be based on them both.

Both major and trace element variation diagrams have been used in the past to try to indicate the geotectonic environment in which magmas were emplaced. Such an exercise has been used with a great deal of

Oxide %	SECTION A Mean	SECTION A STD DEVN	SECTION A Range	SECTION B Mean	SECTION B STD DEVN	SECTION B Range
SiO_2	50.23	6.18	40.09 - 59.90	49.28	2.33	46.32 - 53.11
TiO_2	0.65	0.24	0.45 - 1.31	0.62	0.18	0.46 - 0.99
Al_2O_3	13.97	1.53	10.84 - 16.62	14.39	0.82	13.16 - 15.61
Fe_2O_3	3.93	1.94	0.96 - 8.57	3.05	1.03	0.96 - 4.16
FeO	4.83	2.26	1.41 - 8.61	6.08	0.89	5.07 - 7.62
MnO	0.14	0.03	0.11 - 0.18	0.16	0.02	0.14 - 0.18
MgO	7.73	3.95	1.21 - 11.75	10.90	1.13	9.47 - 12.54
CaO	10.09	5.35	0.37 - 19.63	9.25	1.77	6.02 - 11.40
Na_2O	1.72	0.94	0.32 - 2.78	1.84	0.63	1.03 - 2.78
K_2O	0.51	0.81	0.12 - 0.62	0.34	0.15	0.20 - 0.62
P_2O_5	0.10	0.05	0.03 - 0.14	0.07	0.03	0.03 - 0.11
LOI	5.98	3.88	2.46 - 14.51	4.22	0.59	3.64 - 5.28
	(N = 13)			(N = 7)		

Section A : Data on the whole set (N = 13)

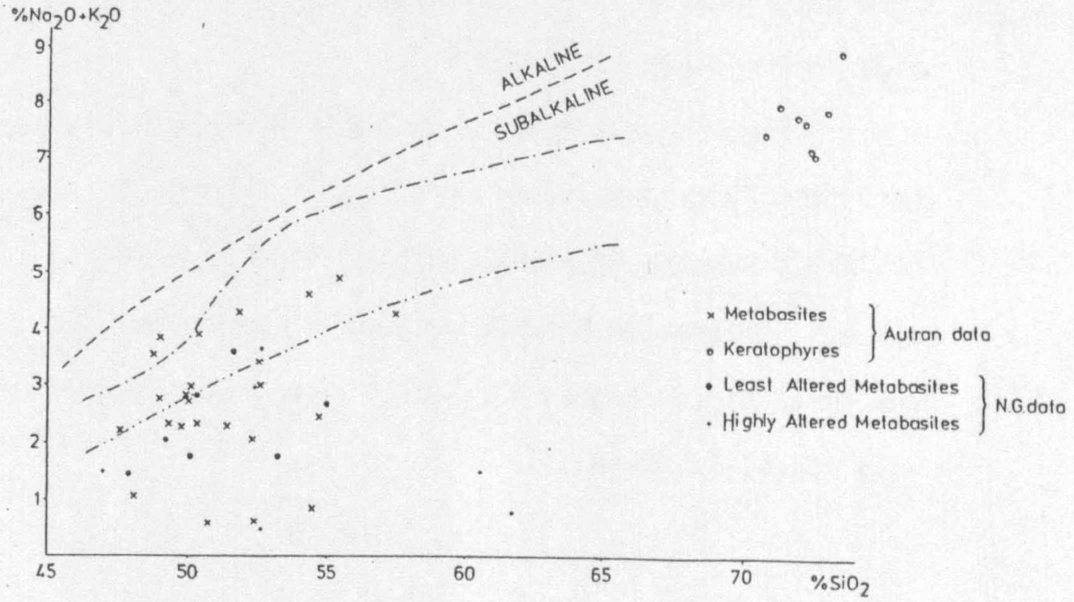
Section B : Data on the least altered samples (N = 7)

TABLE 3 : 5 - SUMMARY SATISTICAL DATA ON THE METABASIC ANALYSES FROM THE FORMATION DE POINTE DE L'ARMORIQUE.

Fig. 3:26 Bivariate plot of Total Alkalies ($Na_2O + K_2O$) vs. SiO_2 for the Formation de Pointe de l'Armorique data of Griffiths (this work) and Autran et al. (1979). The ---- line marks the position of the alkaline-subalkaline divide of McDonald and Katsura (1964). The -·-·- line marks the divide between alkali-basalts and high-alumina basalts, while the -·-·-·-·- line divides the high-alumina basalts from the tholeiitic basalts (both from Kuno 1968).

Fig. 3:27 A-F-M ternary plot of the Formation de Pointe de l' Armorique data of Griffiths (this work) and Autran et al. (1979).

FIG.3:26



Formation de Pointe de l'Armorique

FIG. 3:27

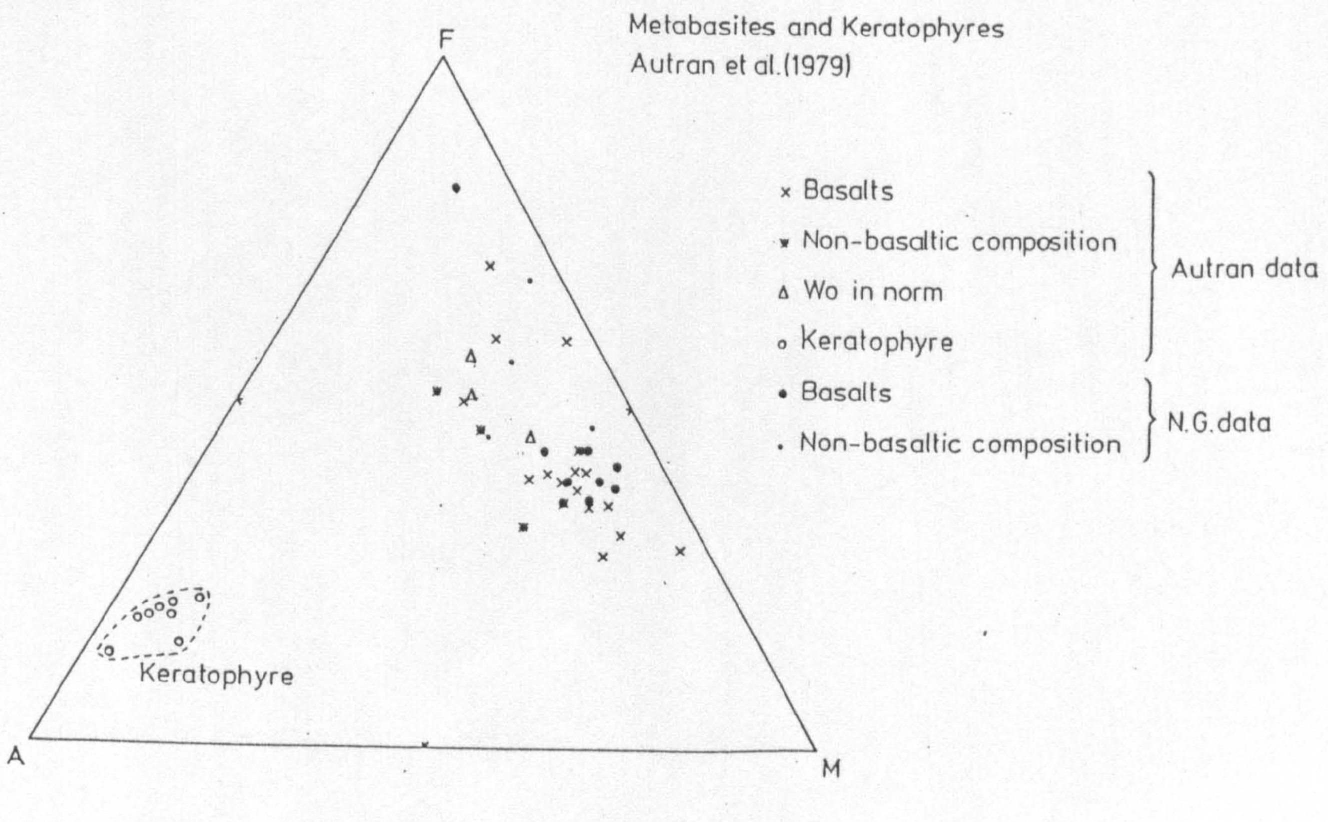


Fig. 3:28 Bivariate plots of Total Alkalies ($Na_2O + K_2O$) vs. Al_2O_3 (after Kuno 1960, 1968).

a,b : Formation de Pointe de l'Armorique data of both Griffiths (this work) and Autran et al. (1979) for the two SiO_2% ranges: 47.51-50.00-(a); 50.01-52.50-(b).

c,d,e : Spilites de Paimpol data of Auvray (1979) for the three SiO_2% ranges: 47.51-50.00-(c); 50.01-52.50 -d); 52.51-55.00-(e).

Formation de Pointe de l'Armorique Metabasites

FIG. 3: 28(a)

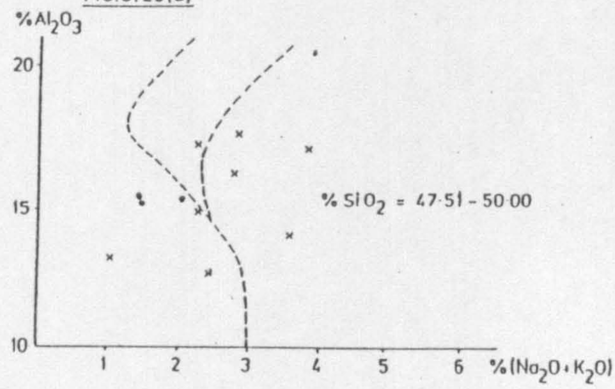
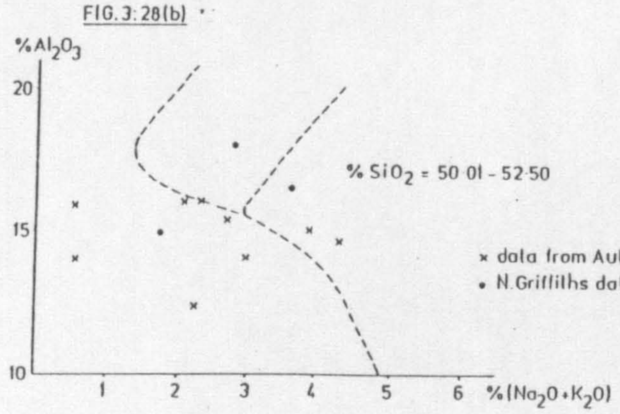


FIG. 3: 28(b)



Metabasites of the Spilites de Paimpol (Auvray, 1979)

FIG. 3: 28(c)

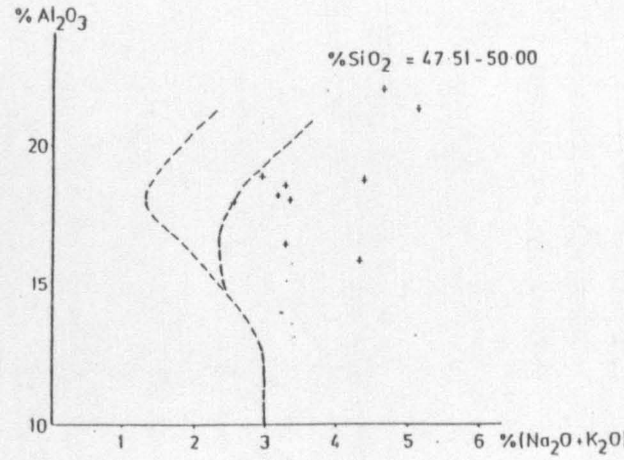


FIG. 3: 28(d)

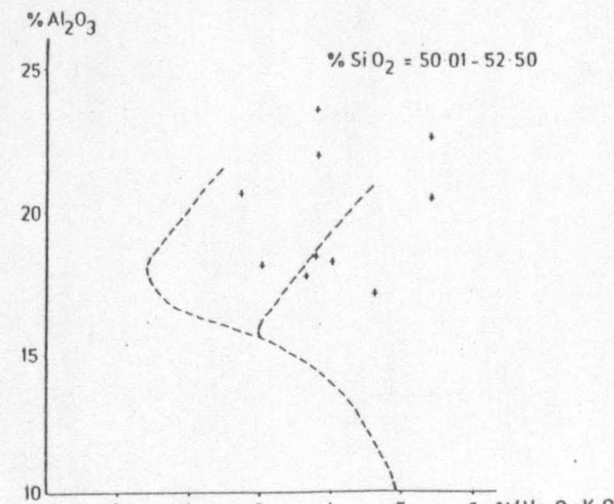


FIG. 3: 28(e)

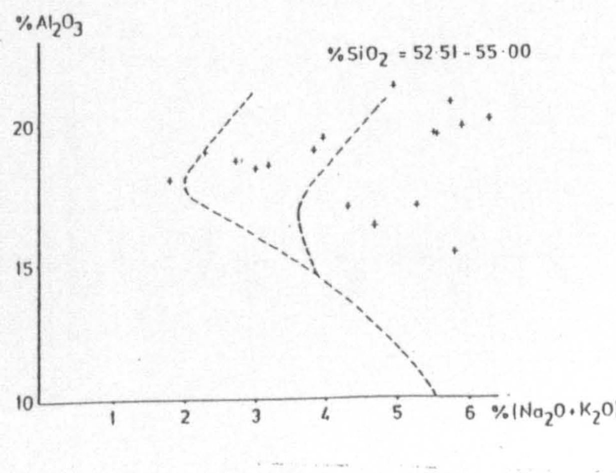
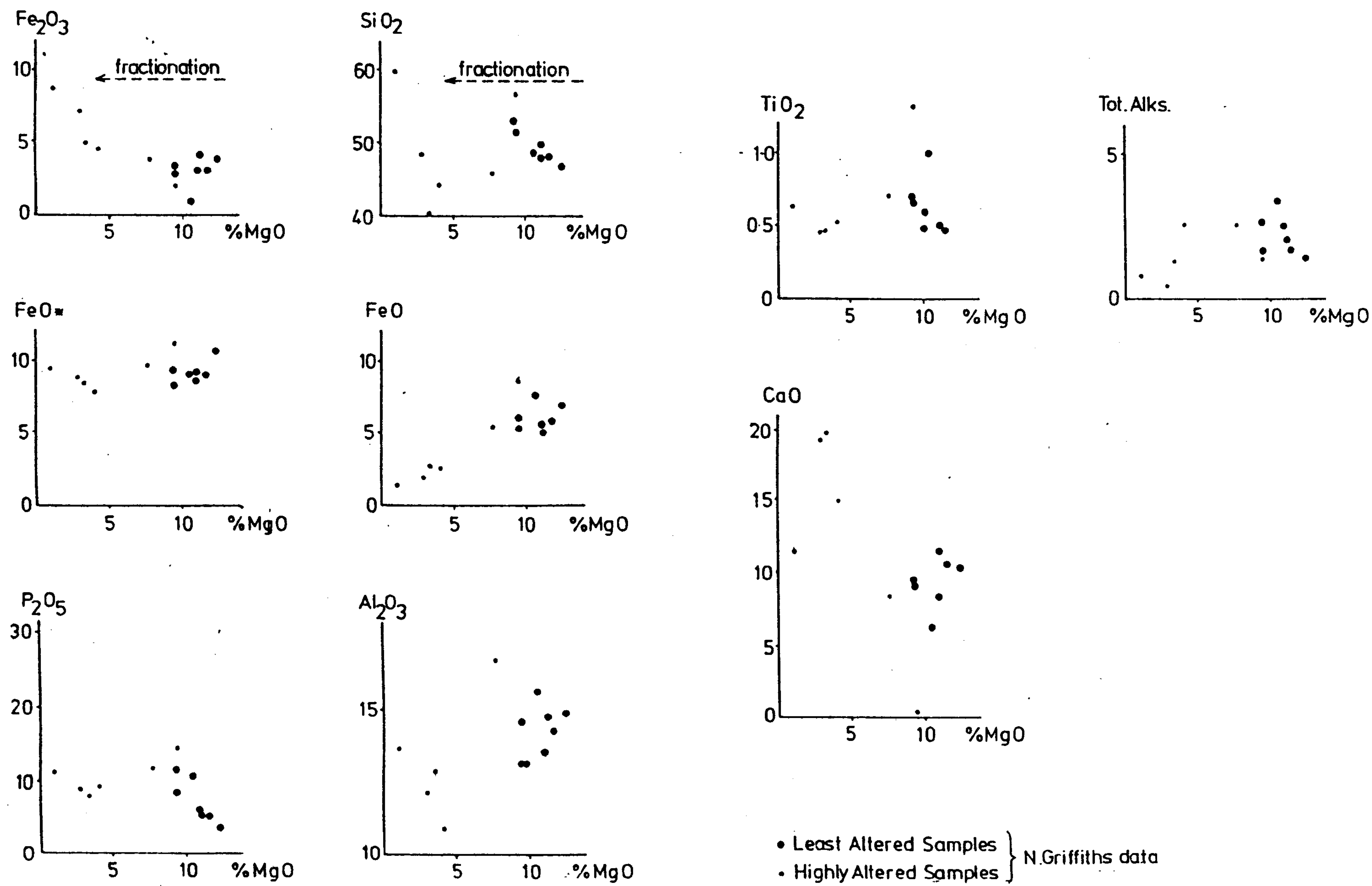


Fig. 3:29 Bivariate variation diagrams for the major element using %MgO as an index of differentiation. The arrows indicate the postulated direction of fractionation in normal basic volcanic suites. (Griffiths data only used).

Formation de Pointe de l'Armorique Metabasites

FIG. 3:29



success for those rock suites which are of recent origin and which have a comparatively simple post-eruptive history. Rock suites which have a much longer post-eruptive history and which have been subjected to one or more orogenic episode of varying degrees of severity, are much more difficult to interpret. The problems involved in classifying such altered metabasic igneous rocks as those of the Formation de Pte de l'Armorique are well known - see Bevins (1979) for a review.

Migration and redistribution of several major and trace elements may have occurred during processes of submarine weathering, burial diagenesis and metamorphism, or regional metamorphism (Roberts 1980). The mobility of some elements, in particular Ca, is important in zones of high strain. This mobility during post-eruptive processes can be indicated on the major element variation diagrams. It can be seen that the 'least altered' subset tends to plot in a relatively small field, while the highly altered samples show a considerable spread. This applies to all the major elements (Fig. 3:29).

In general it can be seen that the fine-grained segregated greenschists derived from pillow lava rims show the greatest scatter, while the massive greenstones and pillow cores show the least, particularly with respect to CaO and Na_2O. The mineralogical variation observed is reflected in the chemical variation, CaO being associated with calcite and epidote, MgO with chlorite, and Al_2O_3 and Na_2O with albite.

The rocks of the Formation de Pte. de l'Armorique have been generally considered by previous workers (e.g. Autran et al. 1979) to be spilitic. Although this is usually accepted nowadays amongst most workers simply to represent a mineral assemblage reflecting low-grade regional metamorphism, it is not universally so accepted (see Amstutz 1974 for discussion). Amongst those workers who do not accept such a view and who have described lithologies from the Massif Armoricain are Auvray (1979), Vidal (1980) and Autran et al. (1979).

Autran et al. (op. cit.) have discussed the geochemical characteristics of the Locquirec Shear Belt (LSB, see Chapter 5) and of the Formation de Pte. de l'Armorique (the Formation de Locquirec, the Formation de Rugunay and the Formation de l'Armorique of their terminology). They have given only major element analyses, from which they conclude that the rocks of the both the Formation de Pte. de l'Armorique and the LSB form a single suite of calc-alkaline affinity. The metabasites they consider to have a spilitic character.

Field evidence presented in this thesis has shown the intrusive relationship of the LSB lithologies (the highly deformed equivalent of the Moulin de la Rive Orthogneiss Complex) into the Brioverian lithologies. Such a geochemical association as proposed above by Autran et al. (op. cit.) is thus meaningless

The samples analysed for this work, together with the samples of Autran et al. (1979), have been plotted on some of the more widely used variation diagrams (e.g. Figs. 3:26, 3:27, 3:30 (a) and (b)). Some of these diagrams have already been mentioned, i.e. total alkalies vs. SiO_2, total alkalies vs. Al_2O_3, and the AFM ternary diagram. Two others are due to Miyashiro (1974), using the ratio FeO* (total iron asFeO)/MgO as the differentiation index on the absicca. The ordinate can be either SiO_2 or FeO*, enabling calc-alkaline (SiO_2 enrichment) or tholeiitic (FeO* enrichment) trends to be identified. These two diagrams have been plotted in Figs. 3:30 (a) and (b). Taking the 'least altered' subset, it can be seen that in the silica enrichment diagram, all but one of the samples plot in the calc-alkaline field with the odd one plotting on the boundary line. Autran's data set shows a more even distribution on both sides of the line, but with the majority of points still lying in the calc-alkaline field. The spread of points into the tholeiitic field may be a reflection of alteration in Autran's data, as

Fig. 3:30 Bivariate variation diagrams after Miyashire (1974) to discriminate calc-alkaline and tholeiitic suites.

(a) Plot of FeO* (total iron as FeO) vs. FeO*/MgO to monitor iron enrichment with differentiation. Both Griffiths (this work) and Autran et al. (1979) data are plotted.

(b) Plot of SiO_2 vs. FeO*/MgO to monitor silica enrichment with differentiation. Both Griffiths (this work) and Autran et al. (1979) data are plotted.

FIG. 3:30(a)

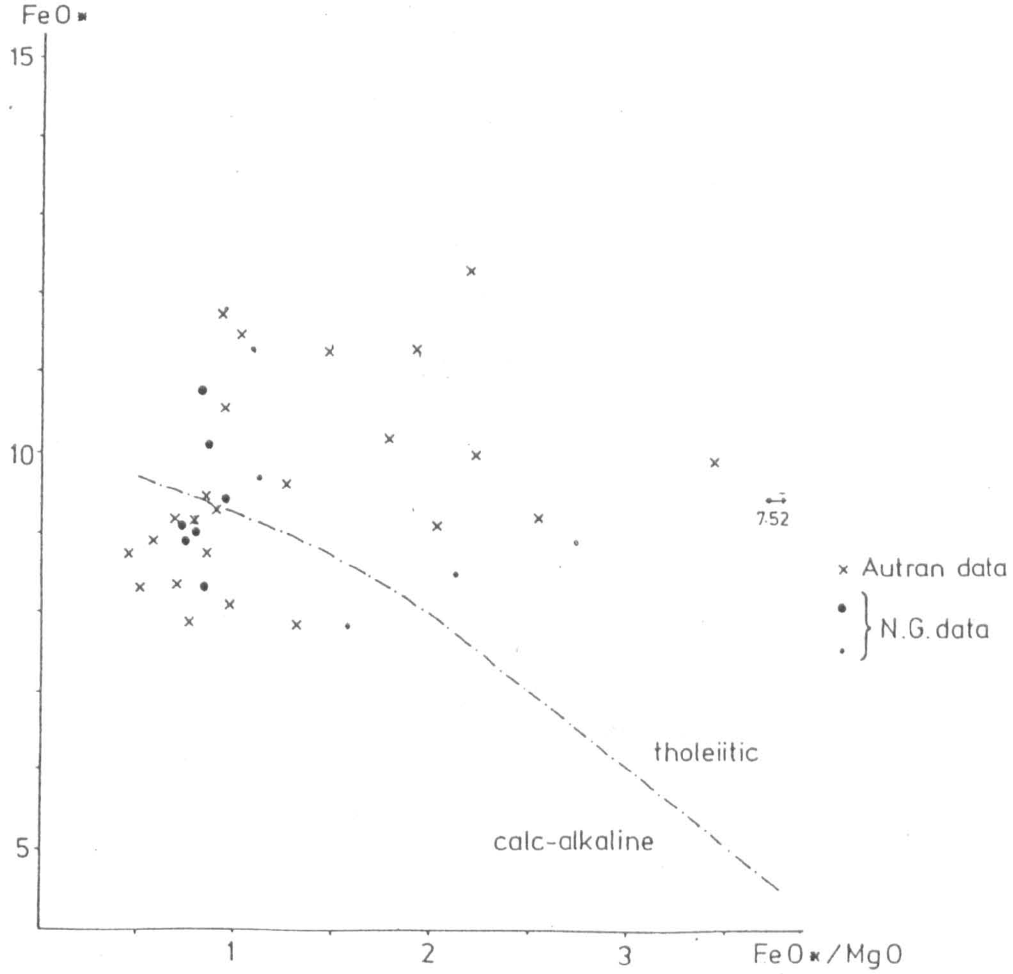
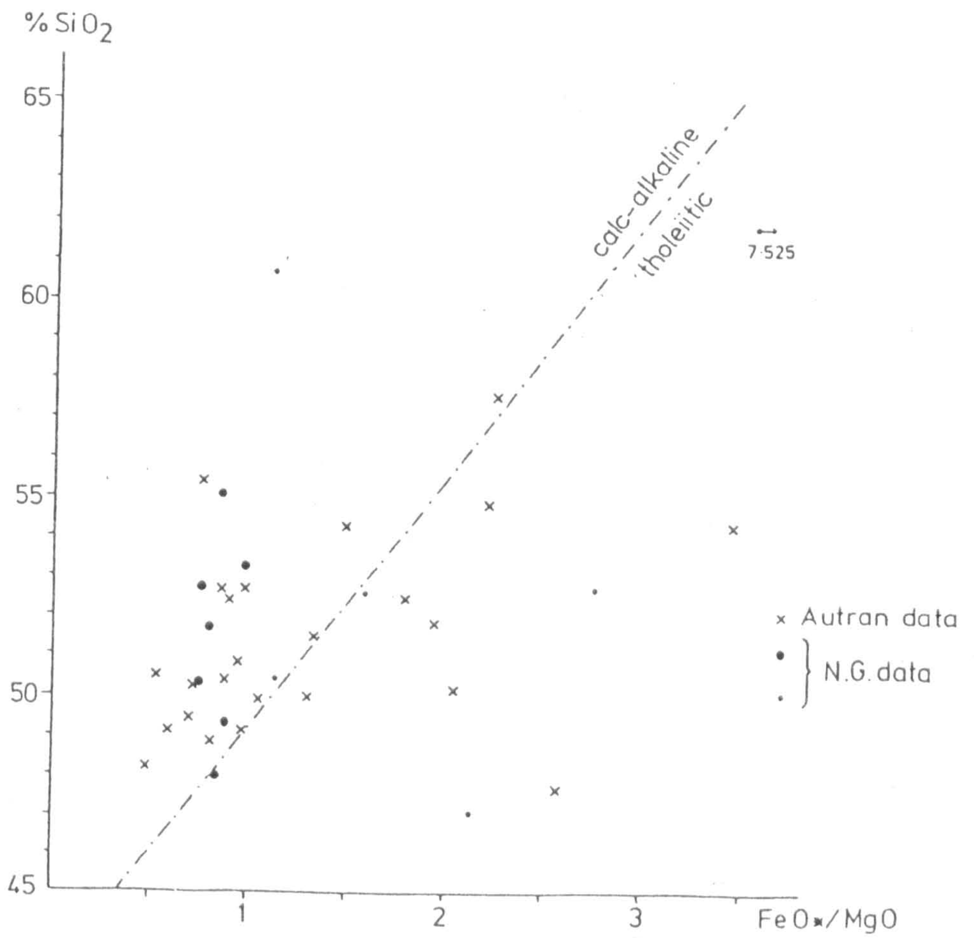


FIG. 3:30(b)



it is in the data set in this work. The iron-enrichment diagram also shows a scatter of points across the calc-alkaline-tholeiitic boundary, but this time much more even for both data sets. However, the majority of the highly altered samples from this study show a scatter in the tholeiitic field, so once again, the distribution of points from Autran's data set in the tholeiite field may in part be caused by alteration.

