"THE SOLID GEOLOGY OF THE AREA BETWEEN BINIC AND BREHEC, CÔTES DU NORD, FRANCE."

A thesis

VOL 1

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ABSTRACT

The area mapped is situated on the west side of the Baie de Saint Brieuc, Côtes du Nord, France. It is bounded by the towns of Binic, Bréhec, Lantic and Plehedel. Rocks of Pentevrian, Brioverian and post Brioverian age were recorded. The Pentevrian, which was previously unreported, is composed of the pelitic and semipelitic Port Goret gneisses, the metasediments and metavolcanics of the Plouha Series and the late Pentevrian intrusion, the Port Moguer tonalite. The Port Goret gneisses and the Plouha Series had undergone at least 4 major fold phases and 4 regional metamorphic events prior to the Brioverian sedimentation. Locally the structural and metamorphic histories are found to be more complex. However the Port Moguer tonalite has a relatively simple structural history.

Two sequences of Brioverian age are recorded, the Binic-Bréhec Series and the Palus plage metasediments and metavolcanics. The sedimentology of the former has been studied and it is conluded that they are a sequence of distal turbidites. The latter are composed of pelites, psammites and acid volcanics and they display an unconformable relationship with the Port Goret gneisses. The original surface of unconformity may not be preserved. The Brioverian and locally the Pentevrian have been affected by the late Precambrian Cadomian orogeny, which has produced 3 main phases of folding and up to five phases of metamorphism. The grade of any one metamorphic event varies throughout the area. Late Cadomian brittle structures are recorded.

The Port Goret gneisses are intruded by a post-Brioverian, syn-Cadomian composite norite, hornblende-ferrohypersthene gabbro and quartz-

hornblende gabbro intrusion, the Saint Quay intrusion. Petrological and petrochemical studies indicate that this body was formed by two intrusive phases, the second of which was more differentiated than the first.

The regional significance of this research has been discussed.

CHAPTER I.

INTRODUCTION

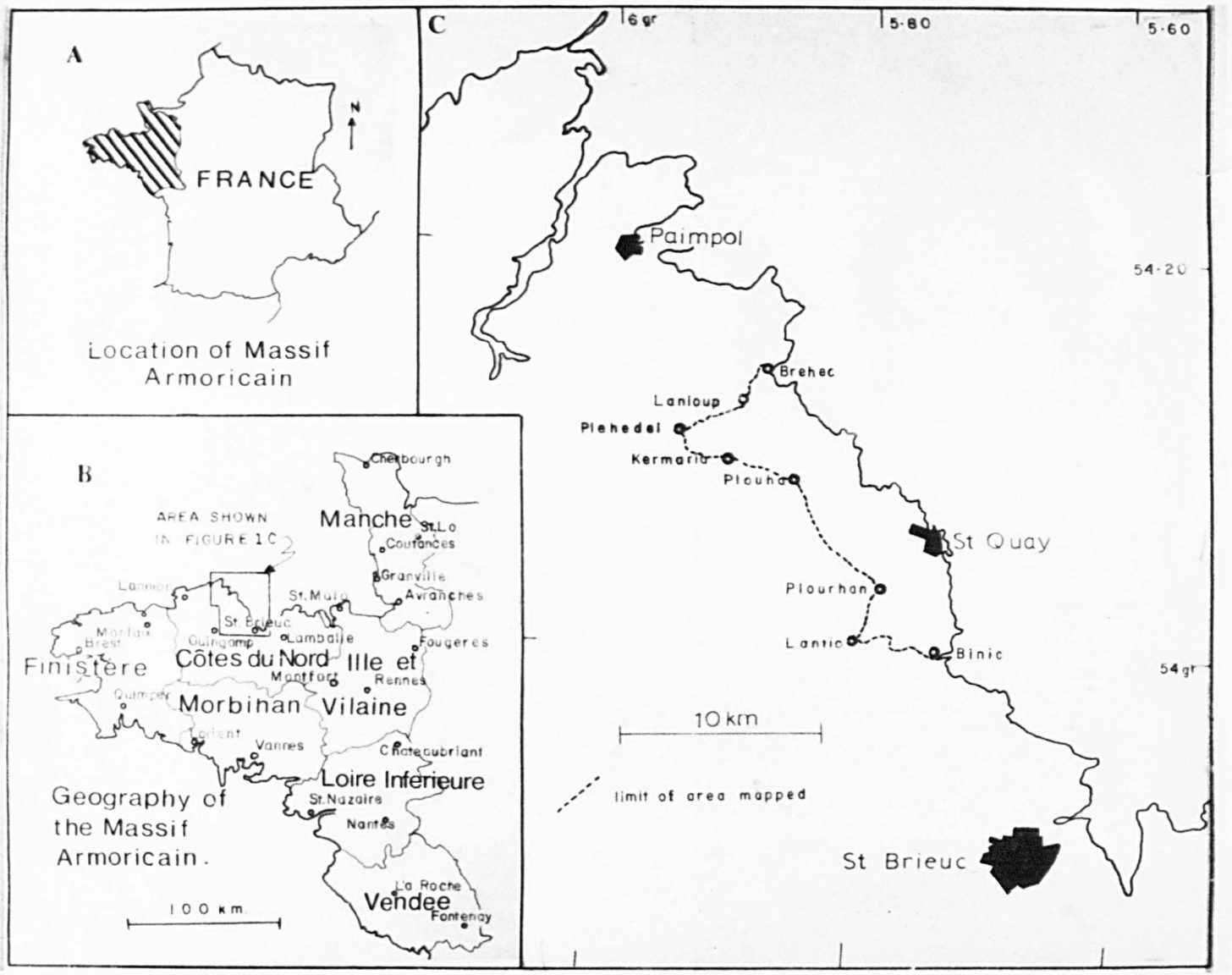
A
FRANCE
N
Location of Massif Armoricain
B
AREA SHOWN IN FIGURE 1C
Cherbourgh
Manche
St.Lo
Coutances
Granville
Avranches
St.Malo
Lannion
St Brieuc
Morlaix
Brest
Guingamp
Lamballe
Fougeres
Finistère
Côtes du Nord
Ille et
Montfort
Rennes
Quimper
Morbihan
Vilaine
Lorient
Vannes
Chateaubriant
Loire Inferieure
St.Nazaire
Nantes
Geography of the Massif Armoricain.
La Roche
Vendee
Fontenay
100 km
C
6 gr
5·80
5·60
54·20
54 gr
Paimpol
Brehec
Lanloup
Plehedel
Kermario
Plouha
St Quay
Plourhan
Lantic
Binic
St Brieuc
10 km
limit of area mapped

Figure 1.1. Map showing A) the location of the Armorican Massif (patterned), B) the geography of the Armorican Massif, C) the location of the area mapped. After the Michelin Carte de la France.

A. Location of area and preliminary statement

1. Location of area:

The area studied is situated on the western side of the Bay of Saint Brieuc, Côtes du Nord, Brittany, France. It is bordered on the coast by the towns of Binic (WU 135833)[1] to the south and Bréhec (WU 038974) to the north. The western inland margin is marked by the towns of Kerlidic (WU 008948) to the north, Plouha (WU 054917), Plourhan (WU 097867) and Lantic (WU 086838) to the south. (Figure 1.1). The are occupies some 70 sq. km. The land is generally flat lying and has an altitude of 60 to 80 m. except near the coast where it is deeply dissected by river valleys. The land rises steeply from the coast which is often comprised of cliffs of 10 to 40 m. in height.

The various lithologies are well exposed along the coast where all the detailed studies were carried out. Inland the exposure is very poor; In some areas there are less than ten exposures per square kilometre and indirect evidence has had to be used in the mapping of certain boundaries.

The area is comprised of rocks of a Precambrian age, except around Bréhec where an area of 1.2. sq. km. is occupied by sequence of red beds that have been variously assigned to different systems withing the Palaeozoic. (Figure 1.2). The rocks of a Precambrian age can be attributed to both the Pentevrian[2] and Brioverian[2], and all can be shown to have been affected by the Cadomian[2] orogeny.

[1]NOTE: All map references are given using the 1000 m. U.T.M. grid, zone 30, international spheroid and are taken from the "Carte de France au 50.000^{e} (type M)" sheet numbers: VIII-15 and IX-15.

[2]Vide infra.

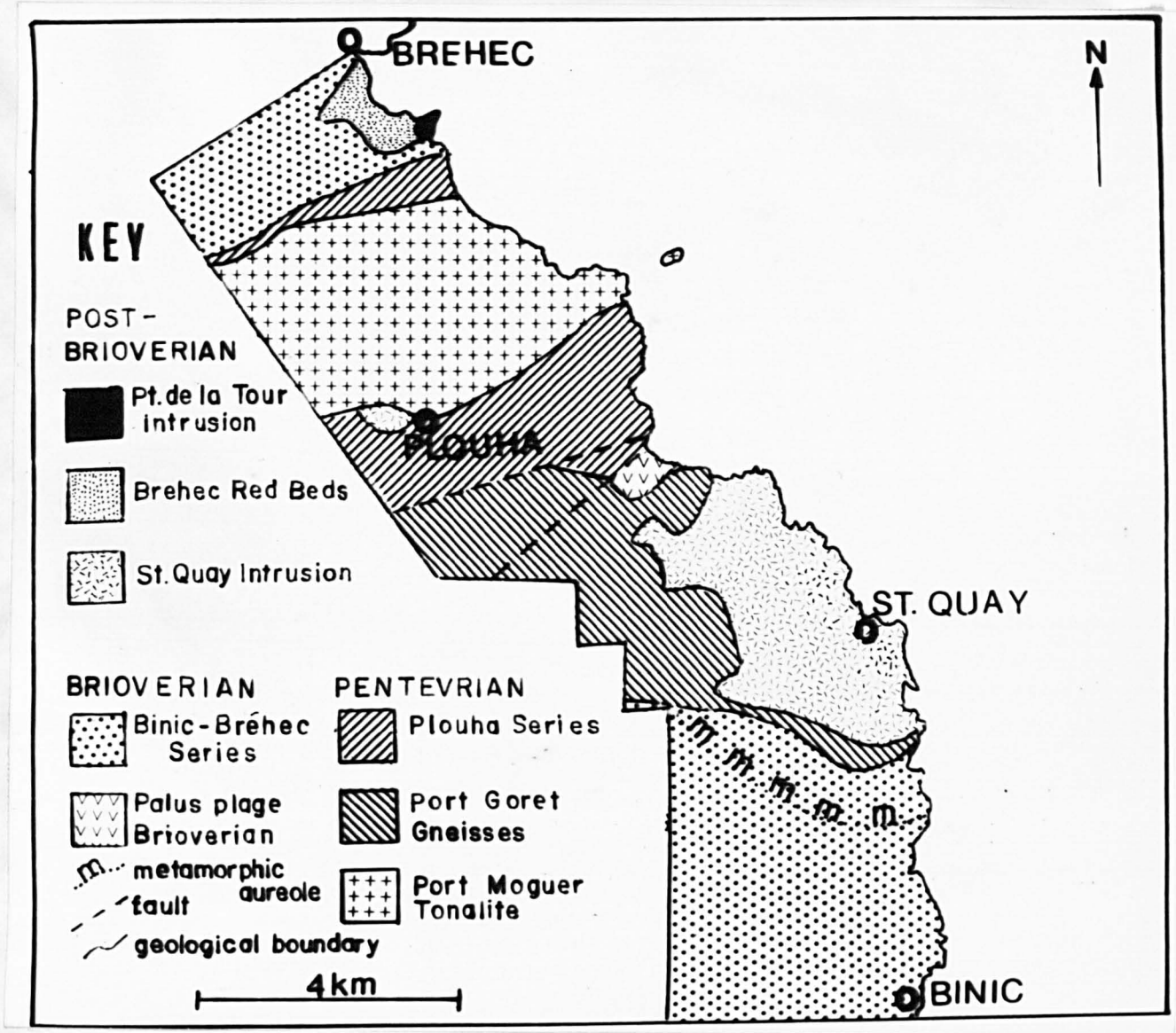
BREHEC
N
KEY
POST-
BRIOVERIAN
Pt. de la Tour intrusion
Brehec Red Beds
St. Quay Intrusion
PLOUHA
ST. QUAY
BRIOVERIAN
Binic-Bréhec Series
Palus plage Brioverian
metamorphic aureole
fault
geological boundary
PENTEVRIAN
Plouha Series
Port Goret Gneisses
Port Moguer Tonalite
4km
BINIC

Figure 1.2. Sketch geological map of the area studied.

2. Preliminary Statement:

Any study of the Precambrian rocks of the Armorican Massif is made difficult by the fact that there are no clearly defined criteria which may be used to assign any given sequence of rocks to either of the two fundamental Precambrian units, unless the existence of a local unconformity can be established. The matter is further complicated as the Precambrian geology of the Armorican Massif is only sparsely reported in the English language journals (e.g. : Barrois 1898; Bigot 1930; Shelly 1966; Adams 1967; Bradshaw et al. 1967; Rast and Crimes 1969; Bishop et al. 1969; Brown et al. 1971; Roach et al. 1972),,the bulk of the information being contained in numerous articles (approximately two hundred) that have appeared in the French literature since 1886. It is therefore necessary that before a study can be carried out on these rocks a clear statement as to the significance of the terms employed should be made.

In view of these difficulties and the fact that some of the results presented below may help to clarify the nomenclature used, a brief review of the history of research and the present state of opinion concerning the Precambrian geology of the Armorican Massif will be given in the following section.

B. Review of the geology of the Armorican Massif.

1. Regional setting:

The Armorican Massif is a large area of pre-Mesozoic rocks that cover the regions of Lower Normandy and Brittany, which are made up of the Departments of Calvados, Manche, Orne, Mayenne, Ille-et-Villaine, Cotes du Nord, Finistere, Morbihan, Loire Inferieur, Sarth, Maine et Loire and Vendée (Figure 1.1). The area covered is about the same size as Wales, extending approximately 400 km. E.-W. and a similar distance N.-S. The massif is bounded along its east and southeast margins by the relatively undisturbed Mesozoic sedimentary cover of the Paris and Aquitaine basins, and therefore encompasses one of the largest areas of Precambrian and Palaeozoic rocks in France. Included within this region are the Channel Isles of Jersey, Guernsey, Alderney and Sark, and numerous other small island groups such as the Ecrehous, Minquiers, Chauseys and the Paternosters.

Geomorphologically the region is low lying, consisting of undulating terrain generally less than 100 m. in height, but reaching over 200 m. in parts of north Brittany and Lower Normandy. In some areas (e.g. Manche) partly dissected platforms can be clearly distinguished. The whole region is characterized by an irregular coast line giving excellent cliff and off-shore reef exposures. Inland exposures, however, are not good except along river valleys, which may be locally drowned as in north Finistère.

A simplified geological map of the central and northern parts of the Armorican Massif (Figure 1.3) shows that the region is essentially composed of four units;

(1) Areas of Palaeozoic sediments, occupying synclinal tracts extending in a direction varying from ENE-WSW to ESE-WNW,

(2) Granitic plutons, often aligned in directions paralled to

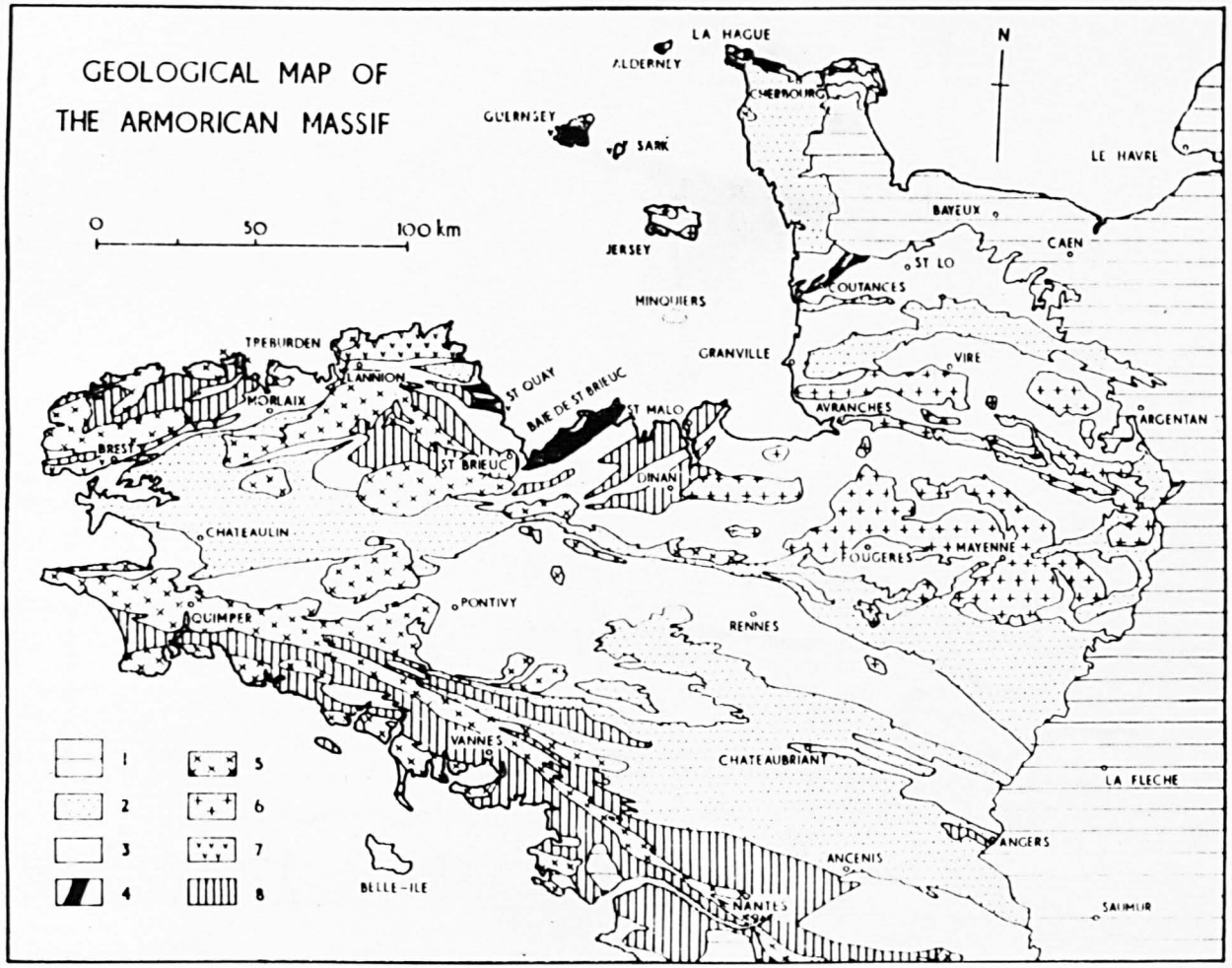

FIGURE 1 — Simplified geological sketch map of the Armorican Massif. 1. Mesozoic and Tertiary. 2. Palaeozoic supracrustals. 3. Brioverian supracrustals. 4. Pentevrian basement. 5. Hercynian granites. 6. Younger Cadomian granites. 7. Older Cadomian granites. 8. Undifferentiated metamorphic rocks.

Figure 1.3. Geological map of the Armorican Massif after Roach et al, 1972.

Table 1.1

THE STRATIGRAPHY OF THE BRIOVERIAN

			Barrois (1895)		Barrois & Pruvost (1930)	
Phyllades de Saint Lô (X) (BRIOVERIAN)	1.	Dalles vertes de Neantes (Xc).	1.	Green shales	1.	Green shales
	2.	Schistes et Conglomerates de Gourin (Xb).	1.	Slates	1.	Slates
			2.	Gourin conglomerates	2.	Slates and quartz-phyllites
			3.	Slates and quartz-phyllites	3.	St. Thurial limestone
			4.	St. Thurial limestone	4.	Slates
			5.	Slates	5.	Gourin conglomerate
	3.	Schistes de Lamballe (Xa).	1.	Slates with Phtanites	1.	Slates with Phtanites
			2.	Slates and greywackes	2.	Slates with greywackes.

the Palaeozoic synclines, and emplaced during either the late Precambrian Cadomian orogeny or the Variscan orogeny,

(3) Late Precambrian Brioverian geosynclinal sediments, which while generally at a low metamorphic grade are locally in a more highly metamorphosed conditions,

(4) Pre-Brioverian crystalline basement, known as the Pentevrian. This last unit covers a small percentage of the Massif compared to the others.

2. History of Research

(a) The Brioverian:

Early studies of Puillon-Boblaye (1827), Bunel (1829-1833) and Dufrenoy (1838) established the existence of two stratigraphical divisions within the Armorican Massif. The lower division comprised a slate-greywacke sequence that was covered unconformably by an upper division, whose base was marked by a horizon of purple conglomerates. Barrois (1895) proposed that the lower division, previously termed the "Schistes de St. Lô" or the "phyllades de St. Lô", actually represented a stratigraphical system which he named the Brioverién[1] and he proposed a stratigraphical column for this system which he later modified (Barrois & Pruvost 1930 and Barrois 1934) (Table 1.1). There was much discussion concerning the age of the Brioverian: De Fourcey (1844), Barrois and Pruvost (1930), Barrois (1934), Pruvost (1949) attributed it to the Cambrian; Herbert (1886) and Bigot (1890, 1922, 1925) felt that it was of Precambrian age; Kerforne (1923) placed it in the Carboniferous; whereas Pruvost (1951) proposed that it was part of a world wide post-Algonkian, pre-Georgian system which he termed the "Infracambrian". The first real evidence for the Precambrian age of

[1](in this work the anglicised versions of Brioverién and Cadomién and Pentevrién i.e. Brioverian, Cadomian and Pentevrian will be used).

Table 1.2

AGE DATES FOR THE POST-CADOMIAN GRANITES

Locality	Method	Rock Type	Author	Age (years x 10^6)
St. Marcan	Rb/Sr-B	granite	Leutwein	580±30
Mt. Dol	Rb/Sr-B	granite	1968	560±30
Athis	Rb/Sr-B	granite	Adams 1967	553±9
Athis	Rb/Sr-B	granite	Graindor &	545±11
Chausey	Rb/Sr-B	granite	Wasserberg	540±11
Vire	Rb/Sr-WR	granite-pegmatite	1962	508±11
Vire	K/A-B	granite	Kaplan &	586±22
Vire	K/A-B	granite	Leutwein	582±1
Vire	K/A-B	granite	1963	581±14
Fougeres	Rb/Sr-B	granite	Leutwein 1968	545±20

The following abbreviations have been used in this table:

B = biotite and WR = whole rock.

Table 1.3

AGE DATES FOR THE CADOMIAN METAMORPHOSED BRIOVERIAN

Locality	Method	Rock Type	Author	Age (years x 10^6)
Lermot	K/A-WR	meta tuff	Leutwein &	530±20
Binic	K/A-WR	meta tuff	Sonet 1965	541
Palus plage	K/A-WR	greywacke	Leutwein, Sonet & Zimmerman 1968	680±20
Pt. Pordic	K/A-WR	quartzite		615±20
St. Clet	K/A-WR	amphibolite		670±20
Erquy	K/A-WR	diabase	Leutwein	670±10
Plessala	Rb/Sr-WR	shale	1968	630±30
Pabus plage	K/A-WR	tuff		680±20
La Bouillie	K/A-WR	shale		600±20
Brest	Rb/Sr (isochron)	gneiss*	Adams in Roach et al 1972	690±40

* early Cadomian intrusion

The following abbreviations have been used in this table:

B - biotite, WR = whole rock.

the Brioverian was given by Bigot (1925) who founded Middle Cambrian fossils in limestones above the purple conglomerates at Carteret, but this did not become universally accepted until the granites that were intruded at the end of a post-Brioverian tectonic episode were shown to have been intruded prior to the Middle Cambrian, which rested unconformably upon them (Chauris, Dangeard, Graindor and DeLapparent 1956, Chauris 1956). This implies that the Brioverian underwent folding, granitic intrusion, uplift and erosion prior to the Middle Cambrian and must, therefore, be Precambrian. This age was later confirmed by isotopic age date studies of these granites (Table 1.2) and the Brioverian (Table 1.3), however, insufficent work has been carried out to enable the exact age of the Brioverian to be determined although Roach et al (1972) have suggested that it was deposited sometime between 900-700 m.y. ago.