Many major element discrimination diagrams have been proposed in recent years in an attempt to indicate the nature of the geotectonic environment within which magma suites have been erupted. Two such diagrams have been proposed by Pearce, Gorman and Birkett (1975, 1977). These are the TiO_2-K_2O-P_2O_5 ternary diagram for discriminating between oceanic and non-oceanic basaltic rocks, and the MgO-FeO*-Al_2O_3 diagram for discriminating rocks of more basaltic-andesitic composition into five possible geotectonic settings. For a discussion of the rationale behind these diagrams, the reader is referred to the original papers. The combined data set has been plotted on these diagrams (Figs. 3:31 and 3:32 (a) and (b)).

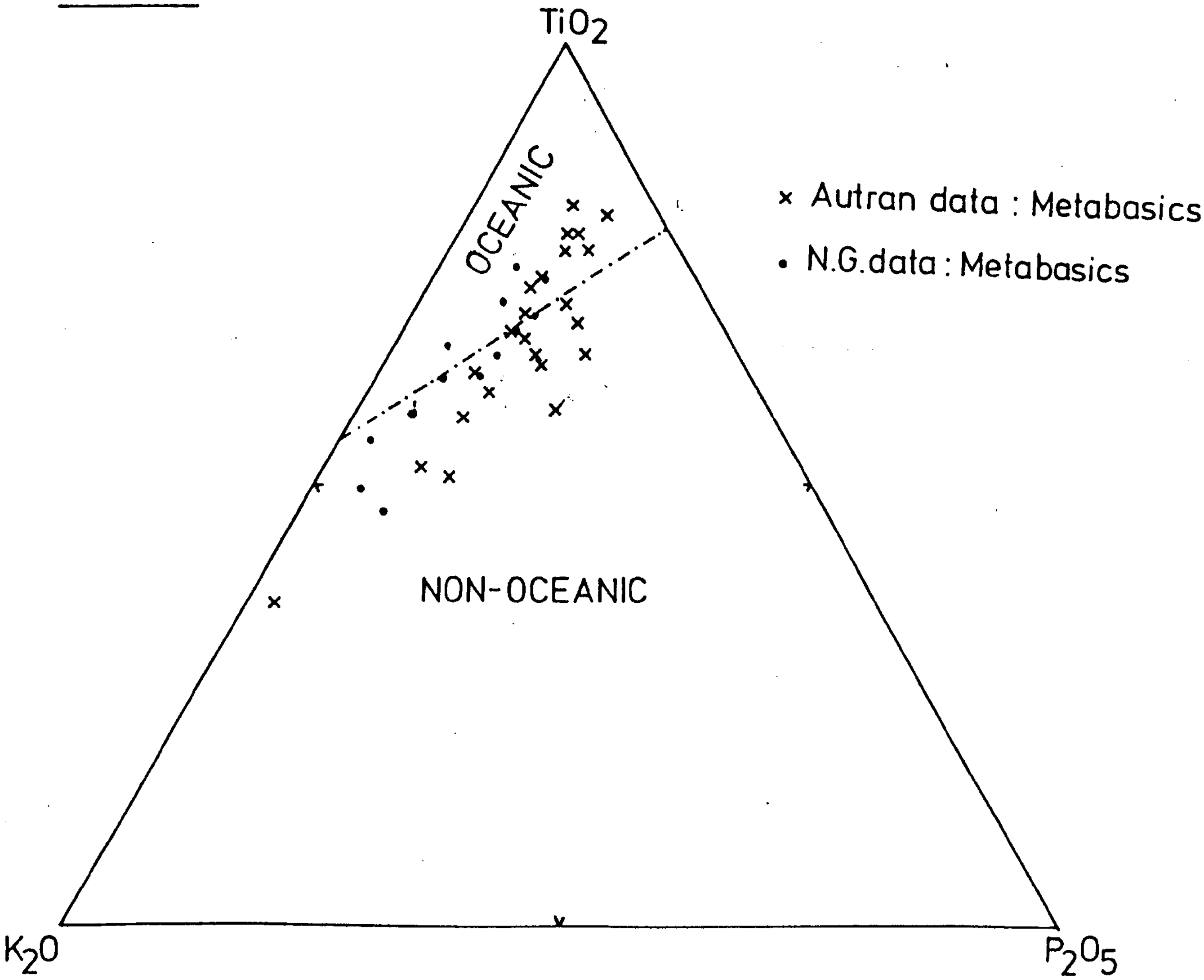
The K_2O-TiO_2-P_2O_5 diagram (Fig. 3:31) might be not be expected to be of much use because of the extreme mobility of K_2O during alteration and metamorphism;so it proves. The sample points scatter fairly evenly across the discriminating line, along a line connecting the K_2O apex to a point on the TiO_2-P_2O_5 join, i.e. they have approximately constant TiO_2 : P_2O_5 ratios. The 'trend' of the current data set is very slightly displaced from that of the Autran data set towards the TiO_2 apex. This may simply reflect differences in analytical bias.

The MgO-FeO*-Al_2O_3 terniary diagram (Fig. 3:32 (a) and (b)) should be much less vulnerable when dealing with rocks subjected to alteration and metamorphism. However, MgO is known to be mobile under greenschist

Fig. 3:31 Major element ternary discrimination plot of TiO_2-K_2O-P_2O_5 after Pearce, Gorman and Birkett (1975) for both the Griffiths (this work) and the Autran et al. (1979) data.

Formation de Pointe de l'Armorique Metabasites

FIG. 3:31



facies metamorphism conditions. This is brought out by looking at the samples analysed in this study as they plot in the triangle (Fig. 3:32 (a)). The least altered subset can be seen to occupy a tight field, while the highly altered samples are scattered about a line joining the MgO apex and that field, between it and the FeO^*-Al_2O_3 join. All the least altered subset samples can be seen to plot in the oceans ridge and floor field. Also plotted is the Autran data set (Fig. 3:32 (b)) which can be seen to behave very similarly, the large majority of points plotting in the ocean floor and ridge field, but more spread out. Here, the field stretches both toward the FeO^*-Al_2O_3 join in one direction and towards the MgO apex in the other, showing that samples enriched in MgO (chlorite-rich?) have also been sampled. The lack of such samples in the smaller data set obtained in this study is probably a sampling bias; chlorite-rich samples being much more difficult to collect than epidote or quartz-rich ones. The outline of the field occupied by the Spilites de Paimpol (Auvray 1979) has also been included in Fig. 3:32. Considering only the inner field containing the majority of data points, it can be seen that it spreads across from the ocean ridge and floor field into the calc-alkaline field, a markedly different distribution from that of the Formation de Pointe de l'Armorique. Unfortunately Auvray did not determine P_2O_5 on these rocks so his data could be plotted neither on the K_2O-TiO_2-P_2O_5 ternary diagram mentioned above, nor on the diagram considered immediately below.

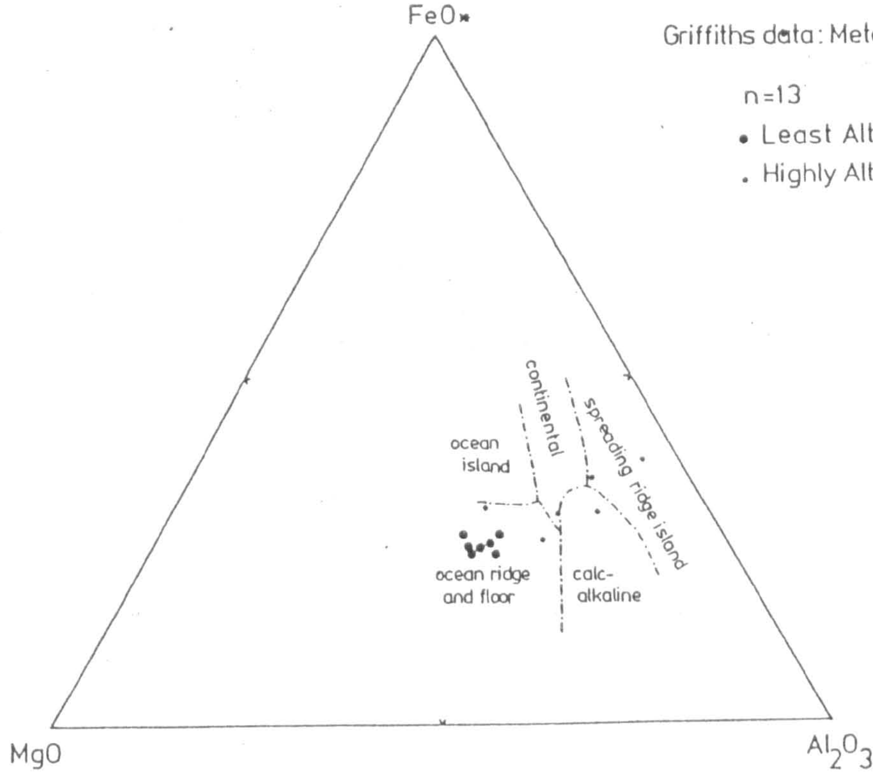
Recently a discrimination diagram has been proposed by Mullen (1983) which uses the three minor element oxides MnO, TiO_2 and P_2O_5 in an attempt to distinguish basaltic and basaltic andesite rocks (SiO_2 = 45%-54%) within different oceanic environments. In this ternary diagram, both MnO and P_2O_5 are scaled to x10 in order to make the diagram more sensitive. It is divided into five fields: calc-alkaline (CAB);

Fig. 3:32 Major element ternary discrimination diagrams

(a) MgO-FeO* (total iron as FeO) - Al_2O_3 plot, after Pearce, Gorman and Birkett (1977) for the data in this work. Note that the least altered samples all plot in the ocean ridge and floor field.

(b) MgO-FeO*-Al_2O_3 plot for the data of Autran et al. (1979). Note the similar position of the sample points to those of (a). In contrast, the field of the data points of the Spilites de Paimpol (Auvray 1979) plot more towards the Al_2O_3 apex, much more in the calc-alkaline field.

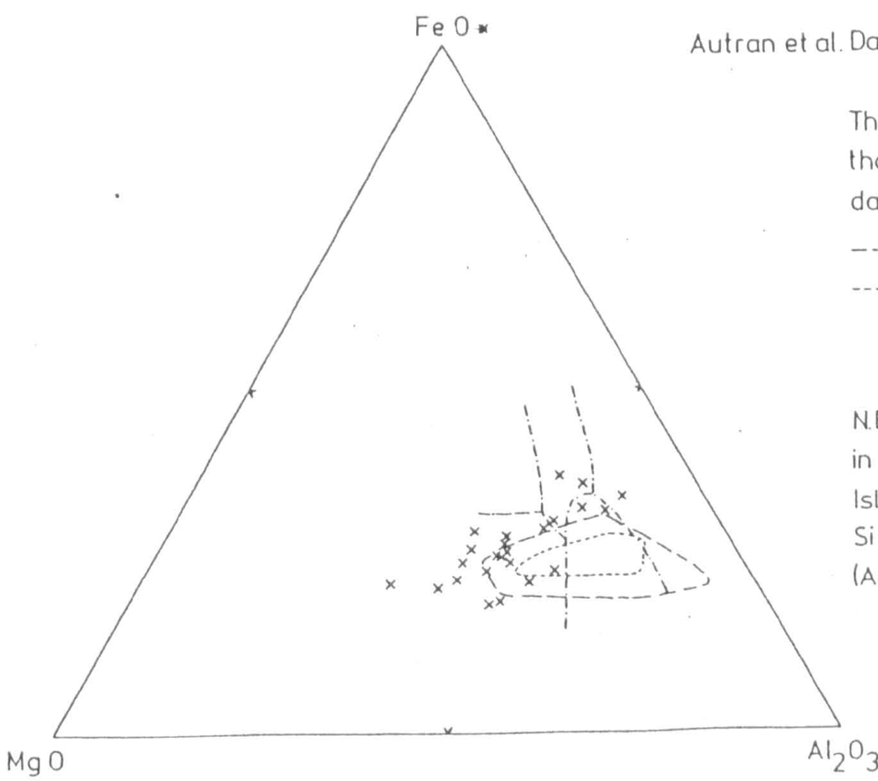
FIG. 3:32(a)



Griffiths data: Metabasic data

n=13
• Least Altered Samples
. Highly Alterered Samples

FIG. 3:32(b)



Autran et al. Data

The dashed fields are those of Auvray (1979).
data:
___ overall data field
----- field containing the major concentration of data points

N.B. The three points lying in the Spreading Centre Island field all have high SiO_2 (58%+) (Auvray's data) island arc tholeiite (AT); mid ocean ridge basalt (MORB); ocean island tholeiite (OIT); ocean island alkalic (OIA). Basalts of primitive composition from either MORB or island arc environments plot very close together in the IAT field near the IAT-MORB join. However, with fractionation the two groups separate into their respective fields, presumably reflecting the fractionation process operating; i.e. MORB fractionates olivine at low fO_2 to give a tholeiitic trend, while IAT fractionates iron ore at high or constant fO_2 to give a calc-alkaline trend. Tests by Mullen (op. cit.) have shown the three elements concerned to be essentially immobile under metamorphic conditions up to greenschist facies with one possible exception. Use of a data set of metabasalt pillow lavas from the Ligurian Alps, (Bearth and Stern, 1979, see Mullen 1983) in which a high percentage of secondary $CaCO_3$ is present, has indicated the possible co-mobility of P_2O_5 and CaO.

Plotting the Formation de Pte de l'Armorique data on the Mno-TiO_2-P_2O_5 diagram (Fig. 3:33) shows quite a wide scatter of points. The 'least altered' data subset for the most part plots on a trend whose extension is towards the MnO apex. However, all the points except one plot about the IAT/CAB join. Only one plots in the MORB field. The other points also cluster about the IAT/MORB join. This pattern is very much reflected in the distribution of the Autran et al. data.

(3) TRACE ELEMENT GEOCHEMISTRY

Thirteen trace elements have been determined on the Formation de Pte de l'Armorique samples; Rb, Sr, Y, Zr, Nb, Ba, La, Ce, Nd, Ni, Cr, Sc and Ga. Not all the samples have been analysed for Ni, Cr, Ga and Ba.

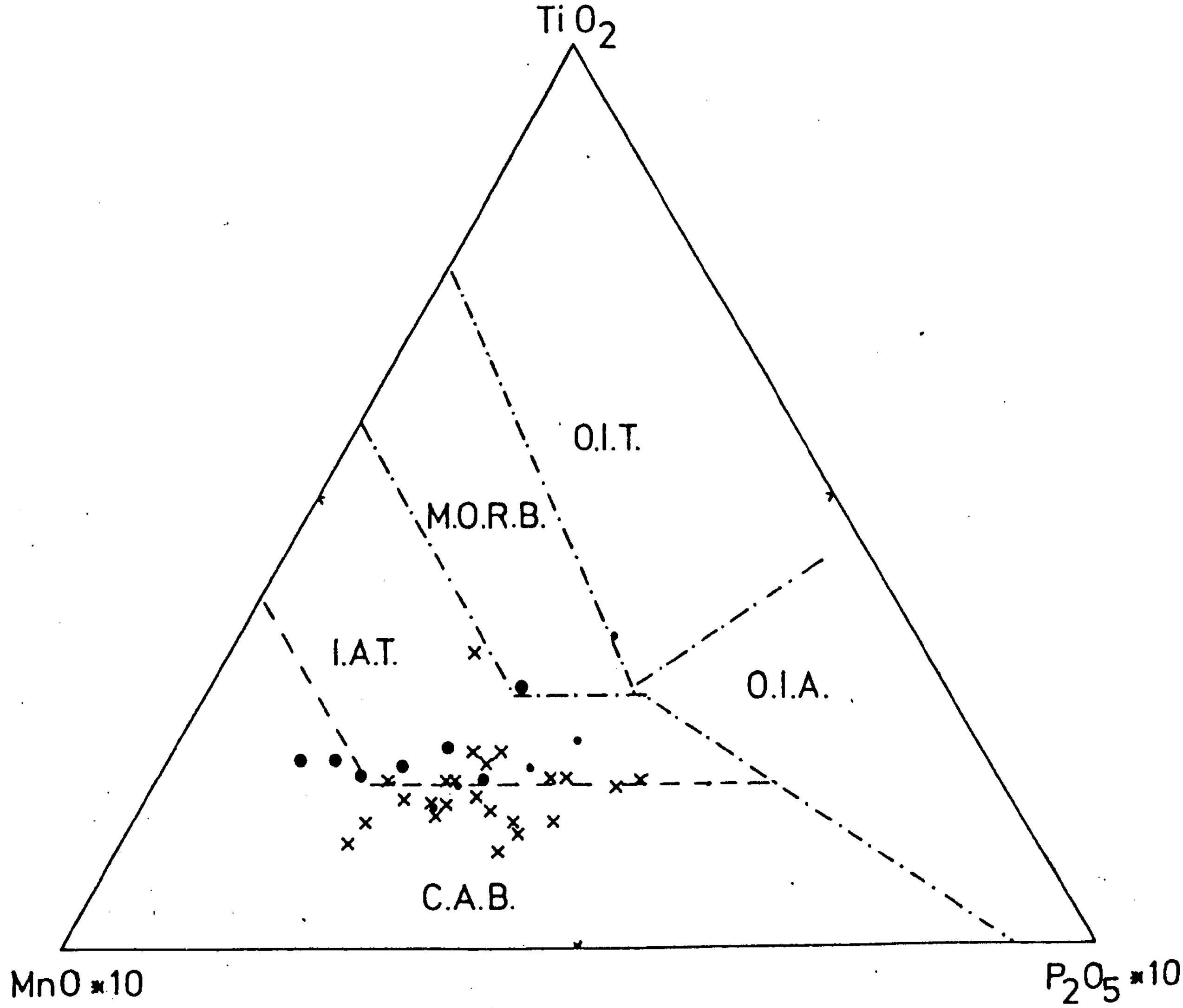
Concentrations of all the incompatible elements (i.e. $K_D << 1$) viz. Rb, Y, Zr, Nb, La, Ce, Nd are low, in many samples hovering around the detection limit. Sr and Ba contents tend to be somewhat low also,

Fig. 3:33 Major element ternary discrimination diagram of $MnO(*10)-TiO_2-P_2O_5(*10)$ after Mullen (1983) for the Formation de Pointe de l'Armorique. Both the data of Griffiths (this work) and Autran et al. (1979) are plotted. Note the concentration of points along the IAT-CAB boundary.

CAB - Calc-alkaline basalt, IAT - Island arc tholeiite, MORB - Mid ocean ridge basalt, OIT - Ocean island tholeiite, OIA - Ocean island alkaline basalt.

Formation de Pointe de l'Armorique Metabasites

FIG.3:33



× data from Autran et al. (n=24)

• Least Altered Samples } N. Griffiths data (n=13)

. Highly Altered Samples

while, in contrast, Ni and Cr contents are high. All these features point to the relatively primitive nature of the basaltic magma on eruption.

Zr shows a concentration range between 5 and 85 ppm and is a commonly used differentiation index for basic rocks. The variation of the other trace elements against the variation in Zr concentration is shown in Fig. 3:34 (a), (b) and (c). Using the 'least altered' subset, it can be seen that all the trace elements plotted show quite a large degree of scatter, though a sample of seven analyses cannot be said to be large enough to give more than an indication of any trend present. The more altered rock samples show a marked divergence in position from the 'least altered' subset in the plots of Sr, Ni and Cr, i.e. those elements which are behaving compatibly - Sr following Ca, Ni following Mg, and Cr probably following Fe. This is perhaps to be expected in the light of the observed behaviour of these major elements.

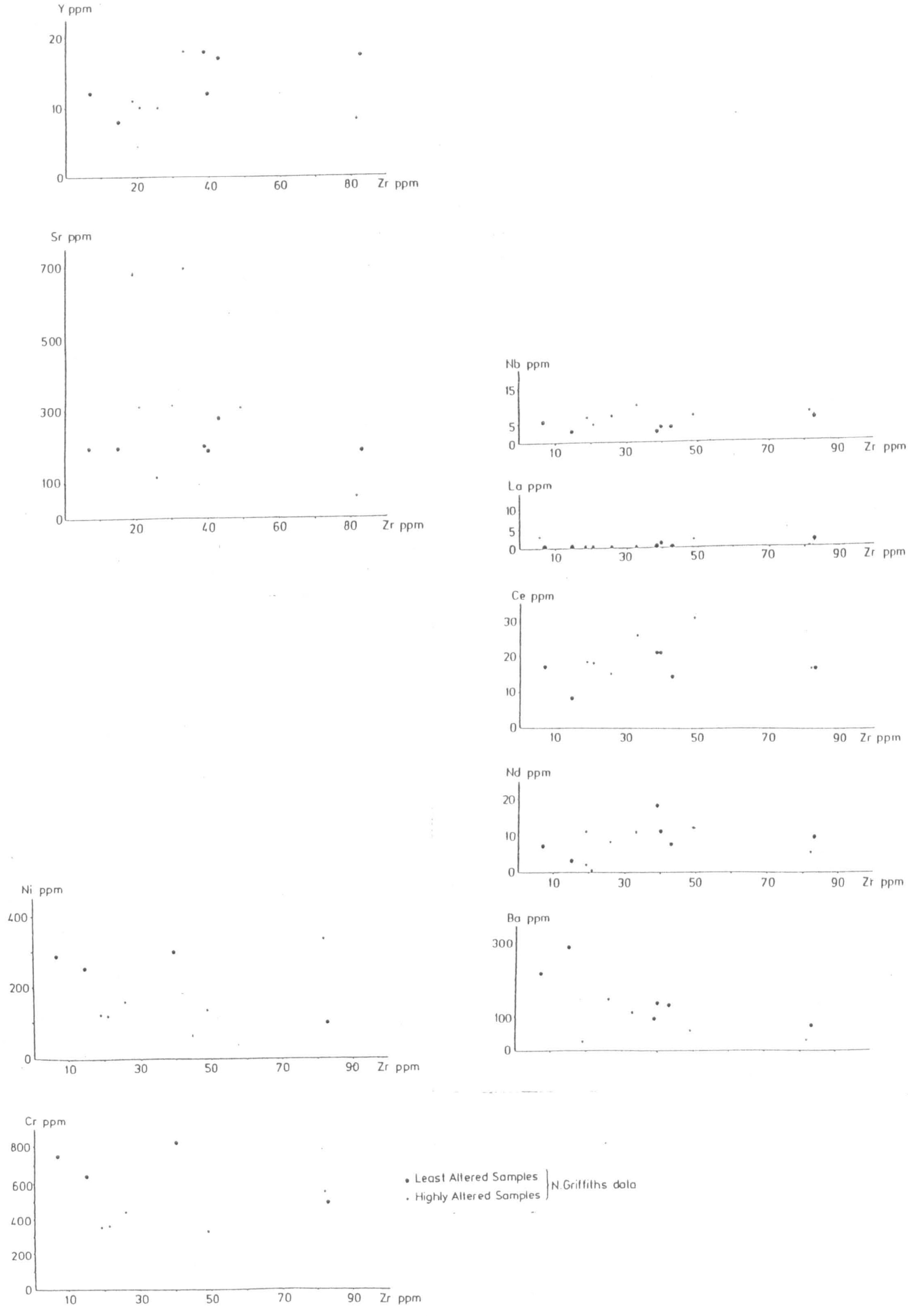
In Fig. 3:34 (a), (b) and (c), it can be seen that Y, Ce and Nd show broadly a positive correlation with Zr, i.e. an increase with fractionation. This is expected behaviour in basic tholeiitic suites, La is below detection limit in almost every sample. Nb does not seem to be behaving either compatibly or incompatibly, showing an apparent trend parallel to the Zr axis (i.e. $K_D = 1.0$). However, the concentration in all samples is very close to the lower limit of detection for Nb so cannot be considered to be reliable. Ba, Sr, Ni and Cr all show a negative correlation with Zr, i.e. they are behaving compatibly. Using the 'least-altered' subset, this does not appear to be an artifact of alteration. It presumably reflects the crystallization of plagioclase, olivine and pyroxene from the fractionating magma.