The stratigraphy of the Brioverian was greatly advanced by Graindor (1954, 1957) who, after the identification of the conglomerates within the Brioverian as tillites (Wegman, Dangeard and Graindor 1950), proposed a stratigraphic column for the Brioverian (Table 1.4) which has since been generally accepted and extended over the whole of the Armorican Massif by Cogné (1962). Detailed palaeogeographical reconstructions for the Brioverian era have been proposed by Cogné (1962) and Graindor (1964) with the Lower and Middle Brioverian being represented by periods of accumulation of deep water sediments in a geosyncline. This was followed by a period of deposition of 'Flysch' type sediments during the Upper Brioverian subsequent to a regional glaciation that resulted in the formation of terrestial conglomerates on the margins of geanticlinal ridges within the geosycline. This picture is questioned by Dangeard, Doré and Guignot (1961) and Winterer (1964) who point out that the Upper Brioverian tillites are not terrestial and are in fact graded pebbly mudstones that were deposited

Table 1.4

STRATIGRAPHIC COLUMN FOR THE BRIOVERIAN OF CONTENTIN

(after Graindor 1957)

Upper	Étage de la Laize (X3b)	1. shales, ripple-marked sandstones, conglomerates and rare calc-siltstones
	Étage de Granville (X3a)	1. tillites and varves
	Rhyolites de Saint Germain-le-Galliard	
Middle	Étage de Villiers-Fossard (X2b)	1. shales of St. Andre l'Epine 2. felspathic sandstones of Rampan 3. phyllites of Cantilly
	Étage de Landes des Vardes (X2a)	1. Phtanites, graphitic shales and argillites
Lower	Étage d'Erquy (XI)	1. volcanic rocks 2. metamorphic rocks

from turbidity currents. (Winterer op. cit.).

(b) The Cadomian Orogeny:

Bertrand (1921) introduced the concept of the Cadomian orogeny to account for the unconformity between the Brioverian and the purple conglomerates. He defined the Cadomian orogeny as being a late Precambrian orogeny that resulted in the folding, uplifting and peneplanation of the Brioverian. Bertrand's concept of the Cadomian was modified by Graindor (1957, 1965) and Cogné (1962) who proposed that there were in fact two orogenic phases during the Cadomian. The earlier Constantian phase occurred post-Middle Brioverian but pre-Upper Brioverian and was responsible for the development of a regional foliation at depth and granitisation of the Lower Brioverian. The later Viducastian phase occurred at the end of Brioverian sedimentation and caused the development of east-west trending folds throughout the region. The dual nature of the Cadomian arose as a direct consequence of the stratigraphy of the Brioverian, structural evidence for this being given by Roblot (1962) who identifies an intra-Brioverian unconformity at Quibou, Manche and by Jeanette and Cogné (1968) who report a structural discordance between Upper and Middle Brioverian in the Bay of St. Brieuc.

The age of the Cadomian orogeny is best defined by the 690±40 m.y. isochron (Roach et al 1972) obtained for the gneiss de Brest, a granodioritic body that was emplaced prior to the main phase of Cadomian folding (Bradshaw et al 1967). Age dates obtained by other authors for the metamorphosed Brioverian (Table 1.3) and the post Cadomian granites (Table 1.2).indicate that the region did not cool until about 540 m.y. ago and that the post-tectonic granites were intruded between 600 m.y. and 540 m.y. ago.

Table 1.5

AGE DATES FOR THE PENTEVRIAN BASEMENT OF THE ARMORICAN MASSIF

N°	Locality	Method	Rock Type	Author	Age (years x 10^6)
1	Jospinet	K/A-B	diorite gneiss	Adams	536+10
2	Jospinet	K/A-B	diorite gneiss	1967	587+11
3	Pont Neufs	K/A-WR	micaschist		930+10
4	Pont Neufs	K/A-Am	amphibolite		1050+50
5	Pont Neufs	K/A-WR	amphibolite	Leutwein 1968	1010+50
6	St. Alban	K/A-WR	amphibolite		1090+20
7	Lannebert	K/A-Am	amphibolite		1030+100
8.	Pont Neufs	K/A-B	amphibolite-gneiss		1420+20
9.	Jospinet	K/A-WR	diabase		1265+10
10.	Dinard, offshore	Rb/Sr-M	anatexites		510+15
11.	reefs	Rb/Sr-Or	anatexite		1000+30
12	"	Rb/Sr-Or	anatexite	Leutwein	920+20
13.	"	Rb/Sr-Or	anatexite	& Sonet	396+10
14.	"	Rb/Sr-M	anatexite	1965	520+20
15	"	Rb/Sr-B	gneiss		450+15
16	"	Rb/Sr-Or	gneiss		1000+100
17	Port Moguer	Rb/Sr-WR	granite	Leutwein	850+80
18	Port Moguer	K/A-WR	granite	Sonet & Zimmerman 1968	700+50

The following abbreviations are used in the above table:

Am = amphibole, B = biotite, M = muscovite, Or = orthoclase, WR = whole rock. The numbers against each date correspond to those on Fig. 1.4.

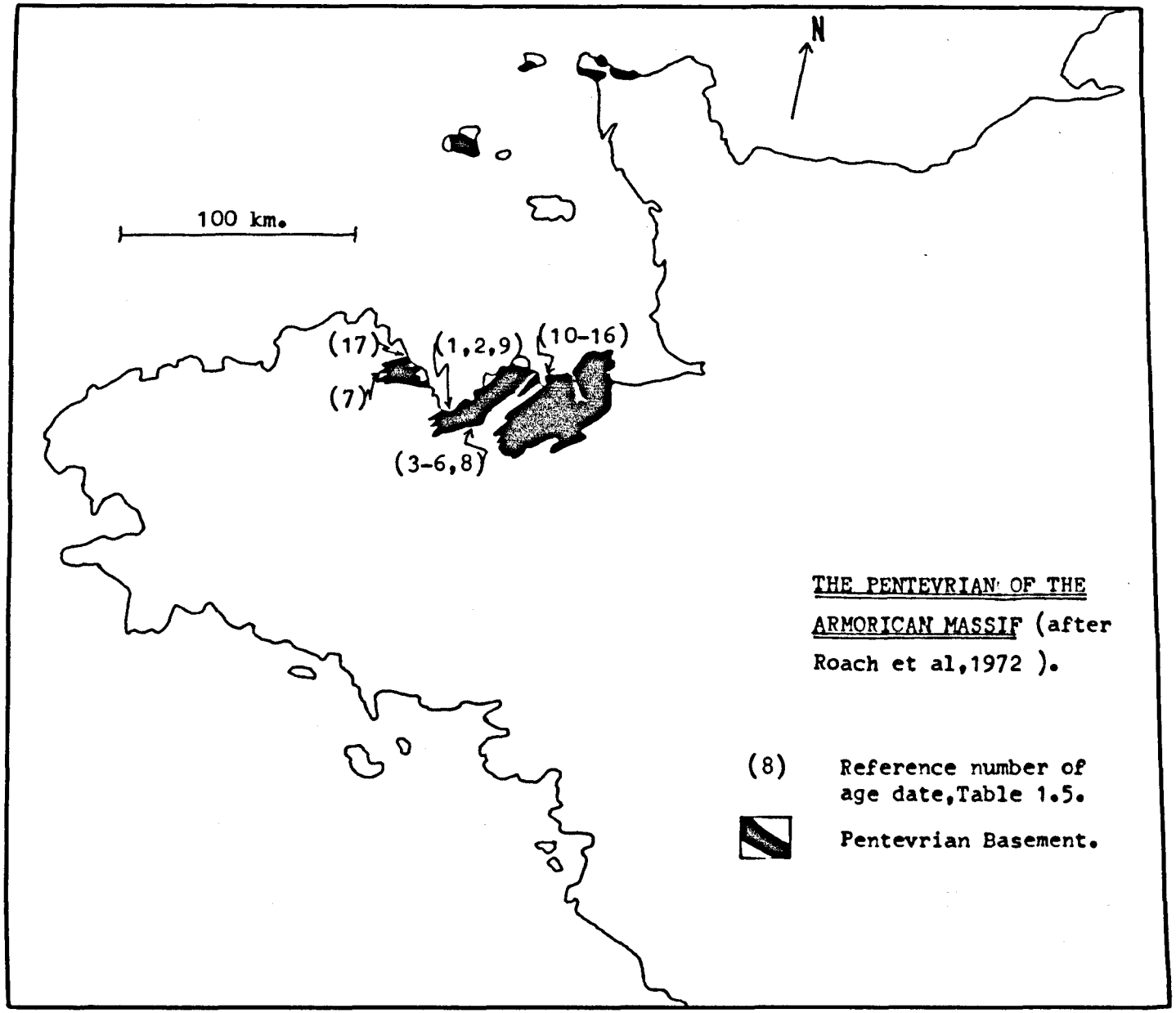
N
100 km.
(17)
(7)
(1,2,9)
(10-16)
(3-6,8)
THE PENTEVRIAN OF THE ARMORICAN MASSIF (after Roach et al,1972).
(8) Reference number of age date,Table 1.5.
Pentevrian Basement.

Figure 1.4. Map to show the known outcrops of Pentevrian basement (black) in the Armorican Massif, after Roach et al 1972, and the location of the age dates given in Table 1.5.

(c) The Pentevrian Basement

Cogné (1959) recorded the existence of a pre-Brioverian basement, termed the Pentevrian, that could be seen to be covered unconformably by the Brioverian at Jospinet on the east side of the Bay of St. Brieuc. Here the basement is comprised of dioritic gneisses which possess a NNE-SSW trending foliation that predates the E-W foliation of the Brioverian (Cogné op. cit.). Subsequently several other areas of Pentevrian basement have been recorded (Graindor 1960, Cogné and Shelly 1966) on the basis of N-S structural trends and high metamorphic grade. Other areas of Pentevrian have been proposed on the basis of age date studies (Leutwein and Sonet 1965, Leutwein 1968, Leutwein et al 1968) which are reviewed in Figure 1.4.and Table 1.5. Brown et al (1971 and 1972) have attributed the migmatites of Saint Malo, Dinan and Saint Cast to the Pentevrian on structural grounds. Present age date studies indicate that the Pentevrian basement evolved over a considerable period of time, with the earliest events taking place some 2600 m.y. ago and possibly the latest events occurring as late as 1000 m.y. ago (Roach et al. 1972).

C. History of research in area investigated.

Little detailed work was carried out in this area before the present study. Previous researches have either been in the form of survey mapping for the production of the 1:80,000 geological maps of France, or a study of features in the area that were thought to have a regional significance. The first detailed map of the area was that compiled by Barrois in 1898. The results were presented in the St. Brieuc and Paimpol sheets of the 1:80,000 geological maps of France (Figure 1:5). In these maps and the accompanying reports (Barrois 1896, 1898) Barrois recognised the unconformity between the red beds of Brehec (h,,) and the shales to the north (X), assigning the former to the Cadomian and the latter to the Precambrian. These shales were

part of map 42
part of map 59
Scale, 1 : 80,000
4 km
N
BREHEC
PLEHEDEL
PLUDUAL
LANVOLLON
PLOURHAN
ST QUAY
BINIC
X
h1-2
h1
γ1
Xaγ1
Xεγiv
bxγ"1
γ1,bx
bx

Figure 1.5. Geological map of the area studied as compiled from the 1:80,000 Carte Geologique de la France. The key to this map is given in Table 1.6. on the following page.

Table 1.6

KEY TO 1:80,000 GEOLOGICAL MAPS OF FRANCE

(see Fig. 1.6)

Map 42, the Treguier sheet. (Barrois and Bigot 1929)

ν_1 Plourivo porphyrite

h^2 Green sandy shales of Plourivo

h^1 Toul Lan red beds

$h_{,,}$ Port Lazo conglomerates, sands & silts

Brioverian

X Schists of Saint Lo

$X^a\gamma_1$ Mica schists

$X^e\gamma_{1V}$ Amphibole schists

Intrusives

$\gamma_{,,}bx$ Diorite of Countances

γ_1 Granulite

γ_1^2 Granite of Plouaret

Map 59, the Saint Brieuc sheet (Barrois 1893/4)

Brioverian

bx Series of Binic

Gr Phtanite

$bx\gamma_{,,}$ Mica and amphibole schists

Intrusives

γ_1 Granulite

$\gamma_{,}bx$ Uralised diorite

$\gamma_{,,}bx$ Hornblende syenite

correlated with a larger outcrop to the south, the "Series de Binic", which in turn were correlated with the "phyllades de St. Lô" and were therefore Brioverian in age. This correlation was based on the fact that both of these series were found to contain bands of pthanites (Gr). The east-west strike of the outcrop of the shales (bx) was attributed to folding about parallel east-west axial planes during the Precambrain.

Barrois described the Saint Quay intrusion ($\delta,,bx$) as a diorite which formed a westward extension of the "Diorite de Coutances". This diorite was thought to have been responsible for the metamorphism of the "Series de Binic". Its age was taken to be Precambrian as boulders of a similar rock type were found in the Cambrian conglomerates at Bréhec. The intrusion to the north of Plouha was described as a granulite, (δ_1) genetically related to several other granulitic intrusions in the region, some of which cut the Carboniferous. The Plouha intrusion was therefore placed within the Carboniferous.

Bands of rock of a higher metamorphic grade than the "Series de Binic" were recognised and mapped as mica schists, amphibolites and amphibole schists ($bx\delta,,/X^E\delta_{1V}/X^A\delta,$). These were also assigned to the Brioverian. They were described as being cut by irregular veins of syenite that was thought to be genetically related to the "Diorite de Coutances".

Mazères (1927) thought that the red beds of Brehec were a facies of the Brioverian but Milon (1927) pointed out that they were in fact resting unconformably upon the Brioverian (as had Barrois previously). He also identified the shales to the south of Pointe de la Tour as being Brioverian and not a continuation of the red beds as Barrois had thought.

In later publications (Barrois 1934, 1938, Barrois, Pruvost and Waterlot 1938) the earlier 1898 stratigraphy for the region was

Table 1.7

THE STRATIGRAPHY OF THE SAINT BRIEUC REGION

(after Barrois (1934))

STAGE:		LITHOLOGY:
NEW	OLD	C A M B R I A N
C^2	S_I	Shales and zeolitic sands of Paimpol
C^I	S_I	Conglomerates of Bréhec and Cesson
$C_,$	xc	Red beds of Bréhec and eruptives
$C_{,,}$	xb	
$C_{,,,}$	xb	Series of St. Brieuc (ophiolites)
$C_{,v}$	xb	
		B R I O V E R I A N
xa	xa	Series de Binic

greatly revised (Table 1.7) although the later edition of the St. Brieuc geological map (Barrois, Pruvost and Waterlot 1938) showed very little change in the geological boundaries of the earlier map, only the outcrop of the "Series de Binic" being substantially altered.

Barrois (1934) proposed that only the "Series de Binic" should be assigned to the Brioverian and that the ophiolites around St. Brieuc were Cambrian in age. This was based upon the correlation of the conglomerates of Cesson, Gourin and Bréhec. The Gourin conglomerates contain pebbles of phtanites and the Bréhec conglomerates, at the base of the red beds, rest unconformably upon the Brioverian. Thus the Cesson conglomerates were assigned to the Cambrian and as the ophiolites lie between these and the "Series de Binic" these were also assigned to the Cambrian. Complexities of outcrop between the ophiolites, conglomerates and Brioverian shales were explained by postulating the existence of large nappes in the ophiolites.

In this work the St. Quay intrusion was correlated with that at Trégomar and both were thought to have been intruded during the Cambrian and to have been associated with the ophiolitic vulcanicity, as were dykes that cut the "Series de Binic". A large scale syncline, the St. Brieuc-Binic-Erquy syncline, with the Cesson conglomerates at its core was described, and was thought to be the result of orogenic movements that took place during the Carboniferous.

Barrois (1934a) reported the occurrence of staurolite bearing mica-schists to the north of the Grève de Palus. These were traced inland as an east-west band as far as Ploemerel. These were correlated with other staurolite bearing rocks in the south of Brittany, all of which he believed to have been formed during the Variscan orogeny.

Barrois (1938) described and identified pthanites and associated graphitic shales over the whole of Brittany, including those in the "Series de Binic", and concluded that they were formed from radiolarian tests and plants. He argued that as they are distributed throughout the Brioverian of Brittany they make valuable stratigraphic marker horizons. The pthanites of the "Series de Binic" were described in even greater detail by Barrois, Pruvost and Waterlot (1938) who concluded, from the outcrop of these and other bands of pthanite, that the "Series of Binic" and that of Erquy occupy the core of a fold of unknown attitude and that their stratigraphic relationship with the ophiolites is therefore not known.

Cogné (1962) assigns the "Series de Binic" to the upper part of the Middle Brioverian as it contains pthanites and rests upon the ophiolites with a marked structural discordance. The Brioverian of Bréhec and Pointe de la Tour is assigned to the lower part of the Middle Brioverian. The mica-schists and amphibolites are assigned to the Lower Brioverian as are the ophiolites. The Saint Quay intrusion and the granite to the north of Plouha were believed to have been intruded syn-or post-kinematically to the Constantian orogenic phase.

Cogné postulated that the higher metamorphic grade of the Lower Brioverian was due to this being structurally lower than the Middle Brioverian and to have therefore been more severely metamorphosed during the Constantian orogenic phase. Melting of the basement to produce the magma for the two intrusions was thought to have also occurred at this time, as was the formation of the regional east-west foliation. The east-west folds that affect the region were thought to have been developed later during the Viducastian orogenic phase.

A detailed map of the occurrence of the pthanite bands within the "Series de Binic" was prepared by Cogné (1962a). This map suggests

that the structure of this region is simple, the "Series de Binic" occupying a synclinal structure with several minor flexures upon its limbs. The arguments for the ages of this series and others were reiterated.

Jeanette and Cogné (1968) have reinterpreted the structural and metamorphic discordance between the Series de Binic and the rocks to the south as indicating an Upper Brioverian, i.e. post Constantian, age for the Series de Binic which they describe as being comprised of flysch type sediments.

A few age date studies have been carried out in this region. A Brioverian tuff band at Binic has been dated at 541 m.y. (Leutwein and Sonet 1965; Table 1.3) and a Brioverian sandstone at Palus Plage at 680±20 m.y. (Leutwein, Sonet and Zimmermann 1968; Table 1.3). Pentevrian ages have been yielded by amphibolites at Lannenbert, 1030±100 m.y. (Leutwein, 1968; Table 1.5. no. 7) and by the granite at Port Moguer, 850±80 m.y. (Leutwein, Sonnet and Zimmermann 1968; Table 1.5. no. 17). The Saint Quay intrusion has been dated at 559±27 m.y. (Vidal et al 1972).

D. Discussion

From the preceding review it can be seen that there still remains much to be done before detailed sedimentological, stratigraphical, metamorphic and structural models for the region can be confidently assembled. It is felt that many of the existing models should be critically re-examined and thay they should be used only with the utmost caution. In this study, certain current definitions for the terms Pentevrian, Brioverian and Cadomian have not been used. Rather the author has returned to the original definitions as far as possible.

The Pentevrian is considered to be any sequence of rocks that may be shown to be pre-Brioverian. In any one region this relationship may be established by proving that the sequence of rocks in question is covered unconformably by the Brioverian or by a detailed structural and metamorphic analysis of both the Brioverian and Pentevrian of that region. Metamorphic grade and fold trend are not in themselves sufficent criteria. The Pentevrian is not comprised solely of granodioritic gneisses as is suggested by Cogné (1959) from his study of the rocks in the type area, but also of paragneisses, migmatites, and metasediments as seen on Guernsey (Roach 1966), at Cap de la Hague (Graindor 1960, Roach et al 1972), in the St. Malo region (Brown, Barber and Roach 1972) and in the area studied by the present author. It should be noted that the Pentevrian is defined with respect to the Brioverian and is a blanket term for any pre-Brioverian basement. The Pentevrian is thus made up of any sequence of rocks that is older than approximately 1,000 m.y.

The Brioverian was originally defined upon lithological grounds (Barrois 1895), the Precambrian age for this sequence only being firmly established much later. The Brioverian is considered to comprise the sequence of Precambrian supracrustal rocks that are found within the Armorican Massif and which were deposited between 1,000 to 700 m.y.

ago. These rocks have been affected by the late Precambrian Cadomian orogeny. No attempt has been made to use the lithostratigraphic succession that has been established for the Brioverian of Lower Normandy by Graindor (1954, 1957) and has been extended over the whole of the Armorican Massif by Cogné (1961). It is felt in view of the complex structural patterns that are found in the Brioverian sedimentation, that any large scale lithological correlation would be un-justified at this time.

Bertrand's definition of the Cadomian (1921) has been used. The Cadomian is considered to be a late Precambrian orogenic event that give rise to the deformation and metamorphism of both the Brioverian and the Pentevrian. This event was then followed by the intrusion of post-kinematic granites and then finally by uplift and peneplanation of the Brioverian before the transgression of the Cambrian seas. The main Cadomian deformation and metamorphism can be dated between 620-650 m.y. (Roach et al 1972). In practice the Cadomian may be identified as it is the only Precambrian orogeny that has affected the Brioverian sediments. There are conflicting views as to the actual nature and timing of the Cadomian orogenic events (Cogné 1961, Graindor 1964, Winterer 1967, Roblot 1962, Bradshaw, Renouf and Taylor 1967 and Bishop et al 1969). Although there is no doubt that throughout the greater part of the Brioverian outcrop the main direction of the Cadomian folds is east-west, it must be noted that this direction is that associated with the second major phase of deformation, an earlier phase having formed north-south structures. Also, no detailed structural analysis of the Pentevrian basement has yet been undertaken and therefore all the structural trends within the Pentevrian are not know. As a result it would be unwise to identify folds as Cadomian in age purely upon the basis of their east-west trend.

CHAPTER II

THE PENTEVRIAN

A. Introduction

Rocks which are older than the Brioverian and can therefore be assigned to the Pentevrian are found within the area studied. These have a much more complex structural and metamorphic history than the Brioverian which may be seen locally to rest unconformably upon them.

The outcrop of the Pentevrian, which occupies the largest proportion of the area studied, extends from Moulin plage (128873) to Bourdonniere (084882) in the south and from Pointe de la Tour (050963) to Le Pouloudou (016944) in the north. All the rocks in this area are Pentevrian, except the Saint Quay and Plouha intrusions which are post-Brioverian, pre-Cadomian in age and the Palus plage metasediments and metavolcanics which form part of the local Brioverian sequence.

The rocks of Pentevrian age have been divided into three suites, namely the Port Goret gneisses, the Plouha Series and the Port Moguer tonalite.

In the first section the lithologies and field relationships of the various suites will be dealt with. In the second section, the structural and metamorphic histories of the Pentevrian rocks will be covered. The third section will contain a synthesis of the preceding information and a sequence of events for the Pentevrian will be proposed.

B. Pentevrian Lithologies

1. The Port Goret Gneisses

(a) Introduction

The outcrop of this highly deformed sequence of staurolite bearinf paragneisses occupies approximately 7 sq.km in the centre of the area studied.

Plate 2.1. Irregular veins of meta-tonalite (light grey) cutting the Port Goret gneisses (dark grey). Palus - Plouha road, 1 mile to the west of Palus.

Plate 2.2. Port Goret gneisses at Port Goret. Note the lighter veins of migmatised gneisses cutting the massive, darker gneisses.