The behaviour of incompatible trace elements in basic rocks, i.e. being concentrated in the residual liquid phase of a magma undergoing fractional crystallization, has led to their extensive use as environ-

Fig. 3:34 Bivariate variation diagrams of trace elements using Zr concentration as the index of differentiation. The trace elements plotted are: Y; Sr; Ni; Cr; Nb; La; Ce; Nd; Ba.

FIG. 3:34

Formation de Pointe de l'Armorique Metabasites



mental discriminants in a plate tectonic context. Since they are little affected by low pressure fractionation processes, their relative concentrations reflect those of the magma source regions. Many of these incompatible trace elements have also been found to be almost immobile during post-eruption alteration and metamorphism (see below).

The most widely used trace element discrimination diagrams for basaltic rocks in the last ten years have been those due to Pearce and Cann (1973). The trace elements used are Sr, Y, Zr, Ti and the diagrams are the Ti-Zr binary plot (Fig. 3:35), and the Ti-Zr-Y (Fig. 3:36) and Ti-Zr-Sr (Fig. 3:37) ternary plots. Scaling factors of ÷100 for Ti, x3 for Y, and ÷2 for Sr have been used.

Four fields are distinguished in the Ti/100-Zr-Y x3 diagram (Fig. 3:36), i.e. MORB, IAT, CAB and WPB. Three fields are distinguished in the Ti/100-Zr-Sr/2 diagram (Fig. 3:37), i.e. MORB, IAT and CAB (for explanation see p. 98).

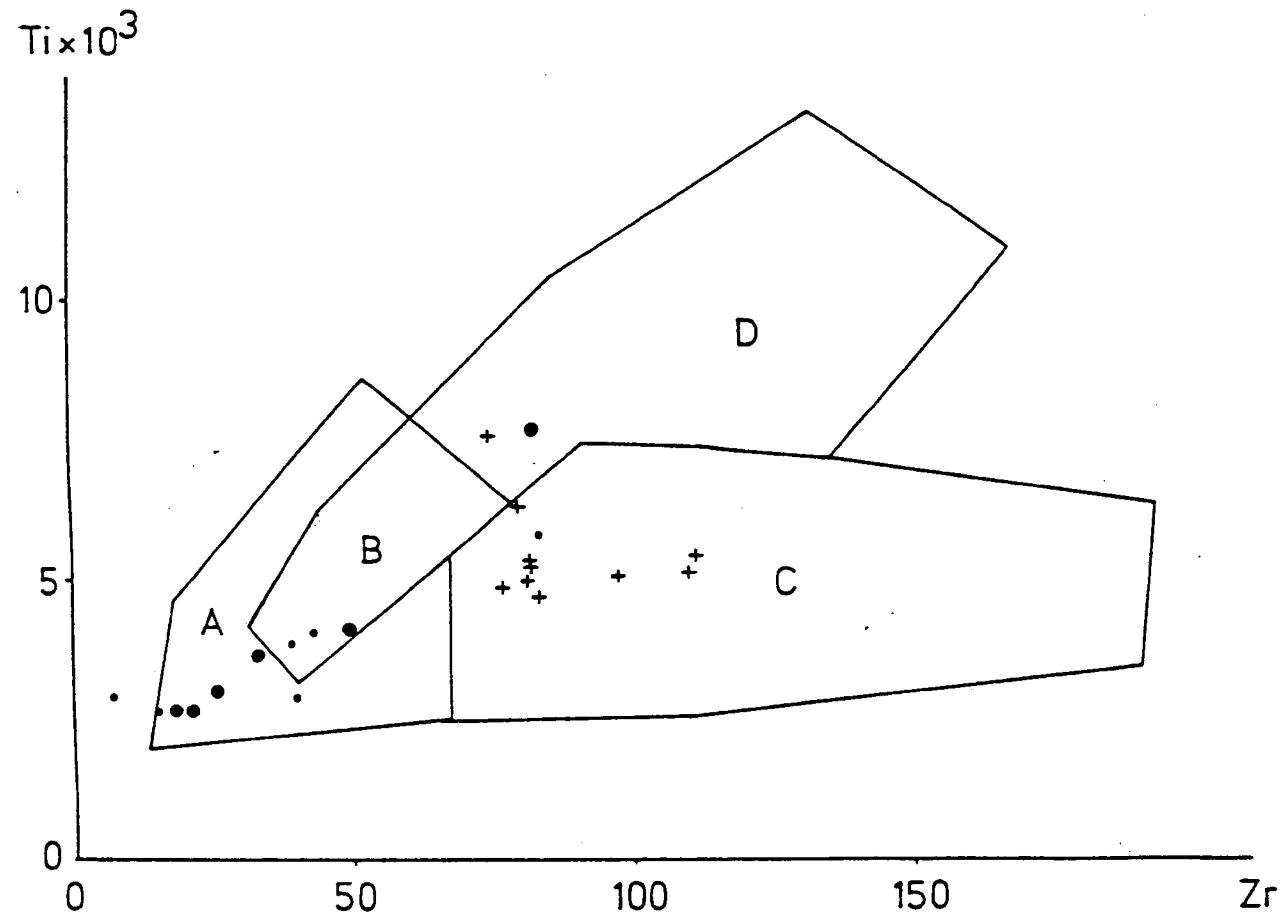
Much discussion has taken place over the years as to the reliability of these diagrams for discriminating altered and tectonised rock suites. A careful appraisal has been undertaken by Smith and Smith (1976) for alteration taking place under burial metamorphism conditions, using material from the classic study on Ordovician calc-alkaline basalts from the Cliefden outcrop, N.S.W., Australia by Smith (1968). Smith and Smith (op. cit.) found that the Ti-Zr-Y plot could be used on this altered material. The points possibly scattered a little more than originally, but still plotted in the calc-alkaline field. However, the Ti-Zr-Sr plot was badly affected, sample points scattering along a linear trend from the Sr apex depending on their mineral composition.

Looking at the data from the Formation de Pointe de l'Armorique, on the Ti-Zr-Y diagram (Fig. 3:36), it can be seen that all the data points, except two, group fairly tightly in either the MORB or the IAT

Fig. 3:35 Bivariate trace element discrimination of $Ti*10^3$ vs. Zr (after Pearce and Cann 1973) for the Formation de Pointe de l'Armorique data (this work) and the Spilites de Paimpol data (Auvray 1979).

Formation de Pointe de l'Armorique Metabasites

FIG.3:35



- ● Least Altered Samples } N.Griffiths data
- • Highly Altered Samples }
- \+ Spilites de Paimpol data from Auvray (1979)

Key to fields:

A : Island Arc Tholeiites (I.A.T.)

B : All Three Basalt Types

C : Calc-alkaline Basalts (C.A.B.)

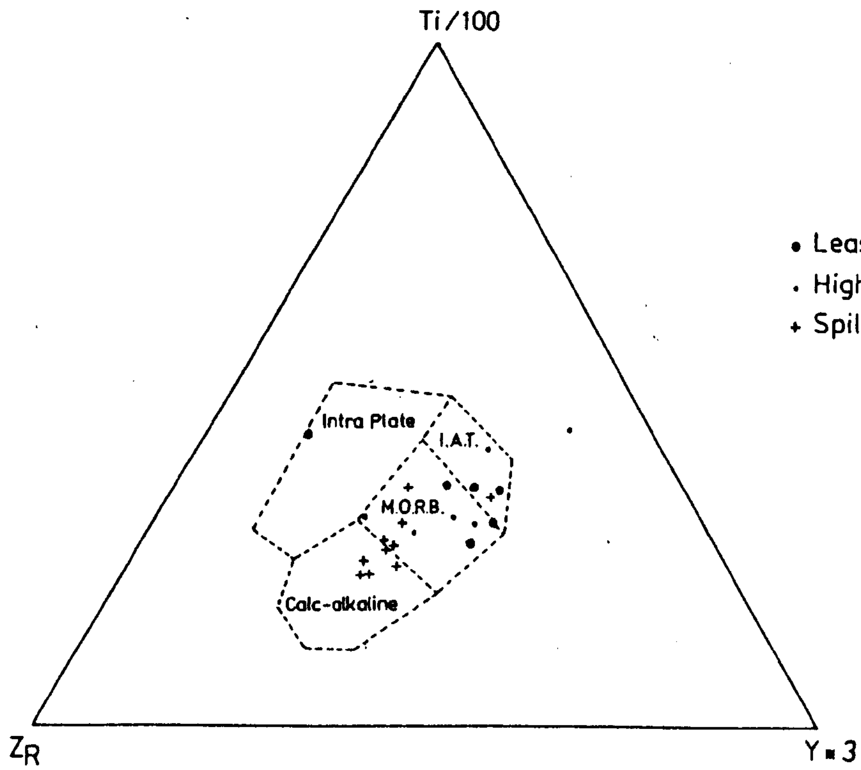
D : Ocean Floor Basalts (M.O.R.B.)

Fig. 3:36 Ternary trace element discrimination plot of Zr-Ti/100-Y*3 (after Pearce and Cann 1973) for both the Formation de Pointe de l'Armorique data (this work) and the Spilites de Paimpol data (Auvray 1979).

Fig. 3:37 Ternary trace element discrimination plot of Zr-Ti/100-Sr/2 (after Pearce and Cann 1973) for both the Formation de Pointe de l'Armorique data (this work) and the Spilites de Paimpol data (Auvray 1979). Note the trend radial to the Sr/2 apex.

Formation de Pointe de l'Armorique Metabasites

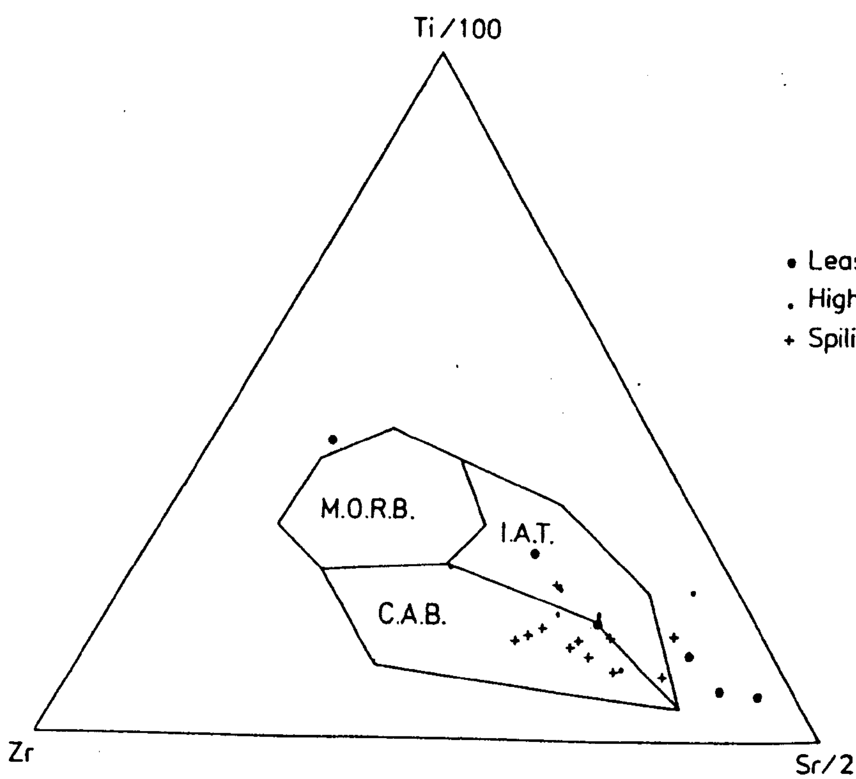
FIG. 3:36



• Least Altered Samples } N.Griffiths data
. Highly Altered Samples
+ Spilites de Paimpol data from Auvray (1979)

Formation de Pointe de l'Armorique Metabasites

FIG. 3:37



• Least Altered Samples } N.Griffiths data
. Highly Altered Samples
+ Spilites de Paimpol data from Auvray (1979)

fields. All except one would seem to lie approximately along a line of constant Ti/Y ratio from the Zr axis. Taking only the 'least-altered' subset, the same pattern is found, but one point lies outside the delineated field due to a very low Zr content. Of the rest of the data, one point lies close to the outer boundary of the W.P.B. (intraplate) field reflecting its low Y content. This may be connected with the $CaO-P_2O_5$ co-mobility mentioned above.

No trace element data is available from Autran et al., but Auvray has analysed a limited subset of the Spilites de Paimpol suite for the relevant trace elements (Figs. 3:35, 3:36 and 3:37). In the Ti-Zr-Y triangle it can be seen that the Spilites de Paimpol plot across the join between the calc-alkaline arc field and the MORB field, with one sample plotting in the IAT field.

The Ti-Zr-Sr triangle has proved just as much affected by alteration in the Formation de Pte de l'Armorique samples as in Smith and Smith's study. Once again the sample points scatter down towards the Sr apex outside the prescribed fields (Fig. 3:37). Auvray's data set plots similarly but less extremely. The variation of the Formation de Pointe de l'Armorique data can be considered as a variation in Sr at a broadly constant ratio of the Ti and Zr components. If the Ti:Zr ratio can be considered independent of the Sr variation, it can be seen that the Auvray data set trend lies very largely in the calc-alkaline field while the Formation de Pointe de l'Armorique data set lies along the calc-alkaline-island arc Tholeiite join, passing into the MORB field. The Smith and Smith data set also lies, as it should, in the calc-alkaline field.

Floyd and Winchester (1975) and Winchester and Floyd (1976) have published a series of bivariate variation diagrams which use five immobile elements in an attempt to discriminate between alkalic and tholeiitic rock types from different environments. Several of the diagrams rely on ratios between trace elements. In their 1976 paper, which deals with altered rocks, only a discrimination between alkalic and tholeiitic rock types is attempted, since many samples plotted outside the designated fields established in the 1975 paper. This pattern is echoed by the data from the Formation de Pte de l'Armorique because of the uniformly low concentrations of incompatible elements. All the Floyd and Winchester (op. cit.) and Winchester and Floyd (op. cit.) bivariate variation diagrams show the Formation de Pte de l'Armorique data to plot consistently within the tholeiite field.

(4) DISCUSSION

Those diagrams concerned with separating alkaline from subalkaline rock suites (eg. Fig. 3:26) clearly show that the basic volcanic rocks of the Formation de Pte. de l'Armorique are subalkaline. Those diagrams purporting to distinguish calc-alkaline suites from tholeiitic ones (eg. Fig. 3:30) are much more ambiguous. The Miyashiro diagrams (SiO_2 vs. FeO*/MgO and FeO vs. FeO*/MgO) indicate a more calc-alkaline affinity, whilst the A-F-M diagram shows rather an Fe-enrichment tholeiitic trend.

Similar ambiguity is seen in the discrimination diagrams. The environment indicated from such diagrams varies from ocean ridge and floor MORB (Fig. 3:32), through island arc tholeiites (Fig. 3:33) to calc-alkaline basalts.

Some of the ambiguity must be due either to post-eruption sea-floor or early burial alteration or to later deformation and metamorphism. However, it is proposed that the plate tectonic environment in which the metabasic volcanics were erupted lies somewhere between ocean floor basalts and subduction zone calc-alkaline basalts. These basalts were erupted through pre-existing continental crust. Roach (pers. comm.) considers the Amphibolites de Lanvollon (equivalent to the Formation de Pte de l'Armorique) of the Baie de St. Brieuc to have been erupted in a rapidly subsiding ensialic basin and which may also have extended across to the area now known as the Petit Trégor.

Mullen (1983) has shown that continental tholeiites cannot be identified on the TiO_2-P_2O_5-MnO plot, and considers that this inability may be a characteristic of tholeiites erupted through continental crust.

The rocks of the Spilites de Paimpol (considered to be the lateral equivalents of the Formation de Pte de l'Armorique), using Auvray's (1979) data, are clearly calc-alkaline, a character confirmed by the normalized rare earth patterns which show light rare earth enrichment and heavy rare earth depletion. Unfortunately, no rare earth data is available for the Formation de Pte de l'Armorique lithologies.

(G) COMPARISON OF THE BRIOVERIAN SUCCESSION IN THE PETIT TRÉGOR WITH OTHER AREAS OF THE NORTHERN MASSIF ARMORICAIN

Two areas are described briefly that possess similar geological relationships to those observed between the Formation de la Pte. de l'Armorique and the Formation de Plestin.

(1) THE TREGUIER - LEZARDRIEUX - PTE. DE GUILBEN AREAS, TRÉGOR

A thick succession of basic metavolcanics considered by Barrois (1908c) and Delattre et al. (1966) to be equivalent to the Formation de l'Armorique (sensu this study), strikes E-W through the Trégor, parallel to the southern margin of the Cadomian Perros - Guirec Granitoid Complex. There are well-exposed sections in the valleys of the Rivière de la Jaudy at Tréguier and the Rivière de la Trieux at Lezardrieux,and on the coast around the Pte. de Guilben, near Paimpol (Fig. 5:36).

Studies along these sections show the existence of a massive greenstone, pillow-lava and pillow-breccia assemblage which is very similar to the lithologies at the Pte. de l'Armorique. These are overlain by folded semi-pelitic and semi-psammitic sediments which generally young to the south. Both formations are cut by c. 1-2 m thick acid dykes. The greenstones in this area, termed the Spillites de Paimpol (Auvray 1979), show strong metamorphic segregation but are generally less deformed than the Formation de la Pte. de l'Armorique and retain well-preserved pillow structures. Auvray (op. cit.) has termed the overlying sediments the Schistes et Grès de la Roche Derrien.

Auvray (op. cit.) interprets the field-relationships in the Trègor in a different way to the present author. He does not equate, as this author would suggest, the Formation volcano-sedimentaire de l'Armorique-Trédrez (the Formation de Pte. de l'Armorique of this thesis) and the Formation greywackeuse de St. Efflam (the Formation de Plestin of this thesis, Table 3:1) of the Baie de Lannion area with the Spilites de Paimpol, and Schistes et grès de la Roche Derrien, of the Trégor. He gives the following stratigraphy that involves the emplacement of the Perros Guirec Granitoid Complex and the deposition of the so-called Tufs de Tréguier-Locquirec (the Locquirec Shear Belt mylonitized granitoid rocks of this thesis).

Auvray (1979)

6) Schists et grès de la Roche Derrien (youngest)
5) Spilites de Paimpol
4) Tufs keratophyriques de Tréguier - Locquirec
3) Batholite de Perros - Guirce - Bréhat
2) Formation greywackeuse de St. Efflam
1) Formation volcano-sedimentaire de l'Armorique-Trêdrez (oldest)

This is considered to be unneccessarily complicated and is not supported by the field evidence. A simpler stratigraphy was given in Part (C).

(2) THE BAIE DE ST. BRIEUC AND JOSPINET AREA

Near Cesson at the southern end of the Baie de St. Brieuc (Fig. 1:2) a mixed conglomeratic/arkosic succession labelled the Poudingues de Cesson (Cogńe 1974) overlies probable true Pentevrian basement (Roach and Shufflebotham pers. comm.). The conglomerate contains large blocks of orthogneiss of variable composition, some of which is mylonitized and was derived from the nearby basement area. Overlying this epiclastic sequence (which is c. 120 m thick) is a c. 1.5 km thick succession of basic metavolcanics, the Serie de Lanvollon of Cogńe (1974), which is considered to be of Lower Brioverian age. The metavolcanics are overlain by a thick series of metasediments, and throughout the metavolcanics there are metasedimentary horizons.

In the Baie de St. Brieuc the basic metavolcanic sequence is metamorphosed in the middle-upper greenschist facies. This decreases towards the northeast in the area of Jospinet (Roach and Shufflebotham pers. comm.). This regional metamorphic episode is considered to be of Cadomian age (Cogné 1974). Primary relationships are well preserved and there has been little structural disturbance unlike the Baie de Lannion area.

(H) CONCLUSIONS

Studies in the Baie de Lannion, the Trégor and the Baie de St. Brieuc areas show that there is a consistent association of basic metavolcanic rocks which are overlain by a thick sequence of metasedimentary rocks forming the lower part of the Brioverian Supergroup. This association can be established as there are preserved primary structures in both the metavolcanic rocks and the metasediments.

The Brioverian formations have been truncated by several granitic-granodioritic intrusions of Cadomian age, principally the Perros-Guirec Granitoid Complex and the Moulin de la Rive Orthogneiss Complex. Both have in turn been truncated by Hercynian intrusions, for example the Granite de Ploumanac'h and the Granite de Trédrez, which may have well-defined contact aureoles.

In the Baie de Lannion area the Brioverian formations are structurally complicated. The major deformation and metamorphism is attributed to a D1/M1 episode of Hercynian age which may have overprinted and masked any earlier structures. The age of the deformation is discussed in more detail in Chapter 8.

CHAPTER FOUR

THE MOULIN DE LA RIVE ORTHOGNEISS COMPLEX

CHAPTER FOUR

THE MOULIN DE LA RIVE ORTHOGNEISS COMPLEX

(A) INTRODUCTION

(1) DEFINITION OF THE COMPLEX

The Moulin de la Rive Orthogneiss Complex is a deformed composite pluton that lies within the region between the bay at Pors Rodou and the Pte. du Corbeau (see Map 2). The components of this complex show a wide range of compositions and display a complicated pre-deformational magmatic history. The lithologies comprising the complex carry at least one gneissose foliation, and in localized shear zones a mylonitic foliation is present. A series of basic sheets, now deformed and metamorphosed to greenstones and greenschists, post-dates the emplacement of the complex. In this chapter the field relationships within the complex, its contact with surrounding units, the deformational and metamorphic history, together with geochronological data are discussed. Geochemical data is discussed in Chapter 5, together with that for specimens from the Locquirec Shear Belt.

(2) LOCATION OF THE COMPLEX

Map 2 shows the location of the complex. Rocks assigned to the orthogneiss complex crop out with excellent coastal exposure between the bay of Pors Rodou (GR 1570 1274) and the Pte. du Corbeau (GR 1600 1279). Exposure inland is poor, and whilst the southern limit of the complex along the coast is well-defined, the relationship of the complex to adjacent units inland is difficult to establish and is only partly understood.

(3) RELATIONSHIP OF THE COMPLEX TO ADJACENT ROCK UNITS

The orthogneiss complex is clearly cut by an unfoliated Hercynian granite which is considered to be the easternmost extension of the Granite de Primel-Carantec (Delattre et al. 1966). This intrusive relationship is clearly seen on the coast west of the bay at Pors Rodou. The relationship of the orthogneisses to gabbros assigned to the adjacent St. Jean du-Doigt Gabbro Complex to the west is not clearly defined due to lack of exposure in the boundary area at Pors Rodou,but the possibility is considered that the St. Jean-du-Doigt Gabbro Complex may represent an integral part of the Moulin de la Rive Orthogneiss Complex in a significantly less deformed state. Discussion as to the age relationship between these two units is given in Chapter 7.