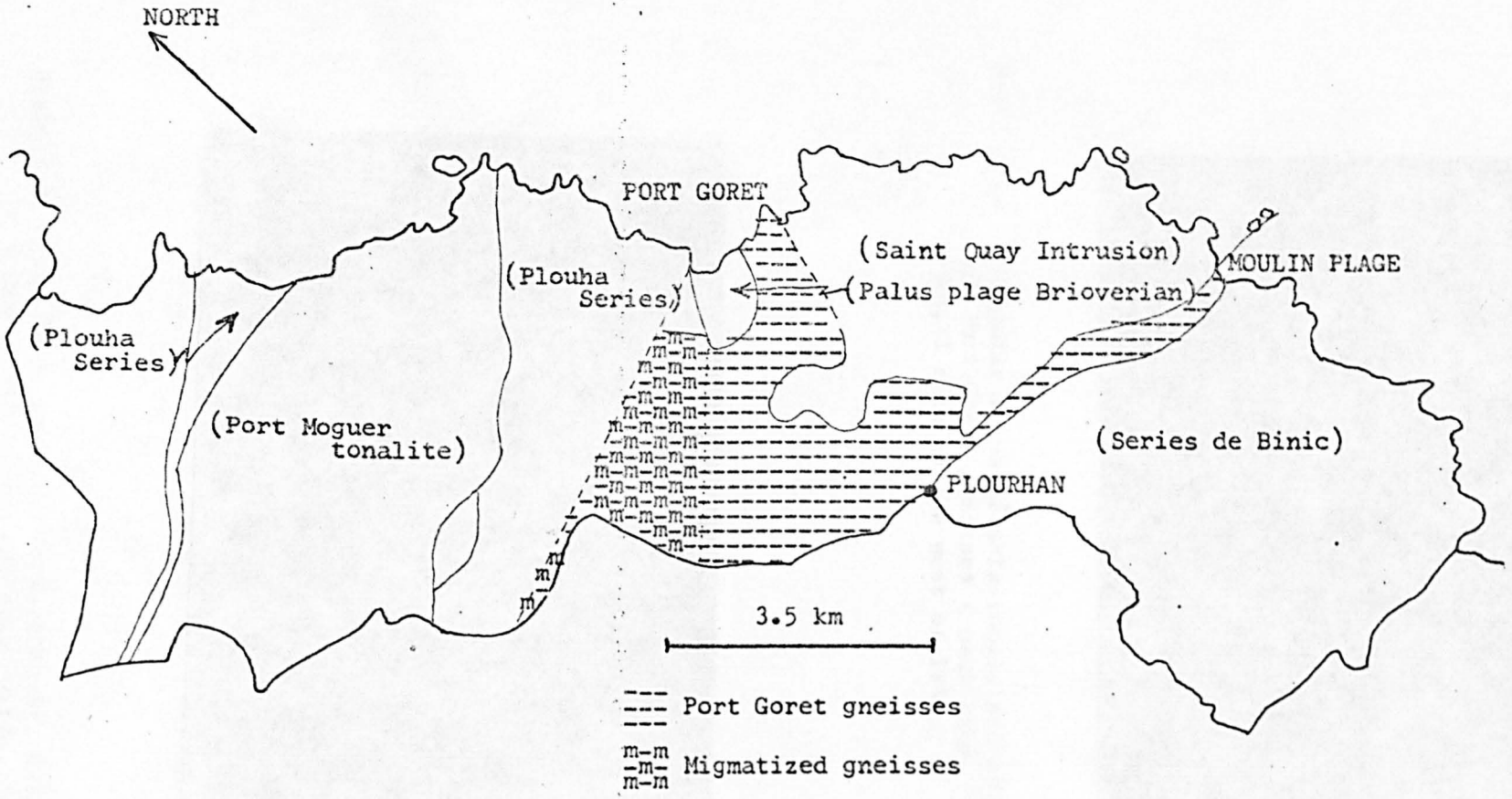
NORTH
PORT GORET
(Saint Quay Intrusion)
(Palus plage Brioverian)
MOULIN PLAGE
(Plouha Series)
(Plouha Series)
(Port Moguer tonalite)
(Series de Binic)
PLOURHAN
3.5 km
Port Goret gneisses
Migmatized gneisses

Figure 2.1. Sketch geological map showing the outcrop of the Port Goret gneisses.

Unfortunately, in spite of their large inland areal extent they only outcrop on the coast in two small rocky headlands, either side of the Saint Quay intrusion (Figure 2.1). At Moulin plage (129874) in the south they are exposed along the coast for 50m, while at Port Goret (095915) to the north the gneisses form a prominent headland and are well exposed for 550m along the coast (Map 1).

The southern margin of these gneisses is faulted and runs approximately east-west along the line of a valley. This contact is found at Moulin plage and runs westwards through Saint Barnabie (094882) and Bourdonniere (084882). The northern margin is an unconformity between the gneisses and the Brioverian. This unconformity is well exposed at Palus plage (093915) and it may be traced inland as far as Keregal (082911). Although this contact is represented on the map as a straight line it may in detail be rather irregular if the contact at Palus plage is taken as the norm (see Chapter IV).

The northern contact may then be followed along the D32 Plouha-Palus road until Lanlorec (052910). In the northwestern part of the outcrop of the gneisses they are cut by irregular veins of tonalite (Plate 2.1). This occurs in the region which is to the south of the D32, and is bounded to the southeast by Keregal and to the southwest by Coray (068900).

This sequence of gneisses has been intruded by the Saint Quay intrusion, and much of the coastal and inland areas between Palus plage and Moulin plage is occupied by this body which extends along the coast from Pointe Bec du Vir (103915) to the north of Moulin plage (129874), and it is found inland at Lan Mergat (081902) and Saint Barnabie (093882).

Staurolite-bearing rocks of Brittany (after Barrois 1934a).

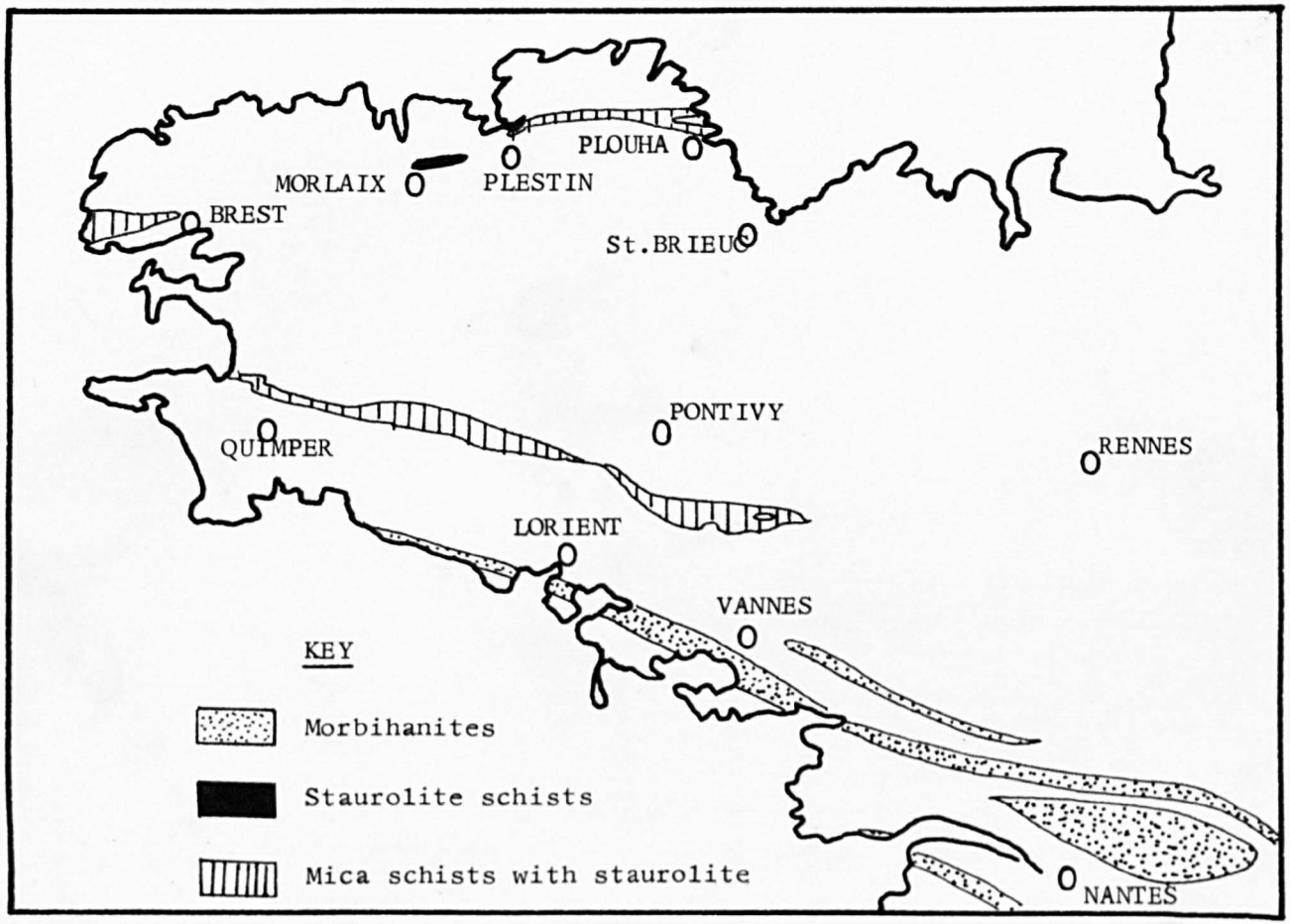

Figure 2.2. Map showing the distribution of staurolite-bearing schists in the Armorican Massif, after Barrois.

The headland at Port Goret is made up of cliffs that rise steeply to a height of 40m and are deeply dissected by steep sided gullies. Inland, the gneisses tend to occupy land that is slightly lower than the surrounding terrain and is cut by many stream valleys. This rock apparently weathers very easily, with the result that inland exposures are in a very poor state of preservation.

(b) History of Previous Research

Staurolite bearing gneisses in this area were described by Barrois (1934a). However, on his map he shows that the gneisses outcropped to the north of Plouha (Figure 2.2). The rocks to the north of Plouha have been called the Plouha Series by the author (Figure 2.3) and although they contain rare staurolite bearing bands they may be clearly differentiated from the Port Goret gneisses which are not shown on Barrois' map.

Barrois named this east-west striking band of gneisses and amphibolites the "Massif du Penthievre" and suggested that it extended inland as far as Morlaix (Figure 2.2). He described this band as being made up of grey micaschists that are interbedded with meta-quartzites. These he assigned to the Brioverian. To the west of Ploumillau the nature of this band changes, being now composed of sillimanite+biotite+muscovite gneisses that are cut by granitic veins. To the east of Ploumillau the predominant rocks are staurolite-bearing gneisses which also contain iron oxides, zircon, apatite, tourmaline, biotite, muscovite, garnet and granular quartz. He also noted that the staurolites were partially altered.

Barrois assumed that the above mineral assemblages were developed during a single phase of metamorphism in spite of the fact that it is obviously not an equilibrium assemblage. He suggested that this

metamorphic event was responsible for the generation of staurolite in the Massifs du Leon and Cornouaille, the Le Mur schists, and the Morbihanites of southern Brittany and that this took place during the Carboniferous.

Cogné (1962) attributed these gneisses to the Lower Brioverian and believes that they were developed during the metamorphic event associated with the pre-Upper Brioverian post-Middle Brioverian (Constantian) orogenic episode.

(c) Age of the Port Goret Gneisses:

The Pentevrian age of this sequence is established by the fact that to the south of Palus plage in a small inlet (093915) these gneisses are covered unconformably by the Palus plage metavolcanics and metasediments which are Brioverian in age.

The contact between the gneisses of the Pentevrian basement and the Brioverian supracrustal sequence is interpreted as an unconformity on the grounds that:

(1) boulders of gneiss are found in the overlying metasediments;

(2) the gneisses have undergone eight phases of deformation (7 Pentevrian and 1 Cadomian) prior to the local development within them of the Cadomian S_{2C} foliation, whereas the Brioverian had only undergone one Cadomian phase of deformation prior to this event. In places the bedding of the metasediments and metavolcanics is parallel to their contact with the gneisses and they contain pebbles and boulders of the underlying gneiss. Here the contact is thought to represent the original unconformity although elsewhere the contact may well be tectonic (see Chapters III and IV).

The Plouha Series and the Port Moguer tonalite have been assigned to the Pentevrian on the grounds that the structural and metamorphic events that are found within these bodies correlate with those that affected the Port Goret gneisses before the deposition of the Brioverian, and also the structural and metamorphic histories of these bodies are far too complex to have been produced during the Cadomian orogeny alone.

This unconformity cannot be interpreted as an intra-Brioverian unconformity formed as a result of uplift of the area subsequent to the Constantian phase of the Cadomian orogeny, because the overlying supracrustal sequence has been affected by the main Cadomian metamorphism, which according to Graindor (1965) was operative during the Constantian phase.

(d) Lithology

The Port Goret gneisses are made up of three main rock types which are irregularily interbanded with one another. These are:

(1) coarse grained staurolite gneisses

(2) staurolite-bearing micaschists, and

(3) calc-silicate rocks.

The coarse grained staurolite gneisses (Plate 2.2) make up the bulk of this sequence. They are red-brown in colour and contain quartz+ plagioclase + biotite + staurolite $\pm$ andalusite $\pm$ cordierite $\pm$ garnet. Bands may be massive and up to several metres in thickness, or they can be as thin as 2-3 cm. The most distinctive feature of these rocks is the dark brown to black porphyroblasts of staurolite that may easily be recognised in hand specimen.

The micaschists occur in bands from 10-40 cm in thickness that are interbanded with the staurolite gneisses (Plate 2.3). They are

Plate 2.3. Banded mica schists at Moulin Plage. Spg_1 foliation is parallel to the ruler. The schists are cut by concordant and slightly discordant Mpg_2 granitic veins. Scale 30 cms.

Plate 2.4. Photomicrograph (ppl)* of metacalc-silicate band in gneisses at Port Goret showing a quartz tremolite zoizite assemblage. Scale 0.69 mm.

* N.B. ppl = plane polarised light and cn = crossed nicols.

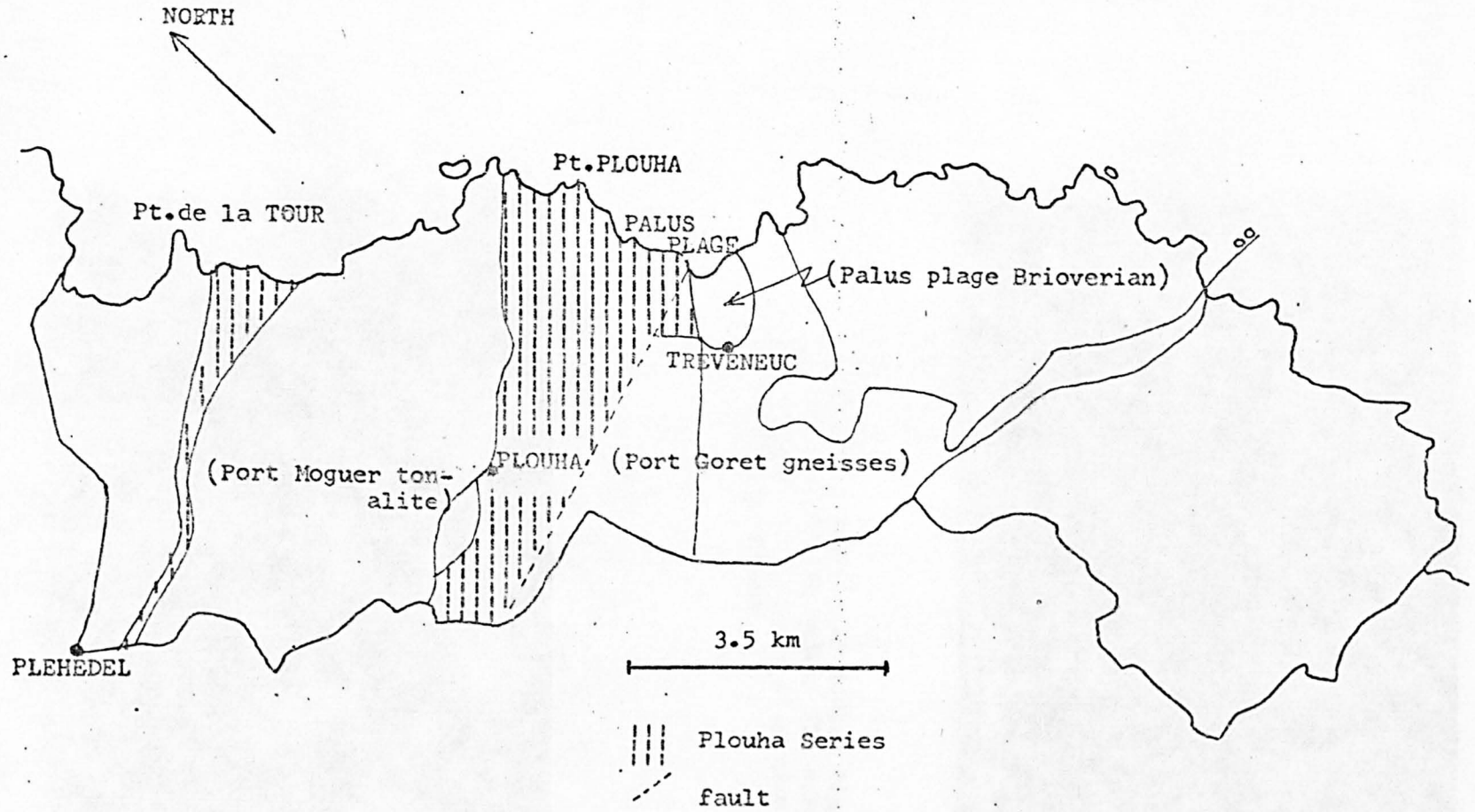
NORTH
Pt.PLOUHA
Pt.de la TOUR
PALUS
PLAGE
(Palus plage Brioverian)
TREVENEUC
(Port Moguer tonalite)
PLOUHA
(Port Goret gneisses)
PLEHEDEL
3.5 km
Plouha Series
fault

Figure 2.3. Sketch map showing the outcrop of the Plouha Series (ornamented) in the area mapped.

fine grained and dark brown in colour due to the predominance of biotite. These weather readily to a crumbly yellow-brown rock.

The calc-silicate bands (Plate 2.4) vary from 5-50 cm in thickness, but are usually around 7-12 cm. Although these bands are often discontinuous, their strike is usually parallel to that of the adjacent bands of micaschist. They are yellow-grey in colour and often exhibit a fine internal banding (1 mm to 1 cm in thickness) which is parallel to the strike of the band. The calc-silicates make up only a very small percentage of the whole sequence.

The Port Goret gneisses are thought to be a sequence of para-gneisses because the metamorphic assemblages developed suggest that the gneisses, micaschists and calc-silicates had quartzo-felspathic, pelitic and calcareous parent rocks respectively. The sedimentary origin of these rocks is supported by the inhomogeneity of the sequence and the occurence of staurolite. The bands of gneiss, micaschist and calc-silicates are parallel to one another and are cut discordantly by the first visible foliation. This banding may therefore represent the original sedimentary bedding.

2. The Plouha Series

(a) Introduction

This series occupies the coast between the northern side of the Palus plage (086918) and the Bay to the south of Pointe de la Tour (050963). It is bounded to the north by the Port Goret gneisses and the Palus plage metasediments and metavolcanics, to the north by the Brioverian of Bréhec and is intruded by the Port Moguer tonalite. The northern contact may be traced from Pointe de la Tour to Le Pouloudou and the southern contact may be traced from Palus plage to Lanlorec (Figure 2.3, Map 1).

The coast in this region is comprised of cliffs of between 60m and 80m in height and unlike the rest of the area there are few beaches and consequently few roads or tracks that descend to the coast. Inland the main outcrop of the Plouha series, that is to the south of the Port Moguer tonalite, occupies the only ground in the area studied that exceeds 100m in height. It comprises a ridge that extends from Kerouziel (081930) westwards to La Sauraie (042918).

The general inaccessibility of the coast and the lack of good inland exposure has meant that it has not been possible to map the whole of this sequence in great detail. Fortunately, however, it has been possible to evaluate a detailed structural chronology for the rocks of this series from the area to the north of Palus plage where they are well exposed.

The rocks of this series are thought to be Pentevrian in age on the basis that their structural history is a good deal more complex than that found in the adjacent Brioverian rocks which have only been subjected to the Cadomian orogeny. Also this structural history is very similar to that of the Port Goret gneisses of proven Pentevrian age.

At both its southern and northern margins this series is in contact with the Brioverian,the Palus plage metasediments and metavolcanics in the south and the Brioverian sediments at Pointe de la Tour in the north. The northern contact can be seen to be faulted, while the nature of the southern contact is uncertain.

Inland, within the general outcrop of this series, in a trench to the west of Plouha (052917) rocks that are petrologically identical to certain members of the Palus plage metasediments and metavolcanics have been found and could therefore be Brioverian in age. There being no exposure in that region it has not proved

possible to map the extent of these rocks or to establish their relationships with the Plouha Series. (Map 1).

(b) Lithology

Although originally there was a great variation in the lithology of this series, a late phase of cataclastic metamorphism has resulted in the destruction of many of the original textures and the major part of the series is now made up of a monotonous sequence of green/grey blastomylonites (Plate 2.7). In the area immediately to the north of Palus plage the effect of this cataclasis is slight and it has been possible to distinguish the following lithologies:

1. Metasediments
2. Metabasalts
3. Meta-acid igneous rocks of possible volcanic origin
4. Granite gneiss
5. Aplites.

1. Metasediments

These comprise the main bulk of the Plouha Series, occurring in bands that are between 5cm and several tens of centimetres in thickness. They are generally pelitic in composition and are distinguished from the pelitic fraction of the Port Goret gneisses in that they are richer in mica, are interbanded with amphibolites and hornblende schists, and do not contain bands of meta-psammite. Mineralogically they are very complex, the textures and mineral assemblages being partly or wholly preserved. The typical assemblage found within the metasediments being biotite + quartz + plagioclase $\pm$ cordierite $\pm$ staurolite $\pm$ muscovite $\pm$ andalusite $\pm$ garnet $\pm$ chlorite $\pm$ sericite.

Plate 2.5. Meta-amygdaloidal basalts showing flattened amygdales (light patches in the centre) which define the Sps_1 foliation. North Palus plage.

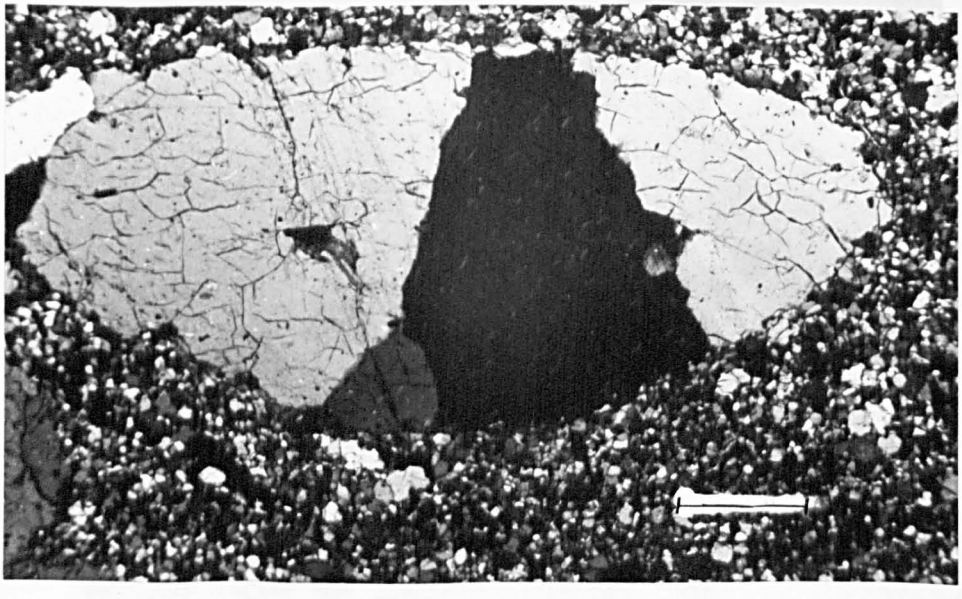

Plate 2.6. Photomicrograph (cn) of flattened quartz filled amygdale in the meta-rhyolites at Palus plage. Scale 1.2 mm.

2. Metabasalts

These are dark green in colour and outcrop as bands that are between 80cm and 3m in thickness. Some of the bands contain amygdales (0.5-0.6cm across) that make up from approximately 1% to 10% by volume of the rock (Plate 2.5). These amygdales are flattened and ellipsoidal in form and lie so that long axes are oriented in a plane of structural significance (S_{1P}) that is of an earlier generation that the foliation within the matrix of the rock. These bands are common in the south but no amygdaloidal rocks are found to the north of the Port Moguer tonalite. The degree of cataclasis increase towards the north and so it is possible that such earlier textures could have been destroyed.