To the east, the orthogneiss complex is adjacent to a thick unit of schistose rocks. These rocks are for the most part mylonites,and the boundary mapped between the orthogneiss complex and the mylonites is interpreted as the western boundary of a major NE-SW trending shear zone, that has already been referred to as the Locquirec Shear Belt (LSB) in Chapter 3. A number of NE-SW trending shear zones occur within the orthogneiss complex and the Locquirec Shear Belt represents the largest of such zones. The mylonites of the Locquirec Shear Belt are discussed in Chapter 5, but it should be emphasised here that the mylonites are believed to represent highly sheared plutonic rocks which are,in part, equivalent to some components of the composite orthogneiss complex.

(4) PREVIOUS WORK ON THE COMPLEX

Several authors have previously described lithologies which crop out within the area here described under the heading Moulin de la Rive Orthogneiss Complex,although they have adopted different names for the complex and the related Locquirec Shear Belt. These differences are summarised in Table 4:1. Delattre et al. (op. cit.) include the

This Author	Moulin de la Rive Orthogneiss Complex	Locquirec Shear Belt (LSB)
Barrois 1909	Cornes amphiboliques	Tufs de Brélévenez
Barrois 1908b	Cornes amphiboliques	Orthophyres et Tufs de Tréguier
Sandrea 1958	Serié de Morguignen	Chloritoschistes à albite
Delattre et al 1966	Epidiorite de Morguignen	Chloritoschistes à albite
Verdier 1968	Series de Morguignen et de Trébeurden	Serié de Locquirec
Auvray 1979	Gneiss de Trébeurden	Tufs de Tréguier - Locquirec
Autran et al. 1979	Formation du Moulin de la Rive	Formation du Locquirec
Auvray et al. 1980a	Gneiss de Trébeurden	Volcanites et Sédiments du Brioverien Supérieur

TABLE 4 : 1 NOMENCLATURE APPLIED TO THE MOULIN DE LA RIVE ORTHOGNEISS COMPLEX AND LSB

Epidiorites de Morguignen within the Serie de Morquignen-Locquemeau and they believed the epidiorites to represent 'une ancienne formation mesobasique, de nature indeterminee'. Verdier (1968) recognised the similarity between rock types and structures of the Gneiss de Morguinen-Moulin de la Rive and rocks occurring at Trébeurden. Verdier (op. cit.) also recognised the mylonite zones within the orthogneisses and the retrogressive metamorphism associated with this mylonitization. He regarded the Series de Morguignen and the Series de Trébeurden as an intrusive granodioritic-dioritic basement,within which interleaved zones of extrusive microcrystalline rocks (dacites and rhyodacites) existed. Verdier (op. cit.) believed the 'sôcle' (basement) to be of Lower Proterozoic Pentevrian age and he drew comparisons with possible Pentevrian lithologies that crop out in the Jospinet area, Baie de St. Brieuc (Cogné 1959a).

Auvray (1979) and Auvray et al. (1980a) also regarded the Gneiss de Trébeurden (sensu lato) as being of Lower Proterozoic age and give a 2000 m.y. U/Pb zircon age for the emplacement age of the rocks forming the complex. It is argued, that interpretation of the dating is open to question, and that the complex is in fact much younger than considered by all previous authors. Field evidence supports this view, but it should be noted that one component (the augen gneiss) may be of early Proterozoic age and has been incorporated within the complex as a basement raft.

Autran et al. (1979) in re-mapping the Lannion sheet endorse previous views of Verdier (op. cit.), Auvray (op. cit.) and Auvray et al. (op. cit.). They recognise a basement complex, the Formation du Moulin de la Rive, which they equate with Lower Proterozoic Icart Gneiss on Guernsey. They consider that the Formation du Moulin de la Rive is stratigraphically overlain by a dominantly volcaniclastic unit which they term the Formation de Locquirec. Autran et al. (op. cit.) consider the western boundary of the orthogneiss complex to be truncated by an intrusive complex (the St. Jean-du-Doigt Gabbro Complex of this thesis) to which they attribute an Hercynian age.

Dixon (1982) has recognised the importance of deformation by a dominantly shearing process in the Locquirec area and he considers that Pentevrian and Brioverian rocks are deformed to produce a series of mylonites.

(5) OUTLINE OF THE DEFORMATION AND METAMORPHIC EPISODES THAT HAVE AFFECTED THE ORTHOGNEISS COMPLEX

A penetrative fabric is developed throughout the orthogneiss complex and defines the gneissose foliation. In detail, this foliation is variably developed and, in localized areas of low strain, primary igneous fabrics and boundary relationships are preserved. The gneissose foliation is orientated 035°-060° (NE-SW) and is generally vertical to sub-vertical.

In localized shear zones (c. 30 cm-60 m wide) mylonitic rocks occur with a well-developed foliation. The schistose foliation developed in these zones is approximately parallel to the gneissose foliation at 030°-050°, but at the shear zone boundaries the gneissose foliation often rotates into the well-defined mylonitic/schistose foliation and the two fabrics may be at 20-30° to each other.

The two fabrics, termed S1a and S1b respectively, are considered to have formed during a single deformation episode, where they may have developed simultaneously or sequentially during a heterogeneous deformation event, termed D1. However, as two essentially distinct types of fabric can be recognised, the term S1a is used for the widely-developed gneissose foliation and S1b for the closely-spaced mylonitic/schistose foliation that is restricted to the shear zones.

In the fine-grained and finely foliated mylonites a crenulation fabric is occasionally developed. This fabric is assigned to the D1 event in the structural sequence. This is distinct from a more brittle deformation episode in which kink-bands were formed in the mylonite schists. The crenulation fabric developed in the mylonites is possibly related to a fabric that is developed in the metabasic dyke suite, which intrudes both the Moulin de la Rive Orthogneiss Complex and the Locquirec Shear Belt rocks. These metabasic dykes are considered to post-date the main D1 gneiss and mylonite-forming episode.

Retrograde metamorphism has occurred throughout the complex and a lower-greenschist facies assemblage is pervasively developed.

(B) FIELD RELATIONSHIPS AND PETROGRAPHY OF THE ROCKS THAT COMPRISE THE COMPLEX

(1) COMPONENTS OF THE COMPLEX

A number of different components, all of which are of intrusive igneous origin, constitute the orthogneiss complex. The magmatic history of the complex can be understood to some extent by studying the nature of the component contacts. Although largely modified by subsequent deformation, careful field examination of igneous contacts shows that there are a number of different phases of magmatic activity. An association of early developed basic to intermediate lithologies can be distinguished from an association of later intermediate to acidic lithologies. However, the relationship of some components to others, and therefore their relative age within the complex, is uncertain. This may be due to the deformation imparted upon the individual components and/or its boundary, or the lack of exposure, or the component may be geographically isolated.

The different components recognised that in total make up the Orthogneiss Complex of Moulin de la Rive are:-

(a)	Augen Gneiss	The Early Components
(b)	Gabbro Component	
(c)	Agmatite Component	
(d)	Tonalite Component (and associated diorites)	
(e)	Granite Component	The Late Components
(f)	Porphyritic Microgranite Component	
(g)	Aplogranite Component	
(h)	Pors Rodou Breccias - Relationship unknown	

It should be noted that the pre-deformational igneous name is used for brevity, and hopefully clarity; two exceptions exist though, these being the a) augen gneiss component and b) Pors Rodou Breccias. These two units are problematical. The augen gneiss component may represent a raft of older material preserved within the host complex and arguments for this are presented below. The nature of the Pors Rodou Breccias and their relationship to other components of the orthogneiss complex is unknown. The breccia component is restricted in its outcrop and it is geographically isolated, cropping out at the western margin of the complex.

The early components recognised are the augen gneiss, gabbro, agmatite and tonalite (which grades locally into quartz diorite and diorite). These are truncated by the widespread granite component. The granite, porphyritic microgranite and aplite comprise the late components. In this section the locality, lithologies and petrography of the components is given.

Map 4 shows the distribution of the various components.

(a) The augen gneiss component

The augen gneiss component is restricted in outcrop to the west of the Baie de Moulin de la Rive (GR 1572 1283). The component is variable, in that augen-rich zones occur together with augen-poor zones which are much darker and arranged parallel to the S1a foliation. The S1a foliation is penetrative but poorly defined in areas. The S1b schistosity is developed within narrow (<20 cms) shear zones in which the foliation is closely spaced and feldspar augen are rarely preserved (Fig. 4:1). The gneiss maps out as three separate units bounded largely by the gabbro component. Both these components are truncated by the later aplitic sheets (Fig. 4:2). The rock weathers to a streaky cream to dark green colour. The feldspar augen are in the size range 0.5-2 cms, usually with an elongate shape (length:width ratio of 1.8:1) aligned parallel to the S1 foliation. Chlorite and epidote can macroscopically be seen to depict the early fabric which envelopes the pink-cream coloured augen of K-feldspar. Quartz is notably concentrated in strain shadow areas adjacent to the feldspar augen.

The mineralogy of the augen gneiss is variable due to the more extensive recrystallization which has occurred within the narrow shear zones. Principal minerals of the typical augen gneiss component are, in order of importance, K-feldspar (largely perthite but with some microcline) + oligoclase (An_{20}) + quartz + epidote + chlorite+ muscovite ± biotite. Quartz displays recrystallization and recovery textures, commonly core and mantle structure (White 1977). The perthite augen show patchy development of sericite. Green biotite, chlorite and muscovite are aligned parallel to S1 and xenoblastic epidote is in common association with the phyllosilicate minerals that define the foliation. Muscovite grains are often

Fig. 4:1 Augen gneiss component, W. Baie de Moulin de la Rive

The blue pencil is parallel to S1a defined by the alignment of perthite porphyroblasts. The yellow pencil is parallel to S1b defined by micro-shear zones in which chlorite and quartz are the dominant minerals.

Scale: Yellow pencil = 15 cm

Fig. 4:2 Augen gneiss component, W. Baie de Moulin de la Rive

A late aplitic dyke truncates the augen gneiss component and an earlier aplite phase. The dykes are foliated parallel to the well-developed S1b foliation developed in the augen gneiss and parallel to the hammer handle.

Scale: Hammer handle 36 cm

large (<0.5 mm) and are arranged obliquely to the S1a foliation. Ore minerals are relatively infrequent and occur as xenoblastic patches. Zircon and sphene are present in variable amounts.

The present mineral assemblage is that of the greenschist facies, while the primary assemblage was that of a granite. The augen are considered to be pre-D1 as their shape was clearly modified during the development of S1a. They must, therefore, represent a primary igneous phase or a metamorphic growth formed prior to S1a.

Field relations suggest that the augen gneiss component represents the oldest part of the orthogneiss complex. It is interesting to note here, that this distinctive rock type is similar to Lower Proterozoic gneisses seen by this author at Port Beni in the Trégor, and to the Icart Gneiss on Guernsey (Roach pers. comm.). It is argued, in part (F), that this component may have been sampled by Auvray et al. (1980a) to give the 2000 m.y. age proposed for the Gneiss de Trébeurden-Morguignen, and it will be further argued that this date as applied to the emplacement age of the orthogneiss complex as a whole is not valid.

b) The gabbro component

The gabbro component has a widespread outcrop in an area east of Pors Rodou and west of Moulin de la Rive. It partly encompasses the augen gneiss component and is therefore considered to be younger than the augen gneiss component. The gabbro is truncated by the younger phases of the complex (principally the granite). A well developed S1a schistosity is developed throughout the gabbro, and the S1b schistosity is commonly developed in shear zones that occur within the gabbro and frequently at gabbro/granite boundaries. Grain size is medium to coarse (as are most of the early components, except for the augen gneiss) with light coloured minerals, principally plagioclase, and dark green hornblendes forming augen or lenticular aggregates around which the foliation, defined by chlorite + amphibole + biotite, is developed. Amphibole clusters (hornblende and actinolite) are 1.5 cm maximum diameter and are lenticular-shaped in parallelism with the S1a foliation. In zones of high strain, dark greenschists are formed (Figs. 4:3 and 4:4), with a closely-spaced schistosity and a conspicuous lozenge structure in which pods of lower strained gabbro host are preserved, enveloped by a fine grained schistose matrix.

A NE-SW trending band of gabbro occurs on the west side of Pte du Corbeau (Map 4). Here it is bounded by the granite and porphyritic micro-granite components. Age relationships here, however, cannot be determined as the contacts are zones of high strain and along these the gabbro has been converted to a greenschist (Fig. 4:11). This occurrence, together with a second at Roc'h Ledan, may represent either the gabbro component caught up as a raft within the younger granitic components or may represent satellitic bodies from the St. Jean-du-Doigt Gabbro Complex as discussed in chapter 7.

In the gabbro component amphibole occurs in two forms, as hornblende prisms <3 mm, and as actinolite plates with poorly-defined boundaries, usually 1-1.5 mm diameter. The actinolite may be pseudomorphs after pyroxene. Plagioclase (An_{12}) is always cloudy due to the presence of white mica and epidote. It forms large grains 1.5-3 mm in diameter. Quartz occurs principally in the pressure shadows of adjacent plagioclase grains, where it is recrystallised. Epidote occurs in xenoblastic clots, and chlorite occurs in plates parallel to the foliation.

In the shear zones the grain size reduction is marked. Here dark-coloured epidote and chlorite-rich greenschists are formed from the gabbro. Epidote may form at the expense of plagioclase and chlorite at the expense of amphibole. A segregation banding is apparent with dark

Fig. 4:3 Gabbro component, E. Baie de Pors Rodou

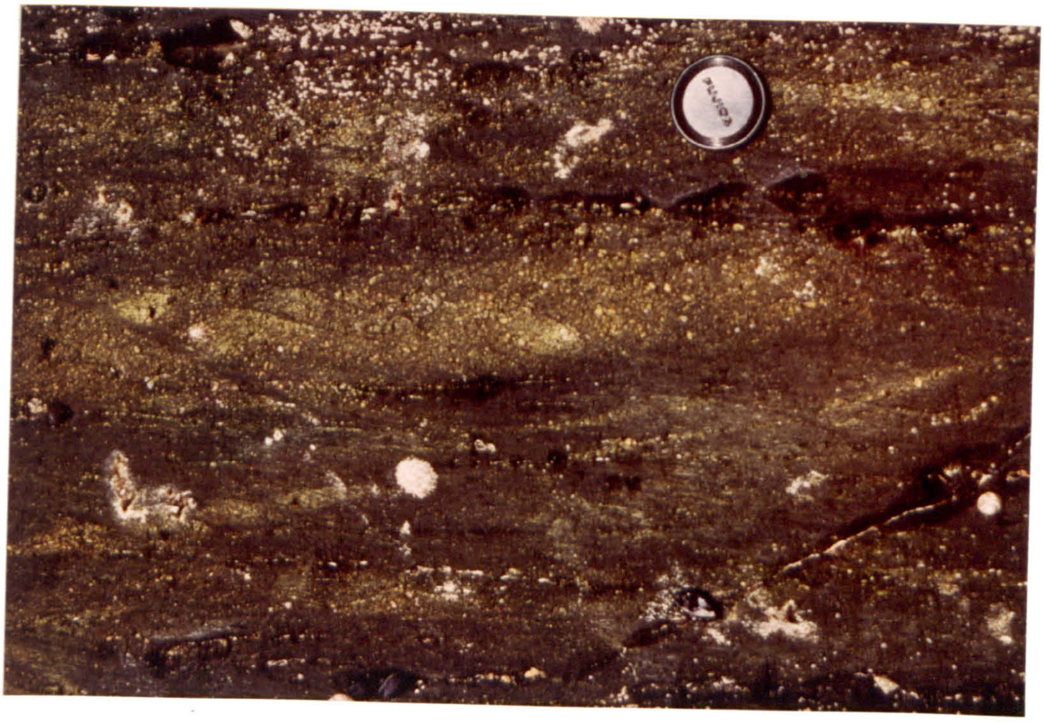
Highly deformed gabbro in small (c. 1 m wide) shear zone, displaying relic lozenge shaped gneissose pods and a well-developed S1b foliation in the anastamosing matrix.

Scale: Lens cap 54 mm diameter.

Fig. 4:4 Gabbro component, E. Baie de Pors Rodou

Plagioclase porphyroclast in segregated greenschist matrix. Segregation of dark and light bands is parallel to the S1b crenulation.

Scale: x16 XPL



bands, rich in chlorite and epidote,alternating on a millimetric scale with lighter bands rich in rounded plagioclase (An_{12}) porphyroclasts, quartz and some chlorite (Fig. 4:4 and 4:24).

Field relations, therefore, point to the gabbro component as post-dating the augen gneiss component and pre-dating the granite component and later phases. The relationship of this component to the St. Jean du Doigt Gabbro Complex, which crops out ajdacent to the Moulin de la Rive Orthogneiss Complex, is discussed in Chapter 7.

c) <u>The agmatite component</u>

The agmatite component is restricted in its outcrop to the east side of the bay of Moulin de la Rive. The agmatite is distinguished from the surrounding tonalite-diorite component by an overall higher mafic content and its mixed, patchy appearance (Fig. 4:5). The agmatite comprises a host mafic rock that appears to have been invaded by a medium to coarse-grained, intermediate quartz dioritic phase. The dark green host is fine-grained and composed of actinolite and green chlorite with minor amounts of epidote and quartz. The mineralogy of the lighter coloured intrusive phase is,in order of importance,plagioclase (An_{16}) + quartz+ biotite + chlorite + epidote + K-feldspar with some ore minerals. A pervasive S1 fabric is the dominant fabric but shear zones were not observed in the relatively small outcrop area of this component.

Plagioclase forms porphyroclasts (<1 cm) which are seriticized and occasionally fractured. Quartz forms both spectacular ribbon structure and core and mantle structure (Fig. 4:7) with quartz grains elongated parallel to the S1a foliation. Epidote is common and occurs in three forms; as relatively large <0.4 mm grains arranged in xenoblastic clots, as fine-grained dark aggregates, and as coronas around earlier formed ore grains.

Fig. 4:5 Agmatite component, E. Baie de Moulin de la Rive

The mixed nature of this component is apparent,in which an early mafic host has been injected by an intermediate composition lithology. Lobate interfaces and discrete pods of the mafic material occur within the medium-grained intermediate component.
Late epidote-rich segregation pods are developed.

Scale: Hammer handle 36 cm

Fig. 4:6 Tonalite component, W. Baie de Moulin de la Rive

Mafic enclaves are frequent within this component. Slbis well developed towards the top of the photograph where greenschists are developed in micro-shear zones parallel to the hammer handle.

Scale: Top hammer handle 36 cm

It is established that the quartz dioritic phase has invaded a more mafic host, which together make up the agmatite component. The outcrop of this component is restricted and its relationship to the established early gabbro component cannot be stated exactly in terms of age within the complex. The agmatite is considered within the early components largely because of its location and petrographical similarities to the other early components, principally the diorite component. It is not seen to be cut by the late components. The veining quartz diorite phase of the agmatite is probably genetically related to the tonalite component.

d) The tonalite component (and associated diorites)

Included with the tonalite component are closely associated rocks of more intermediate composition, which range principally from quartz diorite into rarer virtually quartz-free diorite. In the field the tonalite and quartz diorite are often difficult to separate because of subsequent deformation. The rarer quartz-free diorite is a darker rock which occurs as ill-defined zones along the west side of the bay at Moulin de la Rive. Both the tonalite and quartz diorite crop out extensively along both the east and west side of this bay.

The agmatite occurring along the east side of the bay of Moulin de la Rive is enclosed within the tonalite component, and it appears that it is a variety of this component which actually forms the veining material enclosing the more mafic phase of the agmatite. A more advanced stage, in the extensive veining and fragmentation of a more mafic phase, may be seen in the common occurrence of mafic inclusions within the tonalite component (Fig. 4:6). The tonalite component is cut by sheets of the granite component and blocks or rafts of the former are occasionally observed within the granite. The tonalite component and the associated diorites carry a well-developed S1a foliation, and S1b is characterized by grain-size reduction, a finer schistosity and segregation banding in shear zones.

The tonalite is composed of plagioclase (sodic oligoclase), microcline (often perthitic), quartz, biotite, chlorite, epidote, white mica, sphene and ore. K-feldspar is lacking in the diorites, and quartz becomes a minor component, while a greenish hornblende is a prominent mafic component. In the least strained specimens of tonalite and quartz diorite, the shape of the biotite aggregates (with which are associated epidote, chlorite and sphene) suggests that there may have formed on the sites of primary magmatic hornblendes.

The plagioclase of the tonalites and quartz diorites is often cloudy due to the presence of small epidote and white mica crystals. The plagioclase forms grains up to 4 mm long which may occur singly or in aligned elongated aggregates which partly define S1a (Fig. 4:15).

Generally the mafic aggregates, which include the biotite, chlorite and epidote, are elongated to form crudely aligned foliae which separate the feldspars and the quartz-rich areas. Both the K-feldspar and, in particular, the quartz exhibit stages in grain size reduction through dynamic recrystallization, leading to localized zones of polygonal quartz aggregates. The sphene may occur in trains of small grains within the mafic foliae. Frequently sphene mantles ore. In domains of high strain the K-feldspar may be completely converted to aggregates of fine muscovite flakes.

The more mafic lenticular inclusions within the tonalite component are up to 15 cm long with high length : width ratios. The inclusions, which are generally aligned parallel to S1a (Fig. 4:6), are distinct from the very thin (c. 1 mm) dark dislocation zones which are common in both the tonalite and granite components. The mafic inclusions are composed of amphibole with variable amounts of biotite, chlorite, sphene, ore and quartz. The thin dislocation zones,which are rich in chlorite and epidote, are considered as microshears. These increase in frequency towards the shear zones cutting the orthogneiss complex,which suggests that these microshears are related to the development of the shear zones.

Although the main outcrop of the gabbro component is not in contact with the tonalite component,there is one narrow band of gabbro in contact with the former along the west side of the bay at Moulin de la Rive. Unfortunately, the contacts between the two components are zones of relatively high strain and age relationships cannot be determined.

e) <u>The granite component</u>

The granite component is widespread in its outcrop throughout the orthogneiss complex. It is the dominant component in the Les Sables Blancs to Pte. du Corbeau area and truncates most of the rocks assigned to the early phase in the west of the complex. It is a distinctive rock-type and weathers to a pink-cream colour. The S1a gneissose foliation is well-developed, but is not as conspicuous as in the more mafic component, where a more regular banding is developed. This is due to the lack of phyllosilicate minerals, principally chlorite,that depict the fabric. The grain size is generally coarse and large (<1 cm) K-feldspars (perthitic) depict a crude alignment of their long axes parallel to the S1a foliation.

Shear zones depicted by mylonites with a close-spaced foliation are not well-developed in the granite component and the shear zones are largely restricted to the more mafic or finer-grained components. The granite does,however,possess small crush zones or microshears (described in part c) and tension gashes.

The mineralogical composition is, in order of importance, K-feldspar (perthite + microcline) + albite + quartz + biotite + chlorite + muscovite with some accessory ore minerals (magnetite?). Perthite forms rounded or elongate augen and shows variable exsolved plagioclase. Quartz occurs in a variety of forms; as large, possible original grains (<2 mm) with strong ribbon texture; as xenomorphic recrystallised quartz in pressure-shadows of large feldspars; and in crack infills of the large K-feldspars (Fig. 4:8). Microcline is larger than the albite grains and both exhibit grain slip along preferred twin-planes. Green biotite and chlorite depict the foliation in the granite, and muscovite is commonly developed in the pressure shadows of large feldspars.

The granite has clearly defined sharp boundaries with the early components (i.e. the gabbro, agmatite and tonalite components). Occasionally small rafts of diorite are recorded within the granite. This indicates the injection of the granite into consolidated more mafic host rocks. The granite component is therefore assigned to the later components in the evolution of the complex.

In the granite component (which is similar in appearance to the Gneiss de Trébeurden) the occurrence of micro-shears or crush-zones, rather than a well-developed S_{1b} close-spaced schistosity, is of note and these may be synchronous with or post-date the S_{1a} foliation. Fig. 4:10 illustrates the heterogeneous nature of the deformation affecting the granite component close to the western margin of the LSB at Pte. du Corbeau.

f) <u>The porphyritic microgranite component</u>

The outcrop of the porphyritic microgranite component is widespread throughout the complex, and mapping reveals the sheet-like form of individual units (Figs. 4:9 and 4:11). The porphyritic microgranite is often found in association with the granite and can be seen to cut the latter.