Mineralogically these rocks are very complex. This is because they have been subjected to several phases of metamorphism none of which caused the complete recrystallisation of the rock. The typical assemblage found in these rocks is:

hornblende + plagioclase + magnetite + sphene ± epidote ± sericite ± haematite ± muscovite within the matrix and garnet + quartz + apatite + plagioclase ± sericite ± epidote ± calcite in the amygdales.

3. Meta-acid igneous rocks of possible volcanic origin.

Thin bands of metarhyolite that are 25-75cm in thickness and are sometimes amygdaloidal are found between Palus plage and Port Logot. Mineralogically they are simple, being comprised of quartz + plagioclase ± biotite ± actinolite ± chlorite ± sericite. The amygdales, which are filled with quartz grains are ellipsoidal in form and are from 0.5-3cm across (Plate 2.6).

Associated rock types are found on a poorly accessible section of the coast between Port Logot and Pointe de la Tour. These consist of

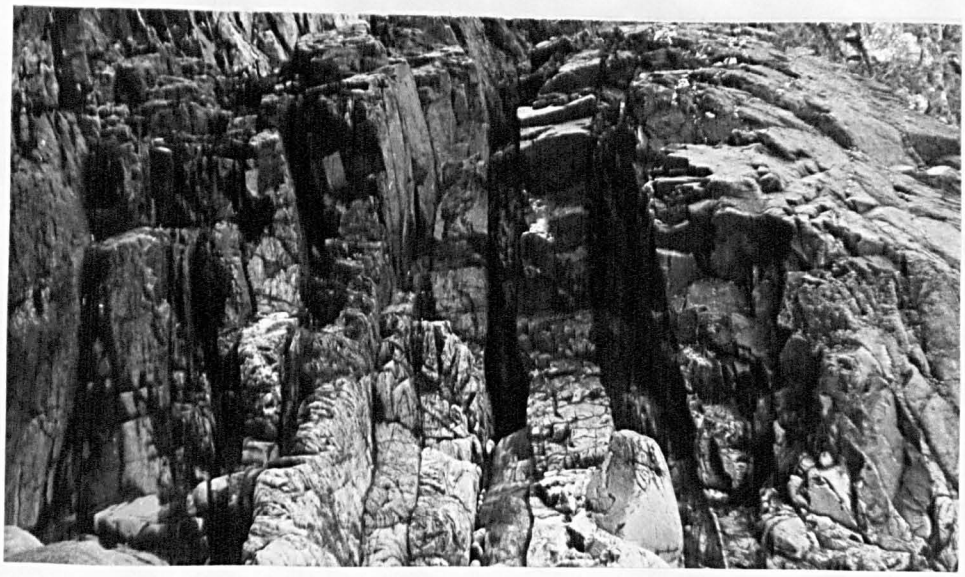

Plate 2.7. Banded blastomylonitic Plouha series, Pointe Plouha. Field of view 4 m.

Plate 2.8. Photomicrograph (ppl) of sheared porphyritic aplite, Pointe Plouha. Scale 0.69 mm.

Plate 2.9. Flattened rhyolitic pebbles in sheared acid tuffs south of Pointe Le Pommier. The elongate pebbles define the Sps_4 foliation. Field of view is 60 cm.

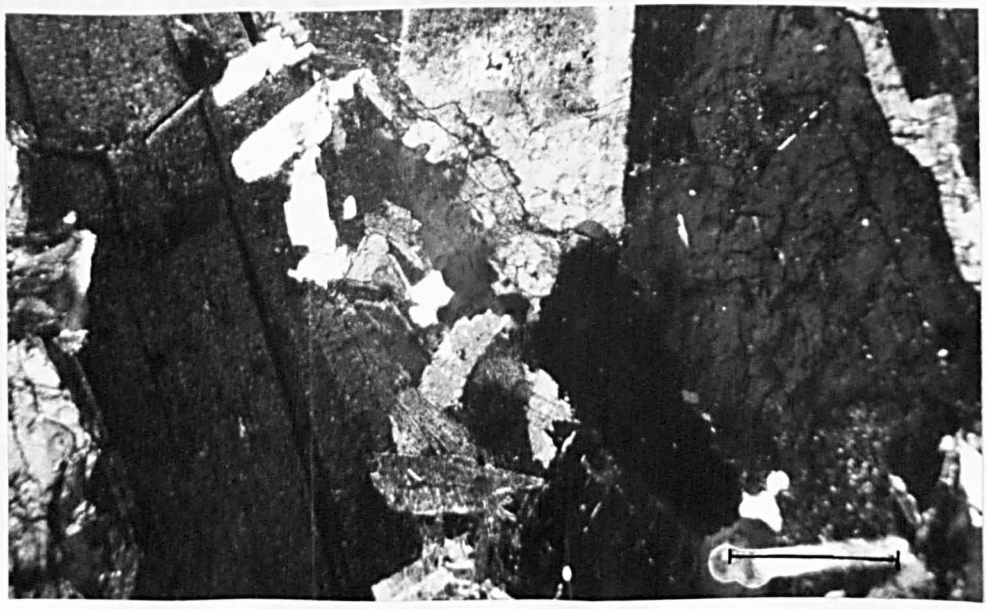

Plate 2.10 Photomicrograph (cn) of metatonalite vein cutting the Plouha Series, Palus plage/Plouha Road. Note static biotite flakes in top centre of photograph.

sheared metarhyolites (Plate 2.8.) and sheared acid tuffs (Plate 2.9.). The rhyolites differ from those found at Palus plage in that they are non-amygdaloidal and they contain relict phenocrysts of plagioclase although their mineralogies are similar. The tuffs outcrop at le Pommier and immediately to the south where extremely flattened pebbles of rhyolite rest in a very fine grained matrix of quartz,plagioclase and biotite. In one locality, 5m to the south of the contact of the Plouha Series with the Port Moguer Tonalite at Le Pommier, there is a band of rock in which angular fragments of quartz, plagioclase and magnetite (0.5-1cm) are set in a matrix similar to that of the tuffs, these are thought to represent fragments of sediment enclosed in an acid tuff (Figure 2.5).

Although there is no direct evidence for the common origin of the rock types described above, most original textures being destroyed, it is felt that, in view of the similarity in their mineralogies, it is possible that they are all associated and were produced during a phase of acid vulcanicity that took place during the deposition of the Plouha Series.

4 Granite gneiss

Occasional bands of granite gneiss of up to 2m in thickness occur throughout the Plouha Series. These were emplaced before the phase of cataclastic deformation and often preserve earlier textures than the surrounding rock. In the north where severe cataclasis has taken place these are recrystallised to a coarse grained quartz + oligoclase + biotite $\pm$ garnet gneiss. However in the south the non-cataclased Plouha Series is cut by veins of tonalite (Plate 2.10) identical to those that cut the Port Goret gneisses (page 2.2.). These veins are similar in both mineralogy and texture to the Port Moguer tonalite. It is thought that all of these veins have a common origin and that they are associated with the

Plate 2.11. Aplite dykes (at base of hammer) cutting the Plouha Series north of Pointe Plouha.

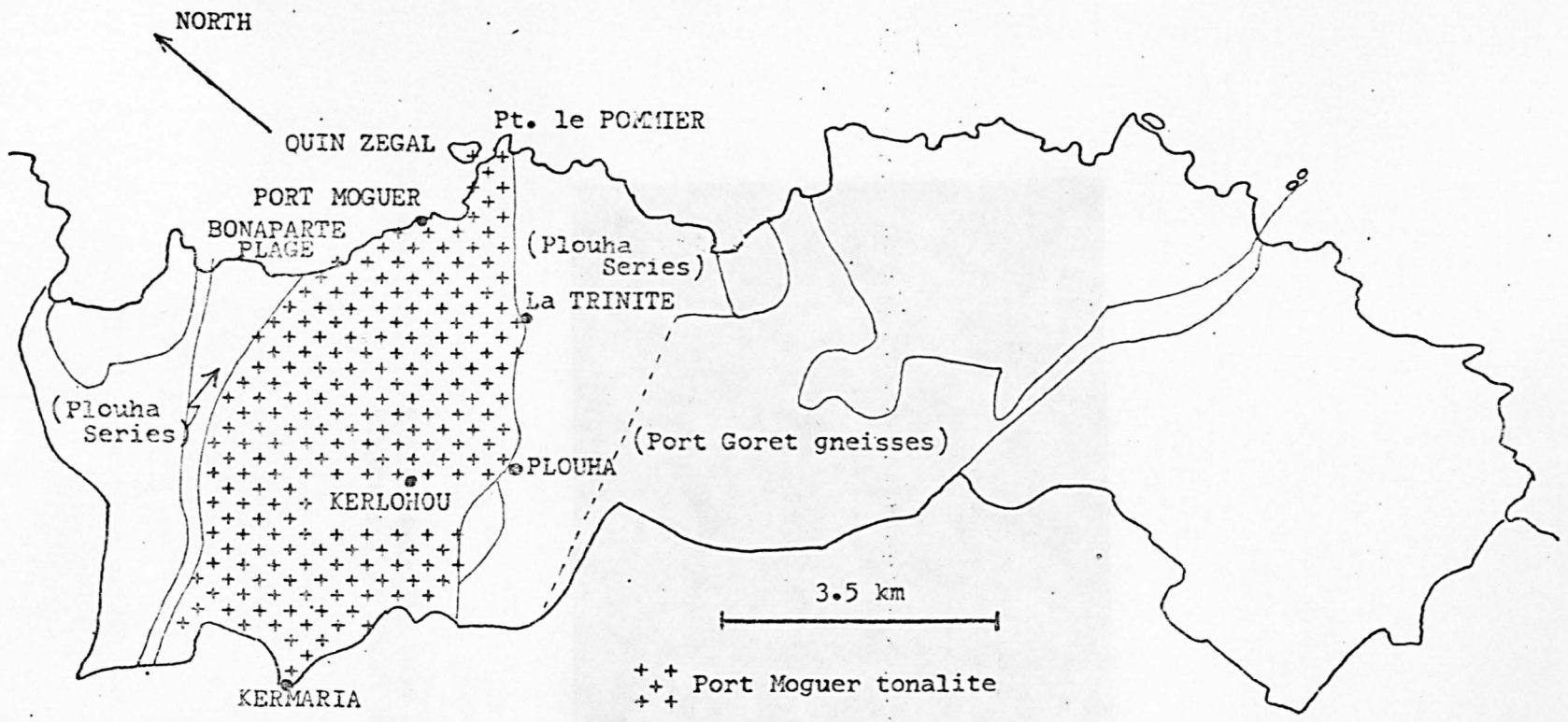
NORTH
QUIN ZEGAL
Pt. le POMMIER
PORT MOGUER
BONAPARTE PLAGE
(Plouha Series)
La TRINITE
(Plouha Series)
(Port Goret gneisses)
PLOUHA
KERLOHOU
KERMARIA
3.5 km
Port Moguer tonalite

Figure 2.4. Sketch geological map showing the outcrop of the Port Moguer tonalite (ornamented) in the area mapped.

Port Moguer tonalite.

5. Aplites

In the area around the Port Moguer tonalite the Plouha Series is cut by bands of aplite that are between 40cm and 1.2m in thickness (plate 2.11). These are always parallel to the foliation. They are white to light grey in colour and composed of phenocrysts of oligoclase set in a fine quartz-plagioclase matrix. These were intruded at the end of, or after the cataclastic event that has affected this series. Some are sheared and have developed a muscovite foliation, this texture is similar to that developed in the tonalite at the end of the cataclastic event (page 2.38). Some of these bands have undergone substantial re-crystallisation with both the phenocrysts and the matrix being replaced by a quartz/plagioclase intergrowth and static needles of actinolite being grown in the matrix.

3. Port Moguer Tonalite

(a) Introduction

This body of rock is intruded into the Plouha Series to the north of Plouha (Figure 2.4 and Map 1). It occupies about 14 square km of the area mapped. It varies from 3.3 km to 2.4 km in width and is at least 5.1 km in length. It is probable that this intrusion extends seaward for at least a further 1.2 km, as the island known as La Mauve (088946) to the east-northeast of Pointe Le Pommier is apparently made up of the tonalite.