Fig. 4:7 Quartz texture in tonalite component, Moulin de la Rive

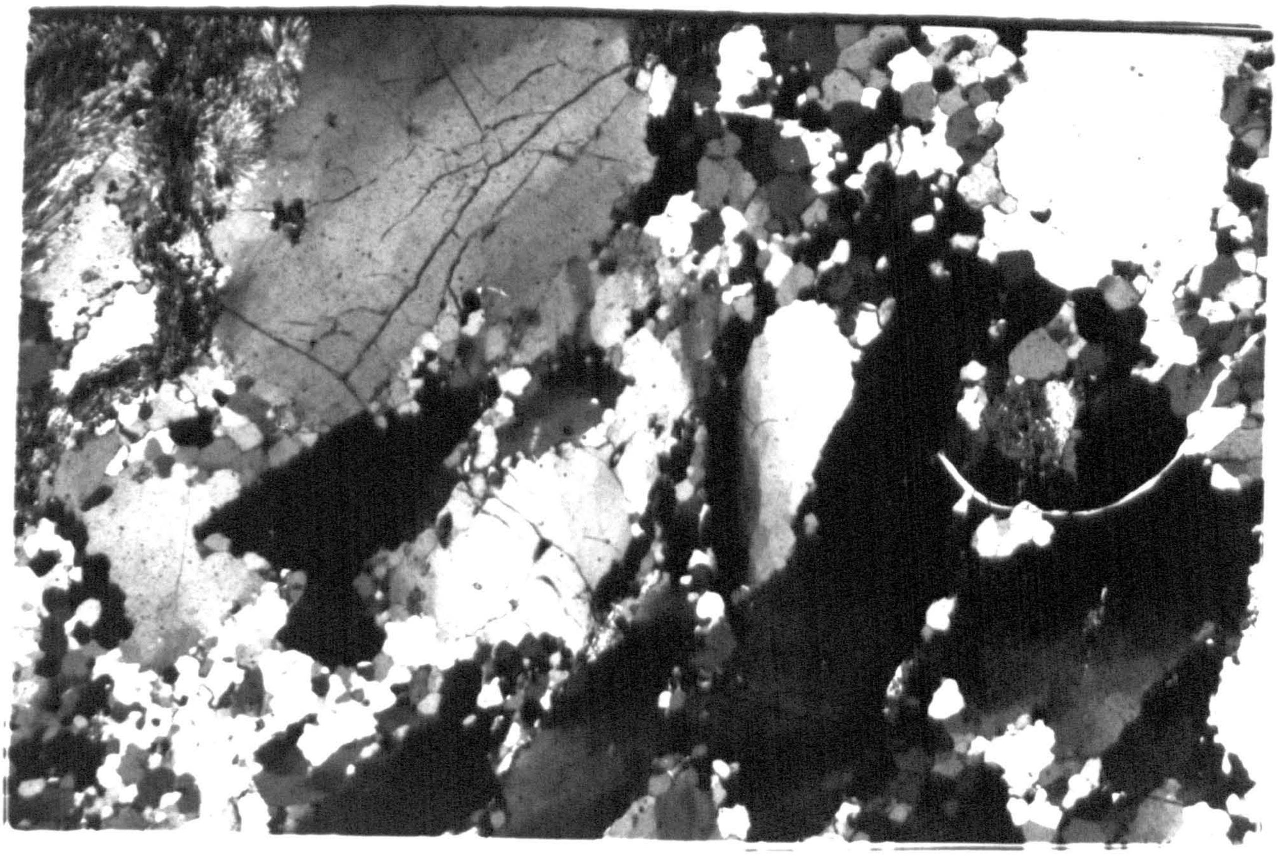
Recrystallized small grains of quartz are developed around the edges of larger, often highly strained, quartz grains to give core and mantle structure.

Scale: x16 XPL

Fig. 4:8 Microstructures granite component, Moulin de la Rive

Large microcline and albite grains are cracked with quartz infill. The quartz grains are elongated parallel to S1a.

Scale: x16 XPL



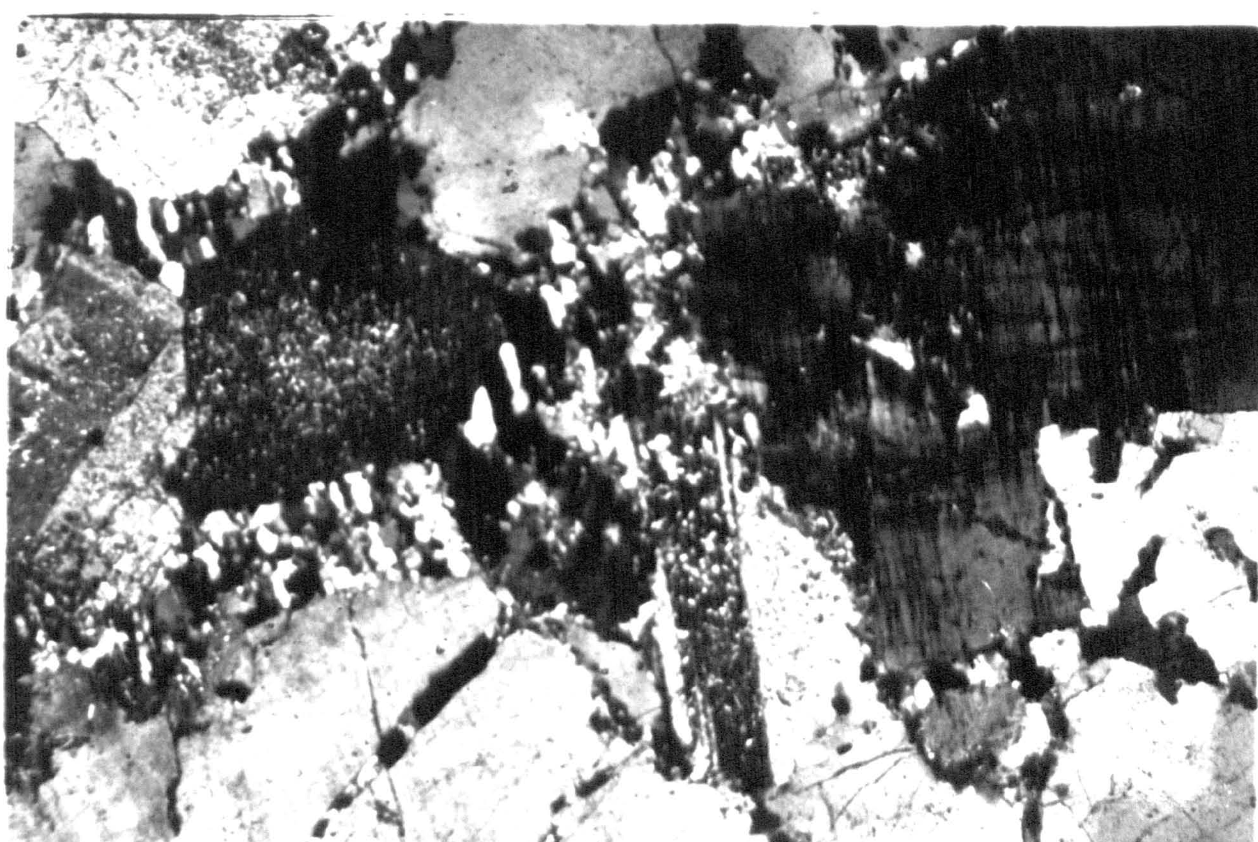


Fig. 4:9 Granite-component with injected porphyritic microgranite component, Pte. du Corbeau

At this locality host granite (g) has been injected by the porphyritic microgranite (pm) component. Deformation has resulted in the formation of S1b which is best developed in the porphyritic microgranite.

Scale: Hammer handle 36 cm

Fig. 4:10 Granite and porphyritic microgranite contact; Pte. du Corbeau

At this locality, close to the boundary of the LSB with the Moulin de la Rive Orthogneiss Complex, recognizable granite is heterogeneously deformed with glomeroclasts of granite and phenoclasts of feldspar set within a foliated fine grained matrix. The pencil is aligned parallel to S1b.


pm

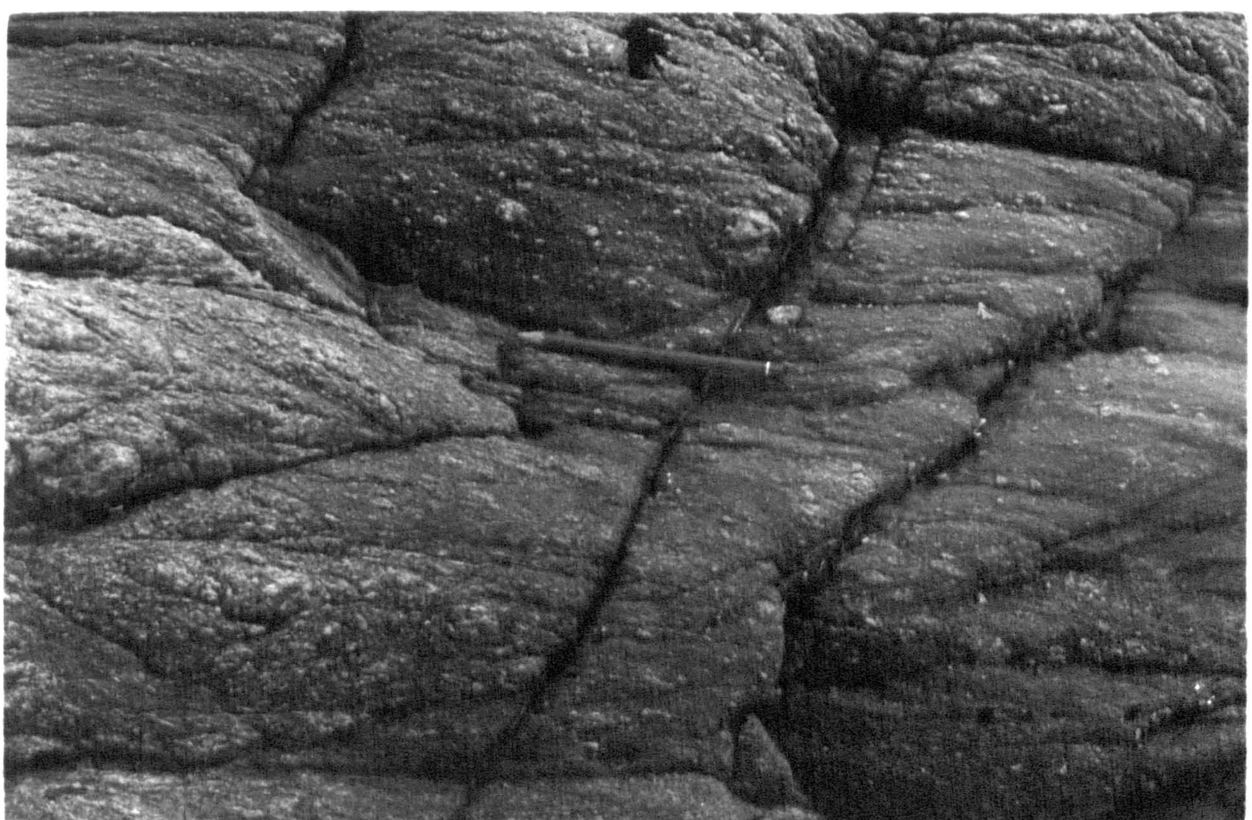
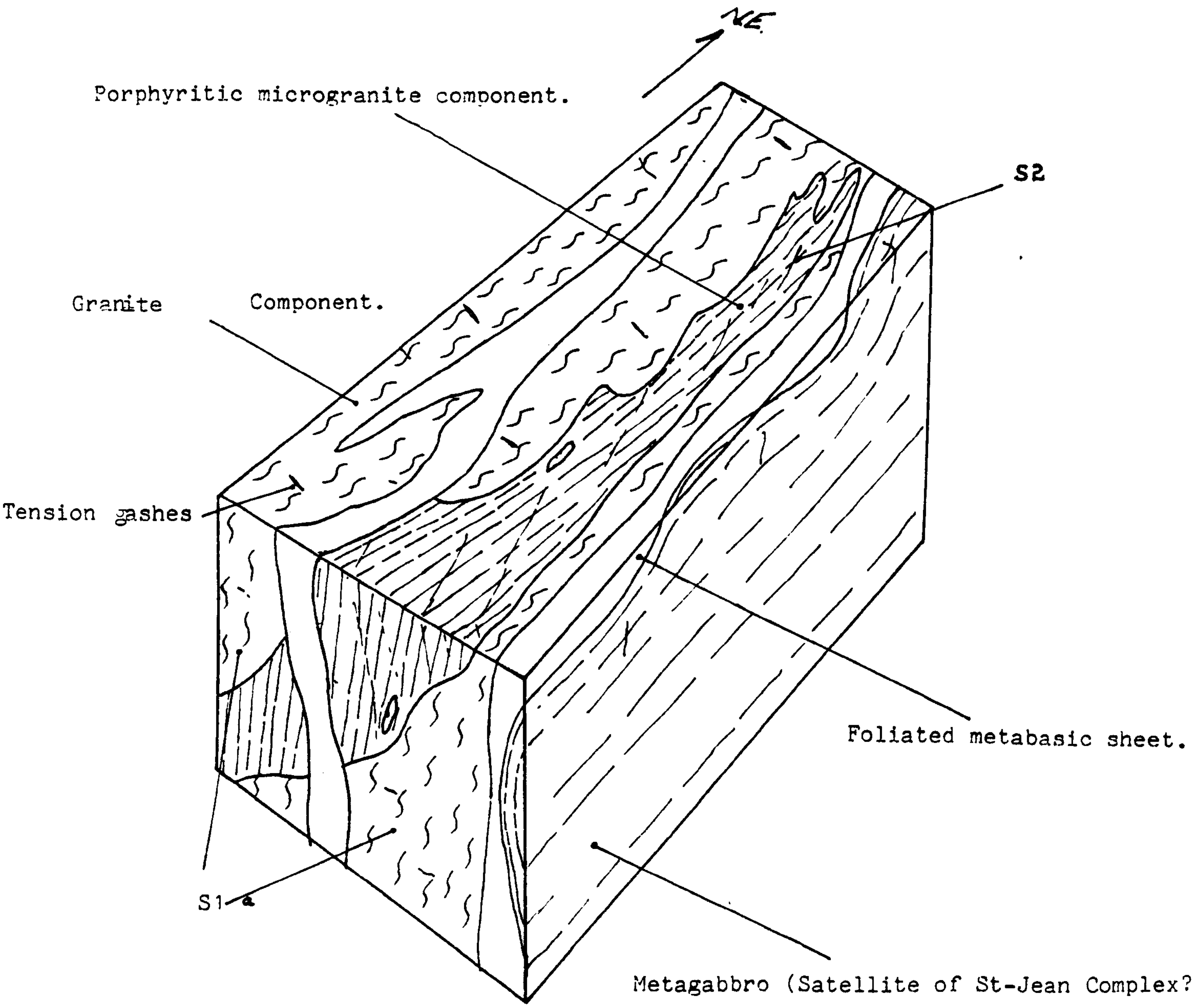


FIG. 4 : 11 MAGMATIC RELATIONSHIPS ; 100 m. S.W. PTE DU CORBEAU



At this locality (GR 1599 1278) the relationship of the granite to the porphyritic microgranite can be seen and the sheet-like form of the younger microgranite is evident. The relative age of the metagabbro is not clear, the margins of the "satellite" intrusions are strongly foliated. A late crenulation fabric is developed in the microgranite that is sub-parallel to the foliation in the greenstone dykes.

The microgranite is a light-grey colour with a 'gritty' appearance and an ubiquitous well-developed schistosity. The characteristic gritty appearance is due to the presence of <2 mm diameter single phenocrysts of K-feldspar and albite set in a fine-grained matrix. Some of the micrograni tes have elongate chlorite or biotite-rich schlieren arranged parallel to the dominant foliation.

The mineralogy of the porphyritic microgranite component is in order of importance K-feldspar (microcline) + quartz + albite + white mica + chlorite + biotite + ore minerals. Large quartz grains are frequent, often in close association with the large feldspar aggregates. Individual quartz grains may show core and mantle structure with recrystallised rims and fractured, strained cores. The fine-grained matrix is composed largely of quartz and white mica with some chlorite. Grain size and white mica (muscovite?) content vary throughout the scale of one thin-section, and may reflect zones of relative high and low strain accordingly. In areas of high strain, the grain size is reduced and white mica content increases with modification to the shape of feldspar porphyroclasts. In lower strain zones, euhedral plagioclase grains remain with long axes arranged parallel to the schistosity. A similar relationship occurs in the mylonitic rocks of the Locquirec Shear Belt (LSB).

A secondary developed crenulation fabric is sometimes developed in this lithology. The fabric post-dates the mylonite/gneissose banding. A discussion as to the various fabrics is given in part (C). The close spatial association of the porphyritic microgranite with the granite has been noted (Fig. 4:11) and so this unit is included within the late components.

(g) Aplogranite component

The aplogranite component is widespread throughout the orthogneiss, but is volumetrically the least significant of the components forming the complex. The aplogranite is an orange to buff weathering leucocratic rock. It is fine to medium-grained, and possesses a series of irregular fractures rather than a well-defined foliation or schistosity. The outcrops are small and the aplogranites appear to be thin (2-30 m thick) sheets, the largest of which occurs to the west of the bay of Moulin de la Rive (Map 4). Fig. 4:2 shows a thin aplogranite dyke that truncates the augen gneiss component and is foliated parallel to the conspicuous S1afabric in the host lithology. In thin-section it is possible to detect a crude foliation that is defined by the patchy development and alignment of chlorite and biotite. The major constituent of this rock is quartz, which is largely fine-grained and recrystallised with a granoblastic texture. K-feldspar (<2 mm) is developed in some of the sheets, where it is widely-scattered amongst a quartz-rich matrix.

The aplogranites are considered as late co-magmatic sheets that truncate all other components.

(h) The Pors Rodou Breccias

The Pors Rodou Breccias are restricted in outcrop to the west of the bay at Pors Rodou where they are isolated from contact with other components of the complex, but are truncated by the Hercynian Granite de Beg An Fry. The term breccia is used in a non-genetic, purely descriptive sense. The breccias are highly deformed and have been included within the orthogneiss complex, although their chronological position is uncertain. The rocks occur towards the western margin of a major shear zone that has largely deformed the gabbro component (Map 4).

The breccias are variable in form and three types are recognised within the outcrop. These occur in parallel zones:-

1. Banded variety: This variety is formed of alternating light and dark bands on a centimetric scale. The boundaries of these bands may be sharp or lobate (Fig. 4:12) and sometimes the layers are more intimately interleaved. The leucocratic bands are composed of quartz + k-feldspar + muscovite + chlorite + ore minerals. Quartz is fine-grained and highly strained, exhibiting strong ribbon texture. K-feldspar is largely altered to sericite. Muscovite (up to 1 mm diameter) and chlorite are arranged parallel to the banding and depict a foliation. The ore minerals tend to be concentrated at the boundaries of the leucocratic and melanocratic bands. The dark bands are composed of very fine-grained quartz and fine-grained platy chlorite.

2. Breccia: This lithology is characterised by large (c. 15x6 cm) fragments with an eliptical shape composed of leucocratic material. These are set within a finer crystalline matrix. The fragments are strongly foliated and some minor quartz segregation has occurred within some of these,parallel to the schistosity (Fig. 4:13). The fragments are composed of medium to coarse-grained quartz (<2 mm) plus muscovite and chlorite. The matrix is composed of white mica + quartz + chlorite + plagioclase (An_{10}) + ore minerals.

3. Micro-breccia: This lithology is similar to that described above, but is distinguished from the above breccias by the presence of smaller fragments (c. 2x1 cm). The light-coloured fragments are composed largely of recrystallised, annealed quartz grains. The grain size varies between clasts. The matrix is dark-grey in colour and composed of plagioclase (An_{19}) + quartz + chlorite + white mica. The fragments denote a poorly-developed linear fabric,and a weak foliation is developed within the

Fig. 4:12   Pors Rodou Breccias, banded variety, Pors Rodou

This variety is composed of alternating bands of leucocratic minerals (quartz + albite + muscovite) with dark bands composed of fine-grained quartz + chlorite. The banding is well-defined and the boundaries may be planar or lobate.

Scale: Lens cap = 54 mm

Fig. 4:15   Highly deformed tonalite component, Moulin de la Rive

The S1b foliation is developed at a high angle to the S1a foliation (depicted by the alignment of feldspar long axes). The S1b foliation modifies grains by rotation and recrystallization of grain edges. The S1b foliation is therefore depicted by the development of quartz + chlorite + albite rich domains which anastomose the feldspar ± quartz rich domains.

Scale: x16 XPL

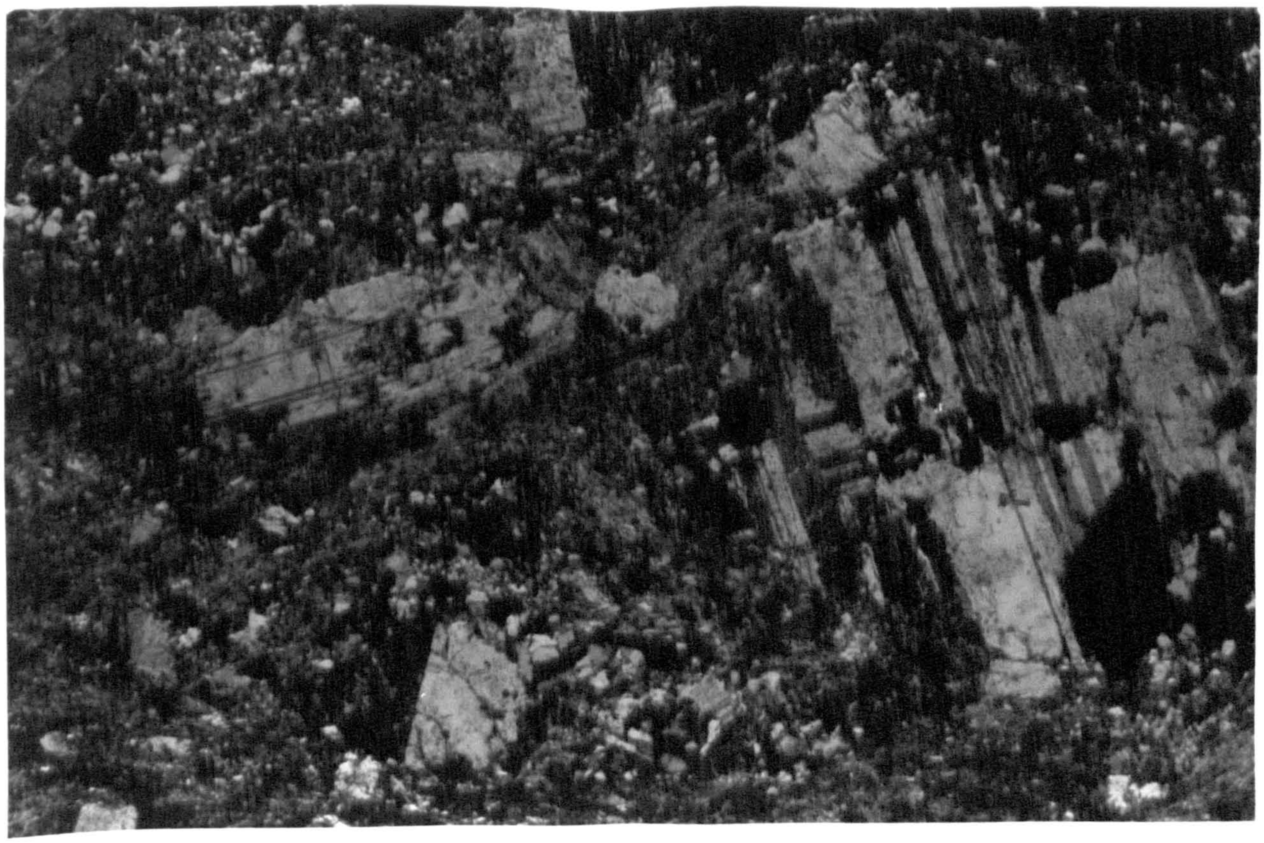


Fig. 4:13 The Pors Rodou Breccias, breccia. Pors Rodou

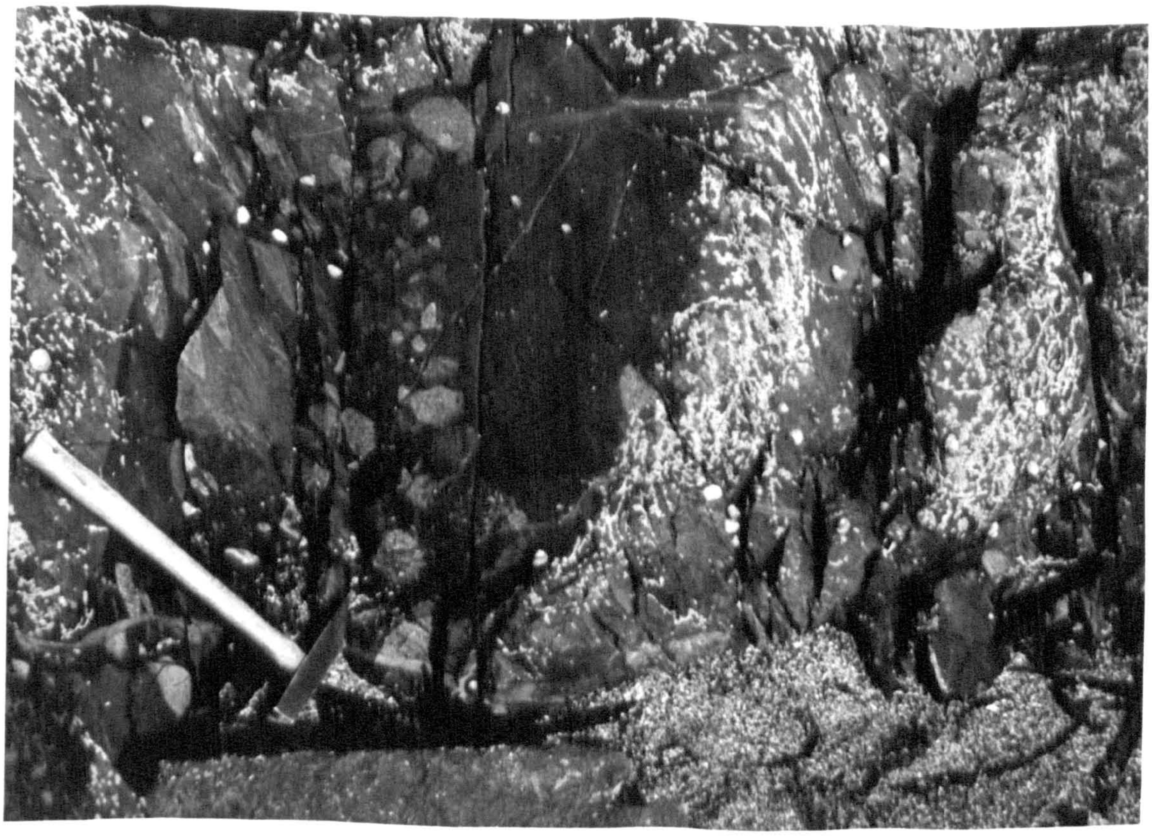
This lithology is characterised by fragments (up to 15 x 6 cms but usually smaller) composed of leucocratic material set within a finer grained quartz-rich host. The fragments show varying degrees of deformation.

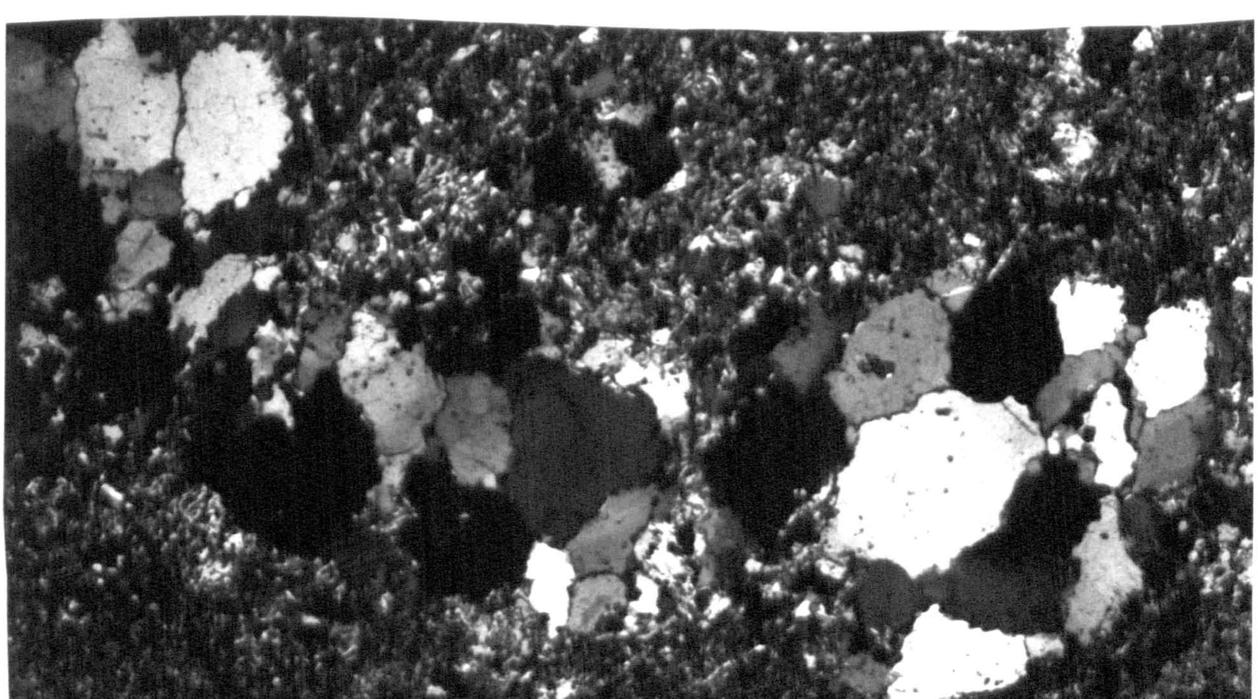
Scale: Hammer handle 36 cm

Fig. 4:13b The Pors Rodou Breccias, micro-breccia, Pors Rodou

This lithology is similar to the breccia shown in Fig. 4:13 but is composed of smaller fragments (c. 2 x 1 cm). The light-coloured fragments are composed largely of recrystallized quartz grains. The matrix is composed of albite + quartz + chlorite + white mica which shows variable development of the S1a and S1b foliation.

Scale: x16 XPL





matrix (Fig. 4:13 and 4:13b).

Autran et al. (1979) include the Pors Rodou Breccias and mylonitic rocks of the Pors Rodou area within the Formation de Locquirec (the Locquirec Shear Belt of this thesis). The breccias resemble the Poudingues de Locquirec (discussed in Chapter 5) and Autran et al. (op. cit.) consider their origin to be sedimentary or volcaniclastic in which (p. 279) "conglomerats a éléments orthogneissiques leucocrates et matrice volcano-detritique" are developed.

This author can find no evidence to support this view and it is considered that other processes may account for the origin of these breccias. The breccias may represent; 1) a true sedimentary breccia in a highly deformed state; 2) igneous breccias or agmatites which have been highly deformed; 3) a metamorphic rock in which segregation has occurred or; 4) a fault breccia that has subsequently been deformed.

Further discussion as to the primary nature of the Pors Rodou Breccias is discussed together with the Poudinques de Locquirec in Chapter 5, in which an igneous origin is suggested, but for which the evidence is tentative.

(2) POST-COMPLEX BASIC SHEETS

A large number of basic sheets with a general NE-SW trend truncate the orthogneiss complex (Map 4). There is a strong schistosity present within most of the sheets, and this is considered to be an S2 fabric that post-dates the S1a gneissose foliation and S1b mylonitic banding, see discussion in part (C). The basic dykes possess a greenschist assemblage of actinolite + epidote + biotite + sphene + chlorite ± quartz.

The sheets range in thickness from 40 cm to 12 m. Several composite sheets are recorded in the areas of Moulin de la Rive and Pte. du Corbeau (Fig. 4:14 and Fig. 4:14B).

The sheets are widespread in their occurrence and truncate formations assigned to the Brioverian (Formation de Pte. de l'Armorique and Formation de Plestin), the Cadomian Perros-Guirec Granitoid Complex, the Gneiss Granitique d'Île de Callot and Devonian to Lower Carboniferous metasediments in the Morlaix Basin. The sheets provide a useful time indicator, and in Chapter 6 it is proposed that they are the product of the same magmatic episode that produced the Lower Carboniferous basic metavolcanic Formation de Barnenéz.

(3) SUMMARY

A number of different components are recognised within the Moulin de la Rive Orthogneiss Complex. Four early phases are truncated by two later phases which are, in turn, cut by aplogranitic sheets. The age of the earliest component, the augen gneiss, is possibly pre-complex and of Lower Proterozoic (Pentevrian) age.

Two fabrics are recognised that were developed prior to the emplacement of the basic dyke suite. The different components have responded heterogenously to the imposed tectonic stresses.

Fig. 4:14 Metabasic sheet truncating the Moulin de la Rive Orthogneiss Complex, W. Baie de Moulin de la Rive

This sheet (c. 40 cm thick) truncates the tonalite component in which the S1 foliation (dipping steeply to the west) is well-developed. The sheet possesses a sub-parallel fabric (S2) developed during D2, the sheet post-dates the S1a foliation.

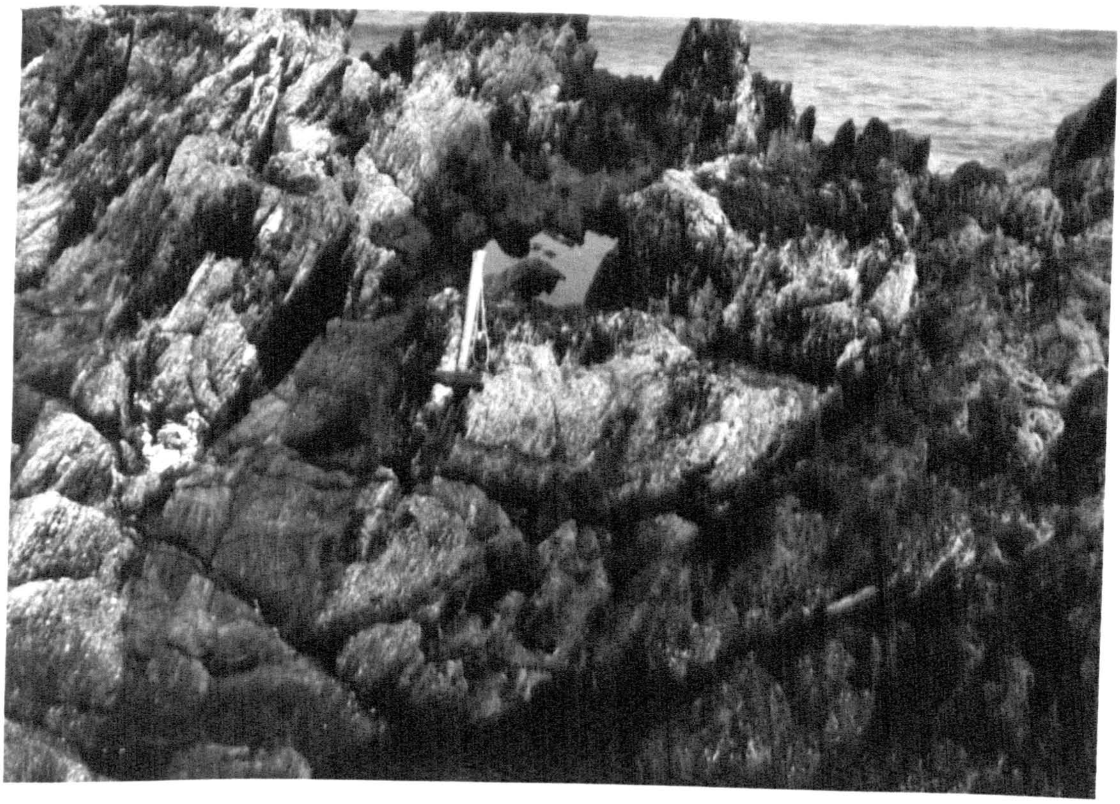
Scale: Hammer handle 36 cm

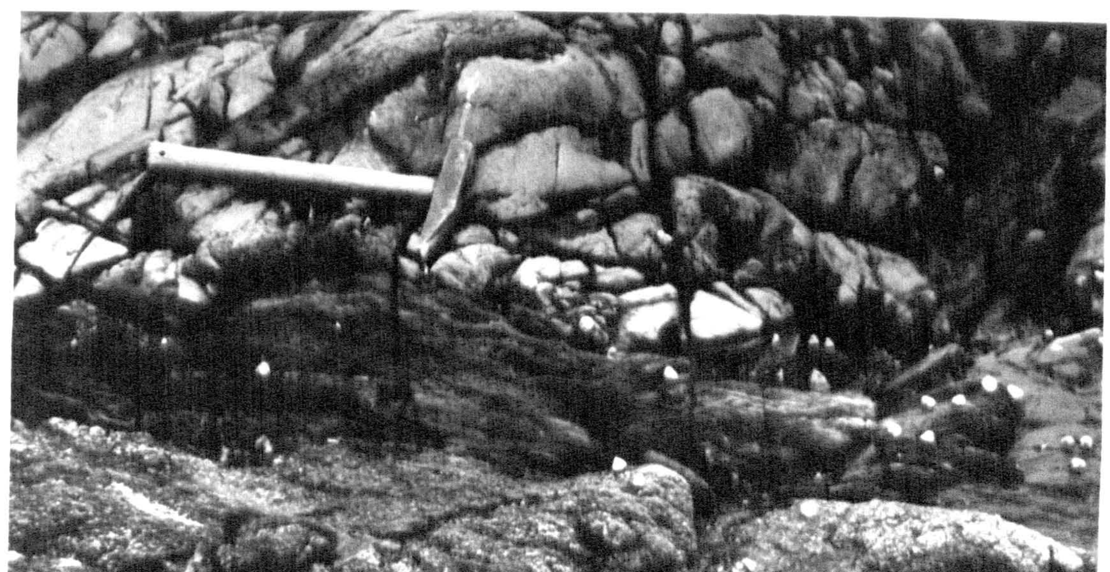
Fig. 4:14b Metabasic sheet, Moulin de la Rive Orthogneiss Complex

The sheets show variable development of the S2 foliation. At this locality, the margin of the sheet is highly deformed with a well-developed S2 fabric relative to the poorly foliated interior of the sheet.

Scale: Hammer handle 36 cm

N.B. Fig. 4:15 attached to 4:12





(C) DEFORMATION AND METAMORPHISM OF THE MOULIN DE LA RIVE ORTHOGNEISS COMPLEX

(1) D1 EPISODE AND DEVELOPMENT OF THE S1a AND S1b FABRICS

In describing the lithologies that comprise the orthogneiss complex in part B, two major fabrics have been distinguished. S1a is a gneissose foliation and is developed throughout the complex, S1b is a closely spaced foliation that is developed in localized shear zones. In part A it was pointed out that the two fabrics are considered to have formed sequentially or simultaneously during a single deformation episode as the result of heterogeneous shear strain. There is no evidence to show that the two fabrics were developed during two separate deformation episodes.

The two fabrics are approximately parallel, although the mylonitic banding developed in the shear zones is a more consistent and regular foliation, which trends 030°-050° NE-SW. At shear zone boundaries a common feature is for the gneissose banding to rotate into the plane of the mylonitic banding, and in these areas the oblique nature (up to 30°) of the two fabrics can be examined.

Deformation of the orthogneiss complex is markedly heterogeneous, in that different lithologies have responded in different ways to the imposed tectonic stresses. A given component may show variable development of the S1a and S1b foliation. The shear zones are largely restricted to the more mafic components and the finer-grained silicic components.

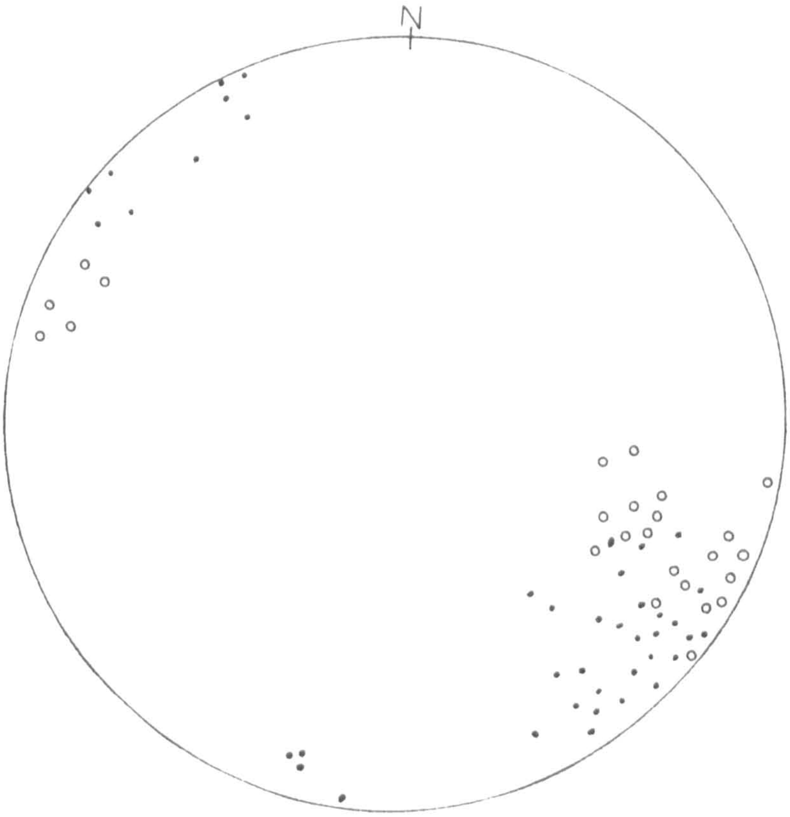
The S1a gneissose foliation is shown in Figs. 4:1 and 4:6. The foliation is depicted by the alignment of phyllosilicate and prismatic minerals, by parallel orientation of the long axes of feldspars (Fig. 4:15), and by the alignment of feldspar and biotite + chlorite aggregates and mafic inclusions. The feldspars may be fractured and extended in the plane of the S1a foliation, and quartz is recrystallized within the fractures and in pressure shadows adjacent to the feldspars (Fig. 4:18). In the agmatite component quartz displays both ribbon structure and core and mantle structure (White 1977; Fig. 4:7). The quartz grains have been extended within the plane of the NE-SW foliation and have undergone partial recovery and recrystallization.

The microscopic textures developed within the gneisses and associated with the formation of the gneissose foliation S1a are similar to those textures developed in the shear zones. Quartz commonly shows ribbon structure, core and mantle structure and recrystallization. Plagioclase is relatively resistant to deformation and may preserve euhedral shapes. They are, however, commonly recrystallized around crystal edges and may be fractured or boudinaged. This is indicative of the relative brittle behaviour of the feldspars in contrast to the other phases present. In the gabbro component hornblende is commonly altered to actinolite around grain edges and readily breaks down to chlorite in highly strained zones (Figs. 4:3 and 4:4).

The shear zones are considered as localized zones of strain softening that formed when the hardening capacity of the deforming material was exceeded (White et al. 1980). The rocks in the shear zones are mylonitic schists and these occur in zones varying from 30 cm to 1.5 km wide. Fig. 4:17 illustrates the main shear zones (those >20 m wide) within the Moulin de la Rive Orthogneiss Complex.

Shape fabrics within the shear zones are more planar and distinct than fabrics in the surrounding gneiss units (Fig. 4:16). Microstructures are indicative of ductile deformation, and various mineral species have responded differently to deformation. The heterogeneous nature of the strain is evident on two scales; a) In the production of distinct shear zones, and b) within these delimited shear zones there are domains of both low and high strain.

Fig. 4 : 16 *S1a/S1b* RELATIONSHIPS, MOULIN DE LA RIVE ORTHOGNEISS COMPLEX



• *S1a* average pole 042/76 (N.W.)

o *S1b* average pole 026/80 (W)

Photograph to show development of mylonitic banding, parallel to *S1b* at Moulin de la Rive beach, west.

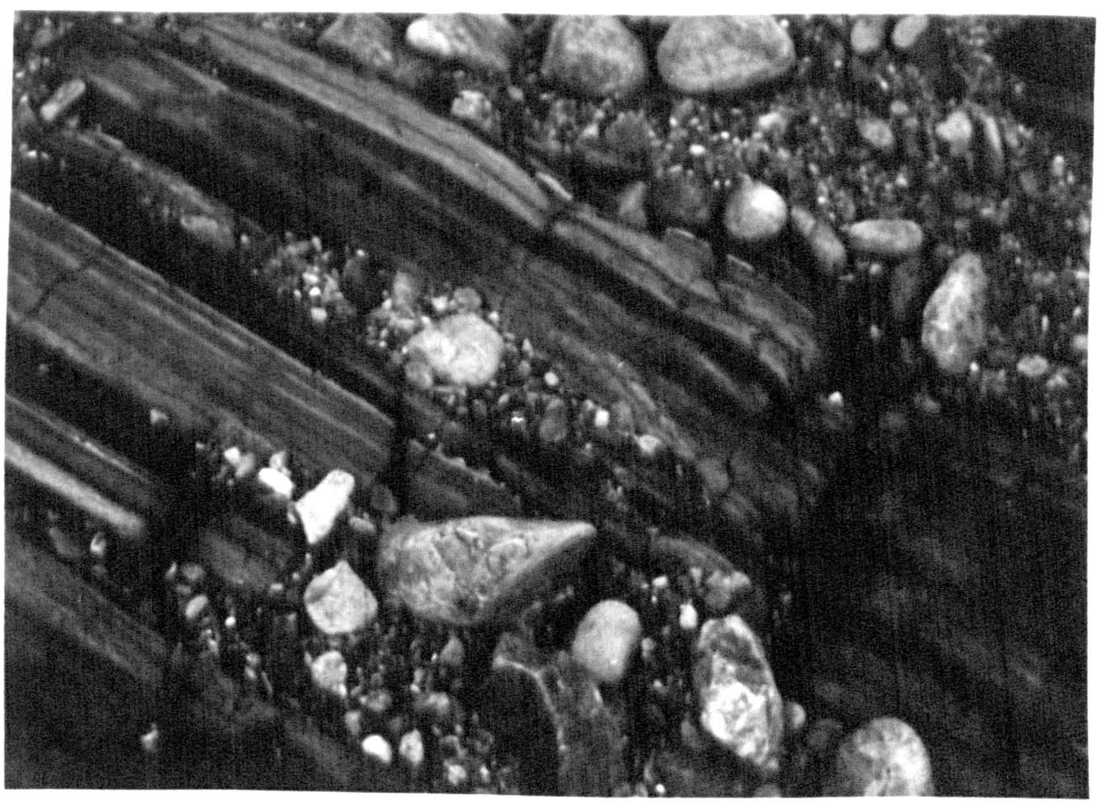
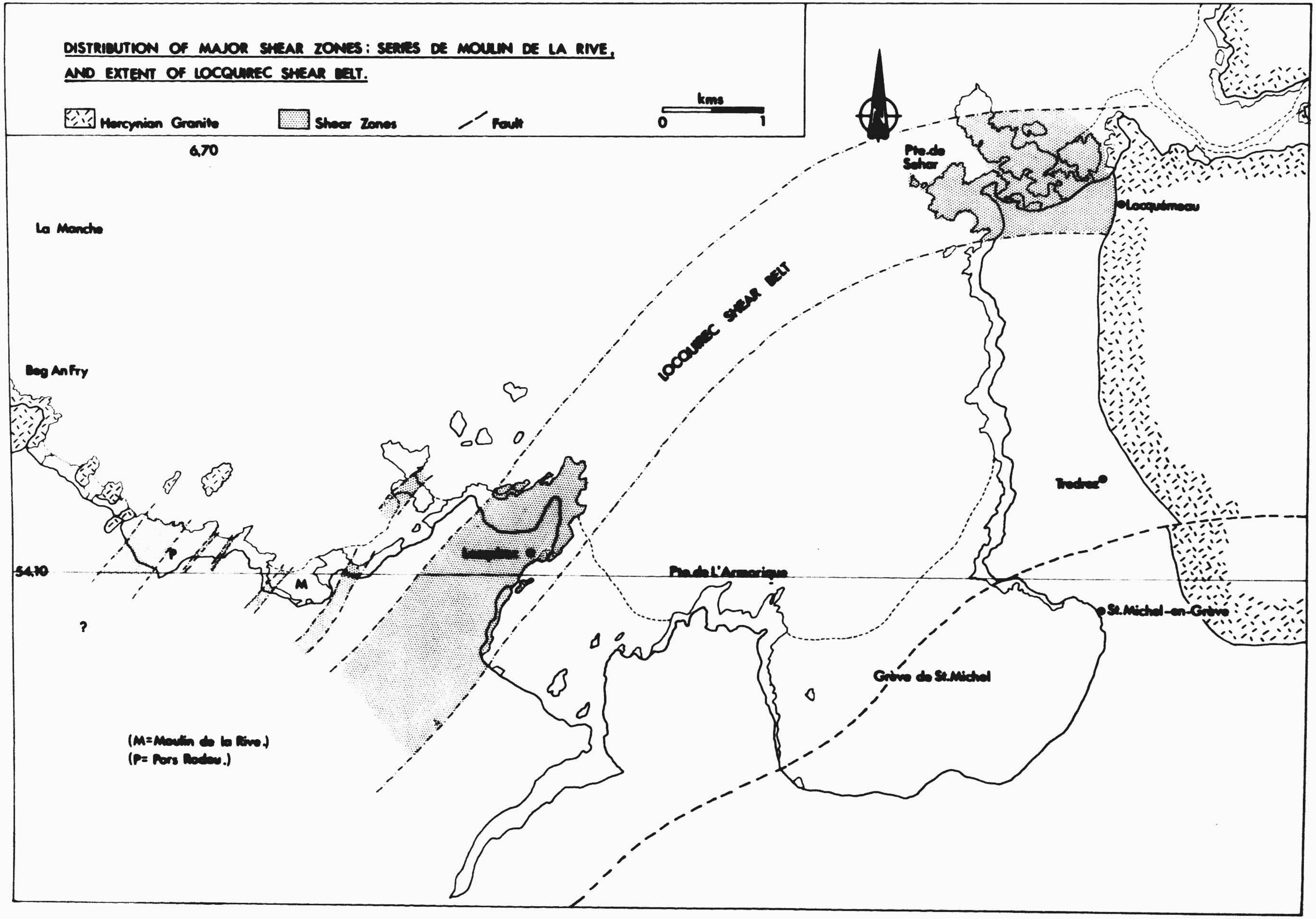


Fig. 4:17 Distribution of major shear zones cutting the Moulin de la Rive Orthogneiss Complex.

Erratum: Figure heading - For Series de Moulin de la Rive read Moulin de la Rive Orthogneiss Complex.


DISTRIBUTION OF MAJOR SHEAR ZONES: SERIES DE MOULIN DE LA RIVE,
AND EXTENT OF LOCQUIREC SHEAR BELT.
Hercynian Granite
Shear Zones
Fault
kms
0
1
6,70
La Manche
Beg An Fry
54,10
?
Pte.de Sehar
Locquémeau
LOCQUIREC SHEAR BELT
Tredrez
Pte.de L'Armorique
St.Michel-en-Grève
Grève de St.Michel
M
P
(M=Moulin de la Rive.)
(P= Pors Rodou.)

and dextral shear zones occur. The major shear zones mapped west of the Pte. du Corbeau show a sinistral sense of movement. In detail, the S1b mylonitic fabric envelopes plagioclase and occasional quartz porphyroclasts, and in high strain zones it is observed that the porphyroclasts are rotated and extended in the S2 plane, where they may also be boudinaged (Figs. 4:18, 4:19, 4:20, 4:22 and 4:23).

Domains of both low and high strain are recognised within the shear zones (Fig. 4:20). Low strain domains are characterised by elongate, lensoidal-shaped or lozenge-shaped pods of gneiss with preserved gneissic foliation sub-parallel to the mylonitic banding. These pods are enveloped by the S1b schistosity. The resultant lozenge structure occurs on both a large scale (c. 1 m pods) and on a microscopic scale (Fig. 4:3 and 4:18). Isolated plagioclase feldspars act as relatively resistant 'hard' minerals about which other minerals (dominantly phyllosilicate minerals and quartz) recrystallise. Micro-shears deform individual crystals and the gneissose pods.

A linear fabric is developed in the mylonites and is formed by the stretching, rotation and modification of the resistant feldspars (Fig. 4:23), and by the rodding of hornblende in shear zones in the gabbro component. Fig. 4:22 illustrates the mylonitic fabric within the gabbro component. The thin section is cut in the Y:Z plane, perpendicular to the feldspar lineation. The lineations are consistent in attitude and plunge to the NE (048^o) at 24^o.

A common feature in the highest strain areas is the production of a schistosity at an angle of between 35-45^o to the dominant S1b fabric, which may be developed sequentially or subsequently to S1b. The S1b fabric is discussed with regard to the rocks of the Locquirec Shear Belt (LSB) in Chapter 5, in which a shear-band structure labelled S1C is distinguished from a later S2 crenulation fabric.

Fig. 4:18   Mylonitic fabric, Moulin de la Rive Orthogneiss Complex

A well-developed S1b foliation is present in which segregated quartz + chlorite + albite + epidote-rich foliae anastomose feldspar ± quartz grains or domains. The feldspar shape is modified by recrystallization and neominerallization at grain edges,and feldspars may also display microboudinage with subsequent neominerallization in the resultant fractures.

Scale: x16   XPL

Fig. 4:19   Mylonitic fabric, Moulin de la Rive Orthogneiss Complex

Detail of the S1b foliation, quartz-rich foliae may exist as attenuated bands in pressure shadows of large feldspars (NE corner). K-feldspar may preserve its euhedral shape.

Scale: x16   XPL

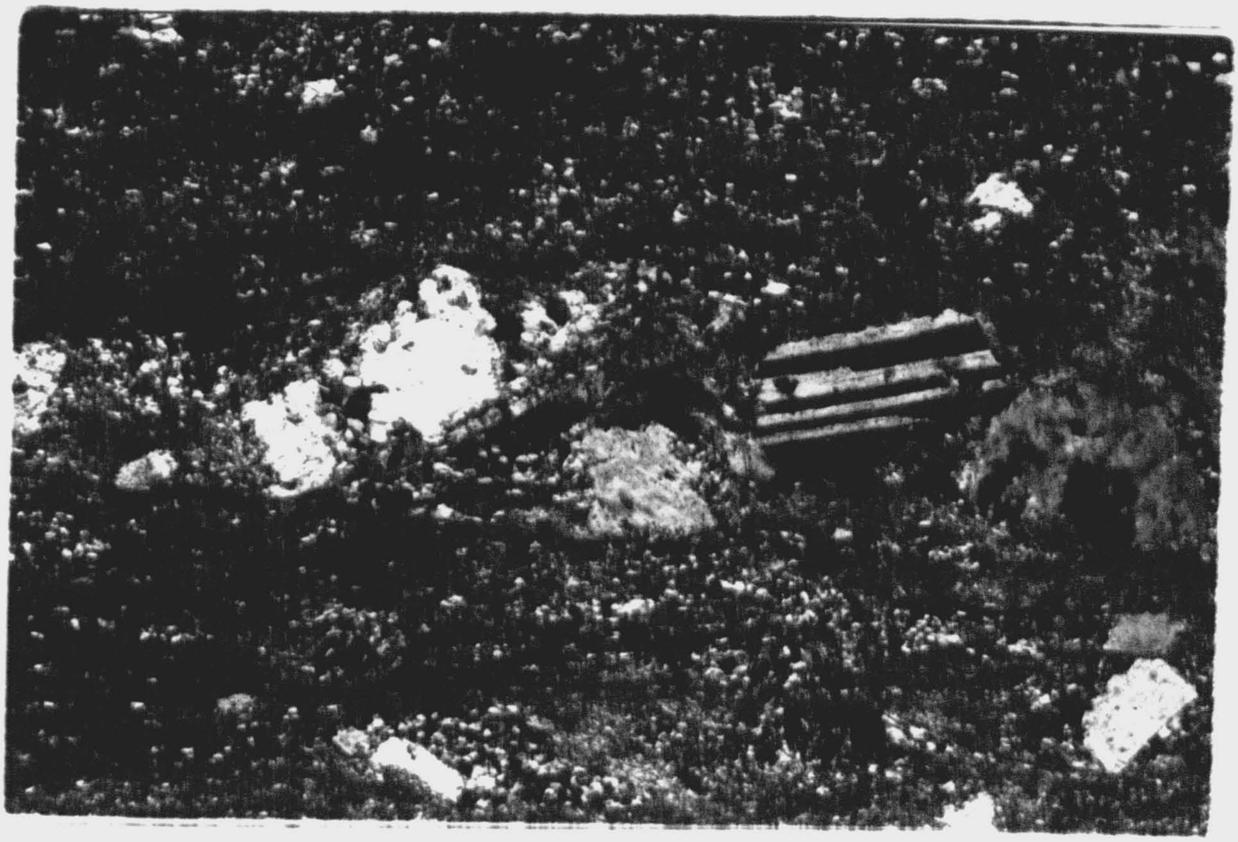


FIG. 4 : 20 Shear zone in the Tonalite Component.

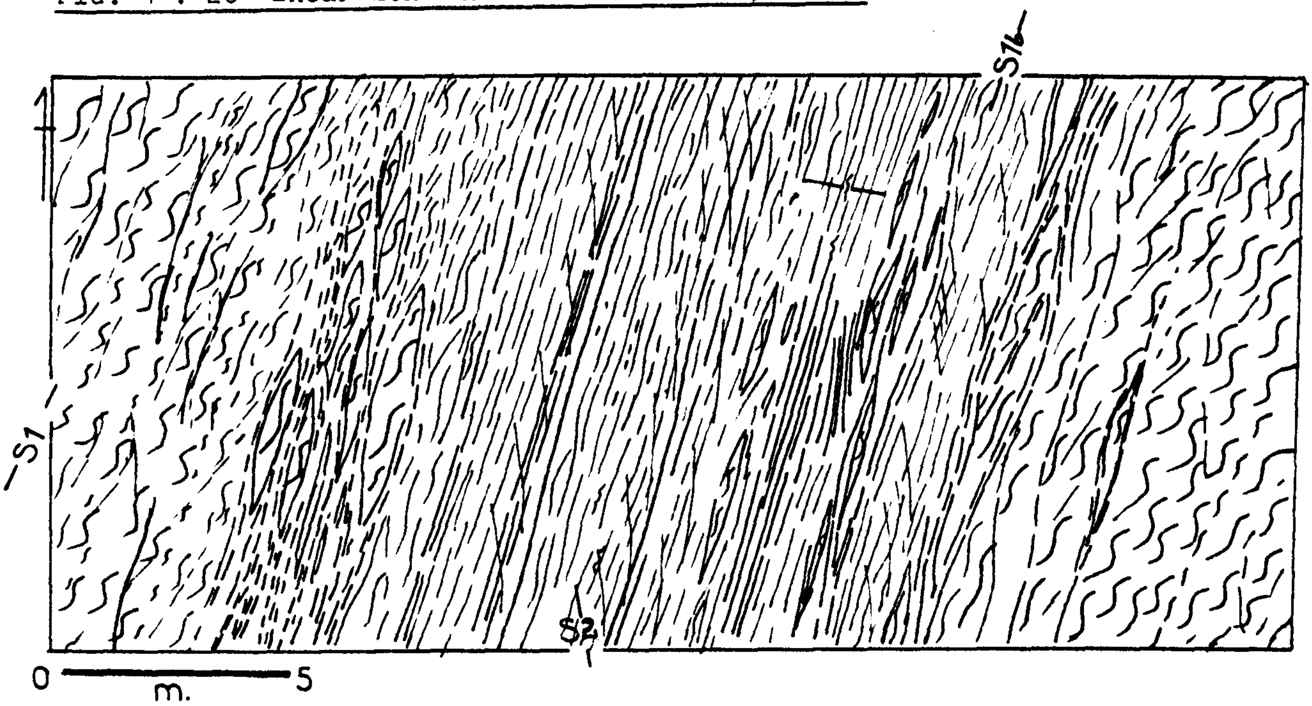
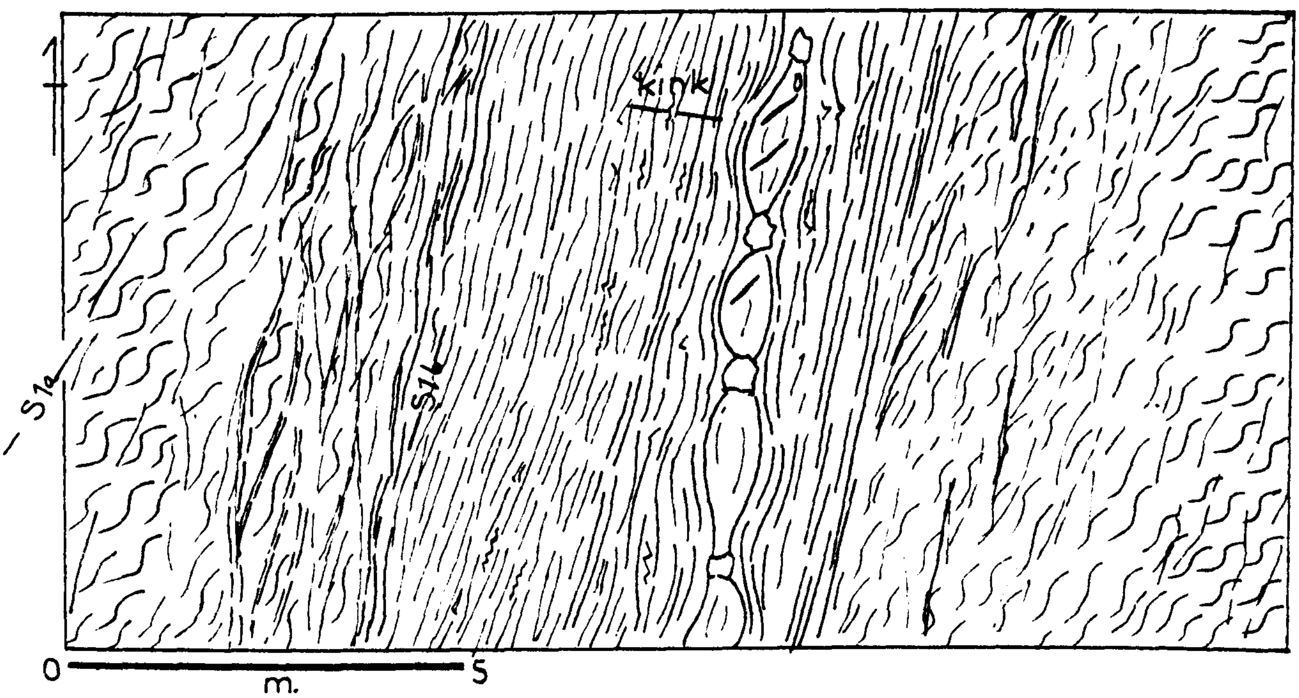


FIG. 4 : 21 Shear zone in the Gabbro Component.



Sketches to show the main features developed in the shear zones.
The shear zones are characterised by the progressive development of the S1b foliae, elongate gneissose pods denote a lozenge fabric and indicate areas of high and low strain. The S1a gneissose foliation may rotate into the plane of the S1b foliation. S1b is best developed in the central part of the shear zone but pods of gneiss may be preserved. Kink bands and a later S2 crenulation fabric occur in the finely foliated mylonites.

Fig. 4:22 Plagioclase microstructure in the gabbro component, Moulin de la Rive Orthogneiss Complex, Pors Rodou

Plagioclase grains are frequently rounded, with modification of the grain by rim recrystallization. Fractured grains indicate brittle deformation of the feldspars. S_{1b} trends left to right across photograph. Section is cut perpendicular to lineation (Y:Z plane).

Scale: x16 XPL

Fig. 4:23 Plagioclase microstructure in the tonalite component Moulin de la Rive

This large albite grain displays micro-boudinage, subsequent mineralization in the fractures is commonly quartz, calcite or chlorite. The grain is orientated in the plane of the S_{1b} foliation and is enveloped by chlorite-rich foliae.

Scale: x16 XPL

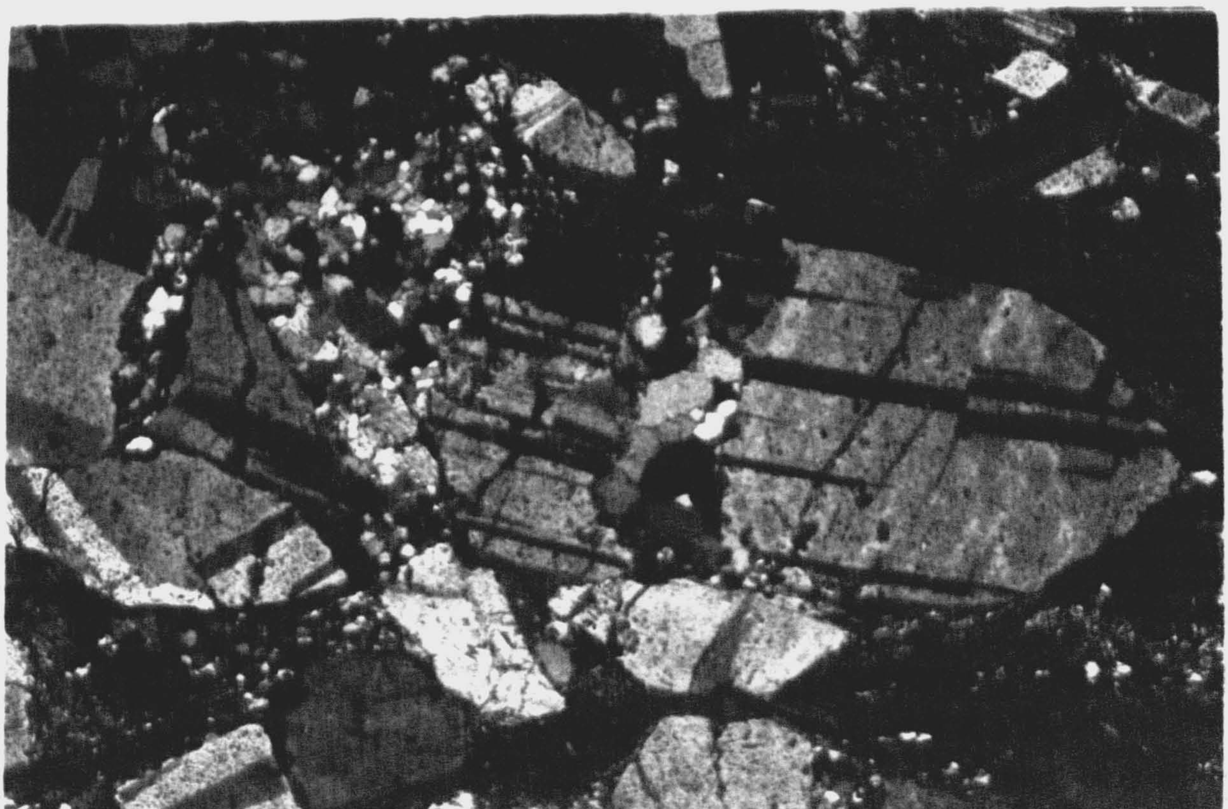


Fig. 4:24 Deformed aplite sheet within a shear zone, Moulin de la Rive Orthogneiss Complex, E of Pors Rodou

The aplite sheet indicates extension within a NE-SW (x:y) plane, parallel to the S1b mylonitic banding developed in the gabbro component. Tension gashes are developed in the aplite sheet and possess quartz infill. Kink-bands are developed at 060^{o}-070^{o}.

Scale: Hammer handle 36 cm

Fig. 4:25 Mylonite texture, Moulin de la Rive Orthogneiss Complex

Large fractured albite grain with fracture infill and anastomosing S1b foliae.

Scale: x16 XPL

Fig. 4:26 Mylonite texture, Moulin de la Rive Orthogneiss Complex

Fractured plagioclase grains with poorly developed S1b foliation in a shear zone.

Scale: x16 XPL

A major retrogressive metamorphic episode is recognised in the Moulin de la Rive Orthogneiss Complex. The complex has undergone lower greenschist facies metamorphism,but assemblages may vary within the complex according to the degree of deformation.

In the gabbro component,primary clinopyroxene has been altered to amphibole,which may retain the original sub-ophitic texture in low strain domains. In shear zones the amphibole is frequently replaced by chlorite. In the tonalite (and associated diorites) a compositional change in plagioclase composition can be related to the shear zone development. Oligoclase may occur in low strained areas,and albite may be developed at the expense of the more calcic plagioclase in the shear zones. The assemblage of the low-strained areas may be oligoclase + biotite + chlorite + epidote + quartz + white mica,with hornblende often replaced by aggregates of the mafic components and,in the shear zones,albite + epidote + chlorite + white mica + quartz.

(2) THE D2 EPISODE

Although the basic dyke suite post-dates the D1 mylonitic banding, the dykes are themselves foliated as a result of a subsequent deformation, termed D2. This later fabric-producing event is recognised within the orthogneiss complex and the LSB as a crenulation foliation,that deforms the mylonitic and gneissose banding in restricted areas and lithologies (see discussion in Chapter 5). This later fabric is termed S2.

In the basic dykes the S2 foliation is variably developed and is usually most obvious at dyke margins (Figs. 4:14 and 4.14B). The foliation is defined by the parallel alignment of phyllosilicate minerals, principally chlorite.

In addition, kink-bands are commonly developed in the finely schistose mylonites (Fig. 2:24). They are orientated in conjugate sets at c. 130° (SE-NW) and c. 060° (NE-SW) and deform the S1b mylonite banding and the S1c shear-band structures. The kink-bands may be related to the S2 foliation or post-date this fabric. The kink-bands are open to tight chevron structures and are commonly fractured in the hinge area, indicating brittle deformation.

(3) SUMMARY

Two fabrics, termed S1a and S1b, have been discussed in this chapter. S1a is a gneissose fabric developed throughout the orthogneiss complex, and S1b is a mylonitic fabric developed in restricted but frequent shear zones that represent zones of high strain. The gneiss fabric rotates into the mylonite fabric, and it is considered that the mylonites represent localised zones in which significant strain softening has occurred. The largest of the shear zones, the Locquirec Shear Belt (LSB), is c. 1.5 km wide (discussed in Chapter 5).

The two fabrics are believed to have formed during the same deformation episode, rather than during two separate events, and the fabrics may have developed sequentially or simultaneously during heterogeneous deformation. Regionally, there is no evidence to support the existence of two separate deformation episodes prior to the emplacement of the basic dykes. The development of mylonites in shear zones, during single stage heterogeneous deformation, has been noted in other gneiss complexes (White et al. 1980; Tullis et al. 1982; Vernon et al. 1983).

A fabric labelled S1c is developed in the highest deformed mylonites (discussed in Chapter 5) that is related to the formation of the mylonites during the D1 episode. D1 therefore, encompasses the S1a, S1b and S1c foliations,and all are related to a single deformation episode.

The shear zones developed in order to accommodate the bulk regional strain, and these structures, hitherto unrecognised in the orthogneiss complex, are of fundamental importance in the structural history of both the Petit Trégor and the Trégor further east.

More brittle events have occurred in some lithologies,in order to accommodate the imposed strain. In the granite component and the tonalite component (to a lesser extent) small irregular crush zones or micro-shears are developed. Related to these are tension gashes which may have formed syn- or post-D1.

The D2 episode resulted in further deformation of the orthogneiss complex with the development of a crenulation fabric and kink-bands in the schistose mylonites. The well-developed foliation in the metabasic suite is a product of the D2 deformation.

The sense of movement depicted by the two foliations S1a and S1b is sinistral. Extension lineations within the shear zones recorded by the elongation and boudinage of quartz + feldspar aggregates are consistent whereby the plunge is moderate at c. 42^{o} to the NE. The Moulin de la Rive Orthogneiss Complex, therefore, moved upwards relative to the Brioverian succession in the eastern part of the Petit Trégor. The same sense of movement is recorded for the Carantec Shear Belt separating the medium-high grade St. Pol-de-Léon Complex and the low-grade Morlaix Basin sequence.

(D) COMPARISON OF THE MOULIN DE LA RIVE ORTHOGNEISS COMPLEX WITH NEARBY PLUTONIC COMPLEXES

(1) INTRODUCTION

Within the study area and immediately adjacent to the Petit Trégor there are two other heterogeneously deformed, pre-Hercynian Granitoid Complexes. These are the Perros-Guirec Granitoid Complex of the northern Trégor (Auvray 1979) (Fig. 5:36) and the Gneiss Granitique d'Île Callot, of the eastern Pays de Léon (Chapter 2, this thesis). Both are similar, in part, to the Moulin de la Rive Orthogneiss Complex. Several localities occur within these adjacent complexes in which critical field relationships show certain similarities with feature of the Moulin de la Rive Orthogneiss Complex.

(2) PORZ ROLLAND, EAST OF PLOUMANAC'H, TRÉGOR

At this locality the Gneiss de Trébeurden (Auvray op. cit.) is truncated by the Hercynian Granite de Ploumanac'h (Barriere 1976). This granite is dated as 303 m.y. (Vidal 1976). The Gneiss de Trébeurden is composed of two components; a series of agmatites (mixed intermediate and granitic rocks) and more abundant granites, which are petrographically similar to the granite component of the Moulin de la Rive Orthogneiss Complex. A well-developed foliation is present within both components at the boundary with the Ploumanac'h Granite. The intensity and development of the foliation decreases rapidly eastwards until foliated granite is reached some 300 m from the boundary with the Hercynian granite. The granite, termed the Granite de Perros in this thesis, (c.f. Granite de Port Blanc, Auvray 1979) is truncated by a large number of NE-SW trending, 5-15 m thick basic dykes (Fig. 4:28).

(3) PLAGE DE PORZ-MABO SOUTH-WEST OF TRÉBEURDEN, TRÉGOR

At this locality there is a transition southwards from strongly schistose Blastomylonites de Trébeurden (Barriere op. cit.) into progressively less deformed Gneiss de Trébeurden which is, in turn, in gradational contact with unfoliated Granite de Perros. The Gneiss de Trébeurden is variable in its nature and a number of components make up the gneiss outcrop. Deformation of the gneiss is markedly heterogeneous and mylonite schists are developed within narrow shear zones.

(4) PTE. DE BIHIT, SOUTH-WEST OF TRÉBEURDEN, TRÉGOR

The heterogeneous nature of the deformation affecting the Granite de Perros can be examined between the Pte. de Bihit and Trébeurden plage. At the Pte. de Bihit, mylonites occur, which are similar to those of the LSB. These mylonites pass gradationally northwards into lesser deformed rocks (the Gneiss de Trébeurden) within which exist shear zones with a NE-SW trend. Northwards towards Crec'h Hery, south of Trébeurden, and adjacent to Ile Milliau, due west of Trébeurden, recognisable unfoliated Granite de Perros crops out.

(5) PLAGE DE TRÉSTIGNEL, PERROS GUIREC

At this locality, host unfoliated granite, the Granite de Perros, is injected by a porphyritic microgranite. The contacts are lobate, and xenoliths of the older granite component are held within the intrusive phase which possesses a strong flow banding, that is particularly well-developed at the margins of the sheet-like intrusions (Fig. 4:27). The lithologies are undeformed. These two lithologies are very similar to components of the Moulin de la Rive Orthogneiss Complex, where it can be argued that similar relationships exist, but in a much higher-deformed state.

Fig. 4:27 Intrusive relationships, Plage de Tréstignel, Perros-Guirec

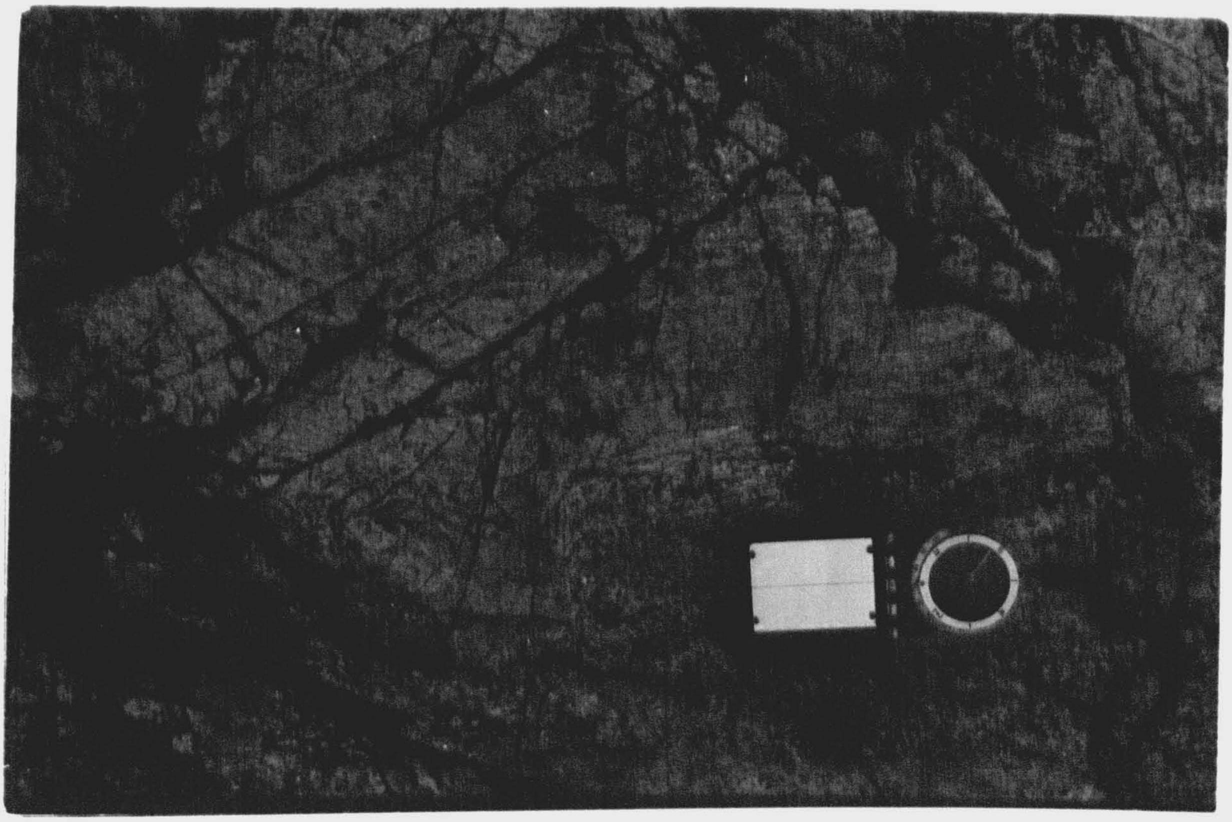
Host Granite de Perros has been truncated by a porphyritic micro-granite with well-developed flow banding. Both components are undeformed and are petrographically similar to the granite and porphyritic microgranite components of the Moulin de la Rive Orthogneiss Complex.

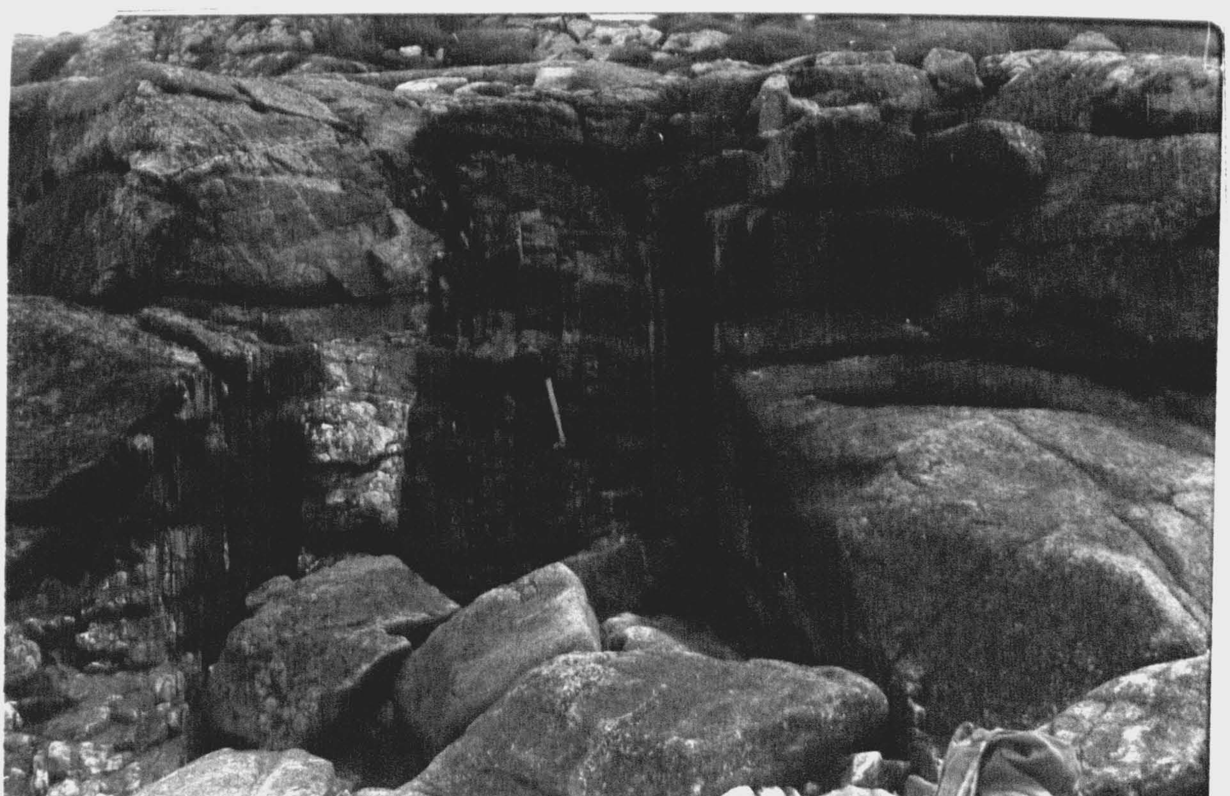
Scale: Compass 18 cm

Fig. 4:28 Basic sheet truncating the Granite de Perros, Perros-Guirec

Host Granite de Perros has been truncated by numerous basic dykes which are considered to be of the same generation as the metabasic sheets within the orthogneiss complex.

Scale: Hammer handle 36 cm





The granitic lithologies above are all cut by a series of basic dykes (Fig. 4:28) that are equated with the greenstone dykes in the Moulin de la Rive Orthogneiss Complex.

(6) DISCUSSION

At all the localities within the western Trégor cited above,a single parent lithology is present,termed the Granite de Perros. This lithology contains enclaves of older material that e.g. at Porz Mabo is of basic composition. When traced westwards from Plage de Tréstignel, the Granite de Perros becomes heterogeneously deformed so that a transition is commonly seen from unfoliated host material into gneissose material and,in restricted shear zones,mylonites are developed.

Some analogies can be drawn between the Perros-Guirec Granitoid Complex and the Moulin de la Rive Orthogneiss Complex. Both complexes can be seen to be made up of a number of components,with granite being the dominant lithology in the Trébeurden-Perros-Guirec area. Heterogeneous strain is observed in both complexes, and a series of basic sheets cuts both complexes. These always post-date the mylonite formation.

The Gneiss Granitique d'Île Callot was discussed in Chapter 2. A number of dominantly granitic components make up this gneiss unit,and one generation of basic sheets (now amphibolites) also truncate the granitic gneiss. There are,therefore, similarities with the Moulin de la Rive Orthogneiss Complex. The mineralogy of the granite component of the Moulin de la Rive Orthogneiss Complex, the granite component of the Gneiss de Trébeurden,and the dominant component of the Gneiss Granitique d'Île Callot is broadly similar. A difference is that the rocks of the eastern Pays de Léon are at higher metamorphic grade than rocks in the Baie de Lannion area and the structural sequence is somewhat different. However, the Perros-Guirec Granitoid Complex and the Moulin de la Rive

Orthogneiss Complex share a common structural history and both truncate Brioverian formations (discussed in Chapter 3).

(E) GEOCHRONOLOGY OF THE MOULIN DE LA RIVE ORTHOGNEISS COMPLEX

Auvray (1979) and Auvray et al. (1980a) have produced a stratigraphy for the Trégor and Baie de Lannion areas that involves an ancient basement complex,represented by the Moulin de la Rive Orthogneiss Complex (Orthogneiss de Morguignen sensu Auvray op. cit.) and the Gneiss de Trébeurden and Orthogneiss de Port Beni. In order to validate their arguments they have presented geochronological data,using material from the three orthogneiss units. In this section the most pertinent points of Auvray's work will be examined with regard to establishing the true age of the Moulin de la Rive Orthogneiss Complex and the rocks of the Locquirec Shear Belt. In addition,other geochronological ages are given for the Perros-Guirec Granitoid Complex that help to establish the age of the Orthogneiss Complex.

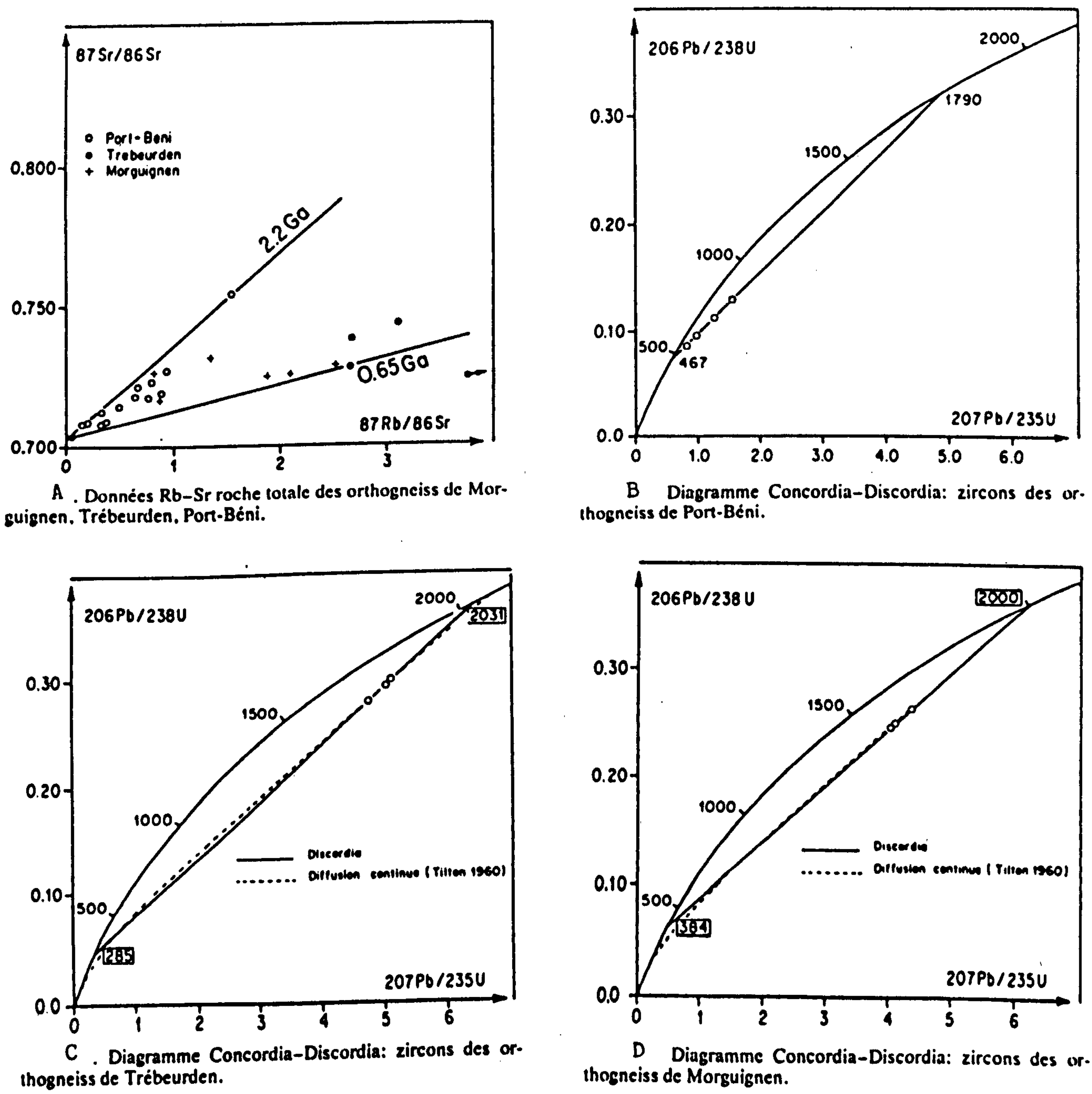
It has been stated earlier (Chapter 3) that the orthogneiss complex is considered to have been emplaced into rocks assigned to the Brioverian and cannot, therefore, represent true Lower Proterozoic or Icartian basement as proposed by Auvray and previous authors. (However, this does not exclude components of the complex from being rafts of older material that have been reworked and incorporated within the complex).

Auvray et al. (op. cit.) derive two isochrons using the Rb-Sr whole rock method,with points showing a wide scatter between 650 m.y. and 2200 m.y. They achieve their interpreted results using the U/Pb method on zircons and obtain data for the three orthogneisses between 1800 m.y.-2000 m.y. The concordia - discordia diagrams are reproduced (Fig. 4:29). The upper intersections show a well-defined age but,as the authors state, the lower intersections of the two discordia lines are poorly aligned with the concordia line. This poor alignment is due to pertubations of the U-Pb systems that create discordances in zircon, which may be due to either continuous lead diffusion (Tilton 1960) or episodic lead loss. Combined diffusion - episodic models have been proposed, together with uranium gain (Davis et al. 1968) to account for discordant U-Pb ages. Scharer and Allegre (1982) prefer a continuous lead diffusion model to account for lead loss in a quartz-fayalite syenite body,in which no metamorphic events are recorded post-crystallisation of zircon crystals.

In Northern Brittany, however, episodic earth movements have occurred and so, in simple terms, an episodic model is preferred to account for the lower intersection and lead loss. The Moulin de la Rive Orthogneiss Complex is demonstrably metamorphosed and this is equated with the Gneiss de Trébeurden (but not the Port-Beni Gneiss). The lower intersection of 384 m.y. for the Moulin de la Rive Orthogneisses may accord to an early Hercynian metamorphic event (Fig. 4:29). The Gneiss de Trébeurden gives a lower intersection of 285 m.y. which may represent a late Hercynian event. An interesting observation as to the lower intersection of the Orthogneiss de Port-Beni data is that the 467 m.y. date may accord to a late Cadomian event. Field relations support metamorphic events that would account for the lower intersection age, whereby the Port Beni migmatite gneisses are held within an undeformed porphyritic microgranodioritic host, see below.

In determining the true age of the Moulin de la Rive Orthogneiss Complex the upper intersection (that gives a date of 1800-2000 m.y.) must be carefully examined,as the whole stratigraphy of the Petit Trégor and Trégor largely rests on this data. The orthogneiss complex has been seen to be made up of several components and Auvray et al. (op. cit.) fail to give a description of the rock type they consider to represent the whole complex. In interpreting the significance of the upper inter-

FIG. 4 : 29 ; Rb/Sr and U/Pb Geochronology , from AUVRAY et AL (1980)



A . Données Rb-Sr roche totale des orthogneiss de Morguignen, Trébeurden, Port-Béni.

B Diagramme Concordia-Discordia: zircons des orthogneiss de Port-Béni.

C . Diagramme Concordia-Discordia: zircons des orthogneiss de Trébeurden.

D Diagramme Concordia-Discordia: zircons des orthogneiss de Morguignen.

A) Rb-Sr whole rock isochrons for all three orthogneisses. The points show a wide scatter, 650-2200 M.y. If the Port Beni material is ignored the points lie close to the lower 650 M.y. isochron.

B) U-Pb. Orthogneiss de Port Beni. Thoe lower intersection may accord to a very late Cadomian event.

C) U-Pb. Orthogneiss de Trebeurden. The lower intersection corresponds to the emplacement of the nearby Granite de Ploumanac'h.

D) U-Pb. Orthogneiss de Morguignen. The lower intersection corresponds to a Bretonic deformation episode.

section (the two discordia lines with the concordia) the authors cite only one possibility. That is,that the U/Pb method gives an age of emplacement of the three orthogneiss units in the age range 1800-2000 m.y. Three options are cited here,that may also account for the age date obtained, the first is that given by Auvray et al. (op. cit.):-

1. The zircons may be of magmatic origin and correspond to the emplacement of the intrusion.
2. The zircons may be xenocrysts, either all or part of them, within the host rock.
3. The zircons may be derived from some lithology other than those of the main components of the three sampled orthogneisses.

It is agreed that the zircons may represent original c. 2000 m.y. old crystals but they are either xenocrysts (argument 2) or they are held in a different lithology to that which makes up the main part of the complex (argument 3). The following localities and field relationships are described that support arguments (2) and (3),and thus the age of the Moulin de la Rive Orthogneiss Complex is somewhat younger than considered by Auvray et al. (op. cit.). It should be noted that, although the present author has not mapped in the Trégor, several localities have been examined with colleagues (Roach, Bevins, Lees and Daly) to determine critical relationships between rocks assigned to lower Proterozoic basement and the Perros-Guirec Granitoid Complex:-

1. <u>Moulin de la Rive</u>: The augen gneiss component is the earliest component of the orthogneiss complex, this lithology if sampled may contain zircons of 2000 m.y. in a host that may represent a raft of considerably older true basement within a younger host. Field relationships support this argument (Map 4).

2. Port Beni (8 km NE of Treguier, Trégor): The Port Beni gneisses are foliated, migmatitic augen gneisses that are fundamentally different to granitic rocks of the Perros-Guirec Granitoid Complex assigned to the Cadomian (Auvray 1979). Mafic sheets are associated with the augen gneiss host and both units are strongly tectonised. The gneisses occur as separate enclaves or rafts (∿50x20 m max.) held witnin an unfoliated host,which Auvray (op. cit.) labels the Microgranodiorite de Pleubian. This is one of the many components of the Perros-Guirec Granitoid Complex of the northern Trégor (Fig. 5:36).

3. Ile Instan (East of Port Blanc): At this locality highly deformed, biotite-rich metatexites (high-grade metasediments) are associated with banded amphibolites. These are assigned to the Port-Beni Gneisses and occur as isolated enclaves within undeformed Microgranodiorite de Pleubian.

The Port-Beni Gneisses show a complex metamorphic and deformational history, being characterised by augen gneisses of granodioritic composition, with metaxites and meta-basic sheets also present. These gneisses have been equated with the Icart Gneisses on Guernsey, dated at 2018 ± 15 m.y. (Calvez and Vidal 1978), and are considered to represent true Lower Proterozoic basement that is preserved within the Perros-Guirec Granitoid Complex.

The similarities between the augen gneiss component of the Moulin de la Rive Orthogneiss Complex and the Lower Proterozoic Port-Beni Gneisses may indicate that the orthogneiss complex is in part composed of true Pentevrian basement; this part being represented by the augen gneiss component which was incorporated into a younger Cadomian multi-component complex in a similar setting to that described above.

Field relationships in the localities previously cited and also discussed in Chapter 5, part (D), indicate that the Moulin de la Rive Orthogneiss Complex is similar to the Perros-Guirec Granitoid Complex (and both may be part of the same batholithic mass) in that:-

1. Relict Icartian/Pentevrian basement is caught up as rafts within the younger igneous complexes at e.g. Moulin de la Rive, Port Beni and Île Instan.
2. The complexes are multi-component with a high proportion of granite and porphyritic microgranite.
3. Both complexes are truncated by a series of basic dykes.
4. Heterogeneous strain is concentrated in zones, particularly near or at the margins of the complexes.

The Moulin de la Rive Orthogneiss Complex differs from the Perros-Guirec Granitoid Complex in two significant ways; firstly, it contains a higher proportion of components that are meta-basic to intermediate in composition; secondly, the lithologies are generally more highly deformed and possess a penetrative gneissose fabric, and are cut by frequent shear zones in which mylonites occur.

Geochronological ages given for the emplacement of the multi-component Perros-Guirec Granitoid Complex are given in Table 4:2. The most reliable dates are those of Adams (1967), Auvray (1979) and Vidal (1980). Their dates point to an emplacement period of the complex at between c. 690 and 530 m.y. and therefore correspond to the late Precambrian-Lower Palaeozoic Cadomian Orogeny.

There has been much resetting of the mineral ages (principally during the Hercynian) and this is indicated by the K/Ar biotite and whole rock ages (Leutwein et al. 1968), and also by the episodic lead loss indicated by the lower concordia-discordia intersection in the U/Pb system (Auvray et al. 1980a). For example, the K/Ar whole-rock date of

ADAMS 1967	Gneiss de Trébeurden	Rb/Sr whole-rock	630 ± 40 m.y.
	Gneiss de Trébeurden	Rb/Sr biotite	690 ± 50 m.y.
	Granite de Perros-Guirec	K/Ar hornblende	670 ± 17 m.y.
	Granite de Perros-Guirec	Rb/Sr biotite	623 ± 17 m.y.
	Granite de Perros-Guirec	K/Ar biotite	587 ± 14 m.y.
LEUTWEIN ET AL. 1968	Gneiss de Trébeurden	K/Ar whole-rock	355 ± 30 m.y.
	Gneiss de Trébeurden	K/Ar biotite	335 ± 15 m.y.
	Granite de Perros-Guirec	Rb/Sr	420 ± 10 m.y.
	Granite de Perros-Guirec	Rb/Sr	770 ± 40 m.y
AUVRAY 1979	Plutonism du nord du Trégor (granites et granodiorites)	K/Ar hornblende	670 m.y.
VIDAL 1980	Granites de Talberg-Bréhat-Pt. Blanc	Rb/Sr whole-rock	c. 650 m.y.
	Microgranite de Porz Scarf	Rb/Sr	529 ± 24 m.y.
	Granite de Porz Scarf	Rb/Sr	536 ± 16 m.y.

TABLE 4 : 2 PUBLISHED GEOCHRONOLOGICAL DATA FOR THE PERROS-GUIREC GRANITOID COMPLEX, TREGOR

c. 335 m.y. obtained by Leutwein (op. cit.) for the Gneiss de Trebeurden is considered to be the result of a reheating related to the emplacement of the nearby, c. 303 m.y. Granite de Ploumanac'h (Vidal 1979; Barriere et al. 1983).

The Perros-Guirec Granitoid Complex and the Orthogneiss Complex of Moulin de la Rive share a similar geological history and are composed of similar lithological components. The two complexes are considered to be related to the same period of Cadomian magmatism which occurred during the period 690-530 m.y.

(F) CONCLUSIONS

The Moulin de la Rive Orthogneiss Complex is a multi-component intrusive igneous complex related in time to the Cadomian Orogeny. It contains xenoliths of the Lower Proterozoic basement, possibly represented by the augen gneiss component. The complex is comparable with the Perros-Guirec Granitoid Complex of the Trégor, and is also possibly related to the Gneiss Granitique d'Île Callot of the St. Pol-de-Léon Metamorphic Complex.

The Orthogneiss Complex has been heterogeneously deformed during two major episodes. D1 resulted in the production of two fabrics S1a and S1b. S1a is a penetrative gneissose foliation and S1b is a mylonitic banding developed in shear zones. The dominant trend of the D1 foliations is NE-SW.

A series of basic sheets were injected into the complex post-D1. The dykes and host orthogneisses were further deformed during D2 which resulted in a foliation in the metabasic dykes and a crenulation fabric and kink-bands in the orthogneiss.

The largest shear zone recognised in the orthogneiss complex is the Locquirec Shear Belt (LSB), which is developed at the eastern margin of the complex and also involves Brioverian lithologies. The origin of the Pors Rodou Breccias is problematical, but they are considered to be related to the Poudinques de Locquirec and are discussed further in Chapter 5.