Topographically the body generally forms an inland platform about 80 m above sea level. This platform is remarkably flat with very few dissecting streams. At the coast the cliffs rise vertically for the first 20 m and then slope steeply until they attain a height of 60 m. There is no rocky foreshore, the cliff line being coincident with the high tide line. Good sandy beaches are exposed along much of the coast

at low tide. At Port Moguer a stream valley cuts into the tonalite.

The sides of the intrusion are sub-parallel for most of its length, the axis of the body trending ENE-WSW. The southern contact with the Plouha Series is seen on the coast at a small bay 200 m south of Pointe Le Pommier (082943). From here it can be traced beneath the Chapelle La Trinite (066934) and through Pouldouran (052923) to the north of the town of Plouha. The northern contact is exposed in the Plage Bonaparte (056953) and though not as well exposed inland as the southern contact, it may be seen to run through La Fauvre (023942) and just to the north of the Convent St. George (025942).

(b) History of previous research

This body was first described by Barrois (1898). In this work Barrois has named the intrusion the Plouha Granite. He noted that it was cutting highly metamorphosed rocks and suggested that it could be of Variscan age. In his later works (Barrois 1934, Barrois, Pruvost and Waterlot 1938) he suggests that the intrusion is in fact Caledonian and not Variscan in age. It should be noted that the boundaries as drawn by Barrois coincide with those proposed by the author.

Cogné (1962) considers this intrusion to be Precambrian. He believes that it was one of the many developed as a result of anatectic melting of the more acidic fractions of the Lower Brioverian sediments and Pentevrian basement during the post Middle Brioverian - pre Upper Brioverian, Constantian, phase of the Cadomian. By inference from his conclusions it appears that he suggests that the body was intruded into the Lower Brioverian (i.e. the Plouha Series) during this orogenic episode and that the E-W trending foliation within the body was developed in conjunction with the regional E-W schistosity that, is axial planar to the main Cadomian folds.

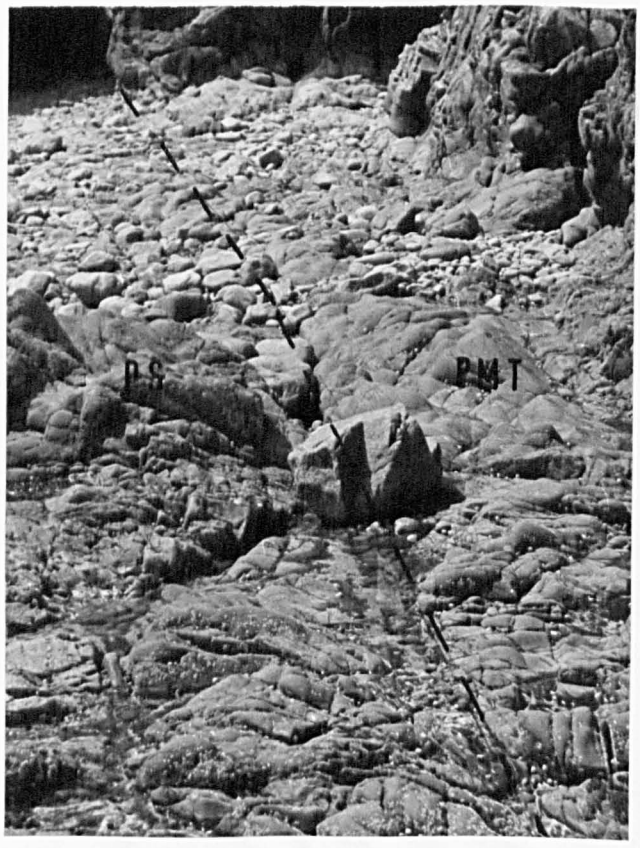

Plate 2.12. Plouha Series/Port Moguer tonalite (right) southern contact at Pointe Le Pommier (see Figure 2.5).

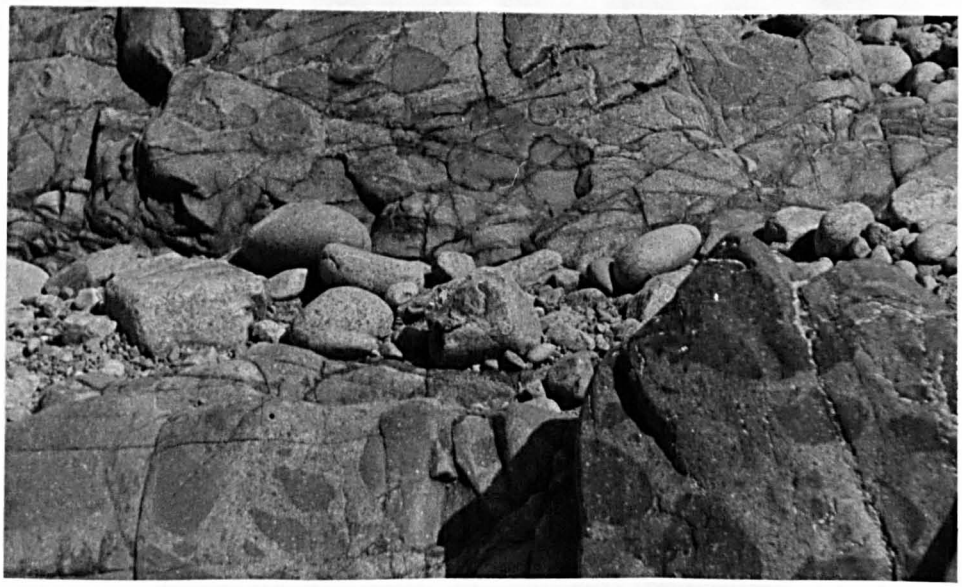

Plate 2.13. Zone in Port Moguer tonalite rich in xenoliths (darker patches) at Quin Zegal. Field of view 3m.

Plate 2.14. Large angular xenolithic blocks in tonalite at Quin Zegal. Scale 30 cm.

The name of this body has been changed from the Plouha Granite to the Port Moguer tonalite for two reasons. Firstly the body does not outcrop in or around the town of Plouha whereas it is excellently exposed at Port Moguer (070945), a small fishing port that lies on the coast approximately in the centre of the body. Secondly, although the body has undergone several phases of metamorphism, including cataclastic retrogressive and progressive regional metamorphisms and metasomatism, enough of the original mineralogy and texture are preserved in several localities in the centre of the body around Kerlohou (046933) to indicate that the original igneous rock is essentially an over-saturated leucocratic plutonic igneous rock consisting of andesine, quartz and biotite, and is therefore a tonalite.

(c) Field Relationships

It can be shown that the tonalite has been intruded into the Plouha Series, although where the contact is seen it is a simple fault surface (Plate 2.12).

In the north, the fault surface is made up of a zone of cataclastic material about 10cm in thickness. On either side, both rock types are cut by chloritised shears that are found up to 10m away from the fault. In the granite thin mylonitised zones are found that are parallel to the fault and cut the foliation within the tonalite. These occur up to 30m away from the contact.

At its southern contact the tonalite may be seen to contain several xenoliths (Plates 2.13 and 2.14). These are not particularly abundant, comprising less than 1% by the volume of the rock. They are ellipsoidal with the long axis of the ellipse lying in the plane of the foliation. They do not usually exceed 30cm in length.

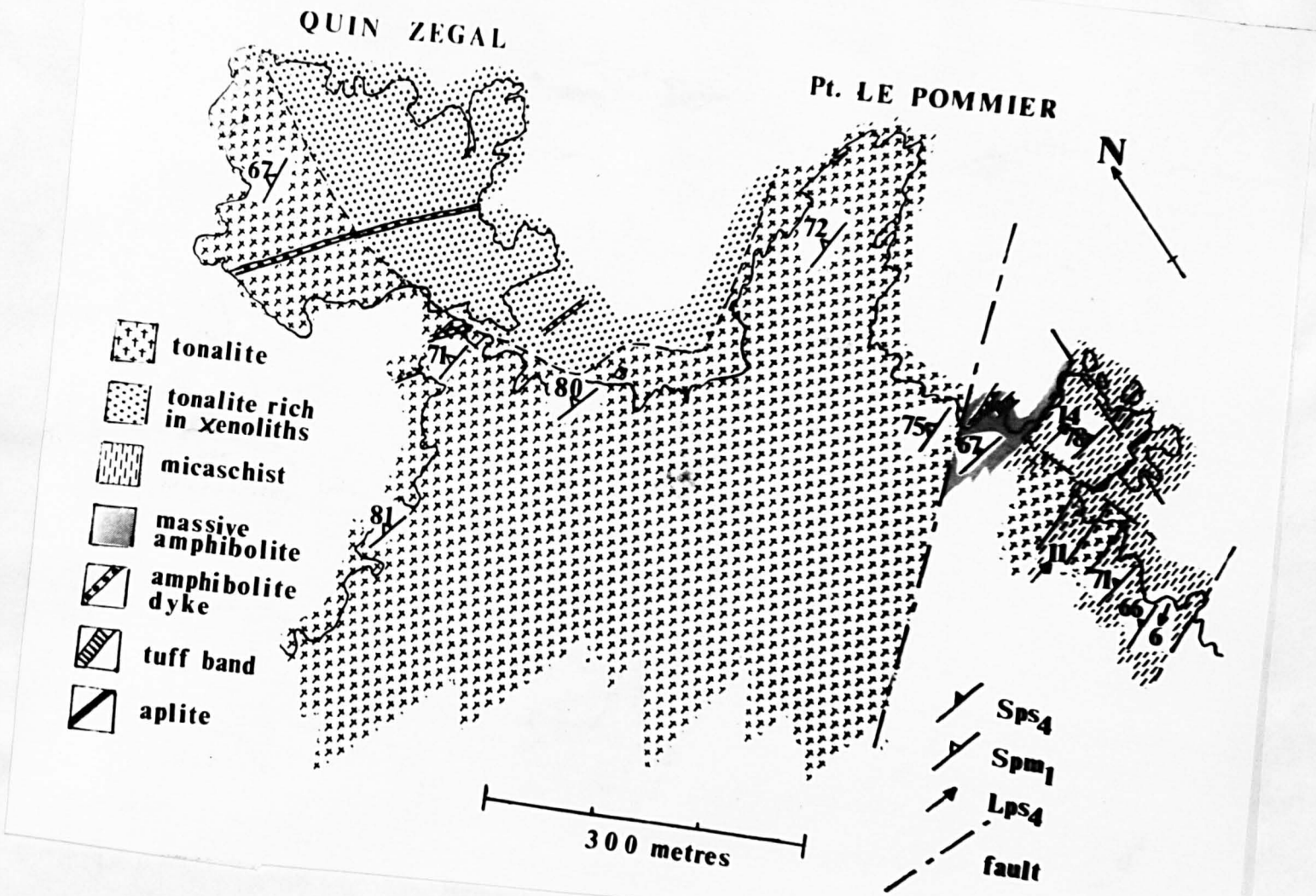
QUIN ZEGAL
Pt. LE POMMIER
N
tonalite
tonalite rich in xenoliths
micaschist
massive amphibolite
amphibolite dyke
tuff band
aplite
300 metres
Sps4
Spm1
Lps4
fault

Figure 2.5. Sketch geological map of the area around Quin Zegal and Pointe Le Pommier showing the southern contact of the Port Moguer tonalite with the Plouha Series. Note the tonalite veins that cut the micaschists within the Plouha Series.

On the island of Quin Zegal[1] (078946) there is a zone that is rich in larger xenoliths (see Figure 2.5). These are irregular in shape and range in size from 5 cm to 5 m, the mean size being 30 to 60 cm. This zone ends abruptly, there being no apparent decrease in size or frequency of the xenoliths as the margin is approached. The tonalite that surrounds these xenoliths is mineralogically identical to that which lies outside of this xenolith rich zone but is less sheared, presumably due to an increase in mechanical strength due to xenolithic inhomogeneties. The origin of this zone is not clear, although there are three possible explanations:

(i) This may be a xenolith rich zone that is situated at the margin of the intrusion.

(ii) This may represent the breaking up and partial digestion of a large stoped block of country rock.

(iii) A combination of both of these.

The second explanation is preferred on the grounds that no such concentration of xenoliths is found anywhere the margin is approached, and secondly that if stoping of small blocks occurred at the margin it would be expected that these would die out gradually into the body of the intrusion. If this explanation is correct, the block must have been of very considerable size. It could extend up to 500 m. in any horizontal direction. The vertical height is not known but it must be greater than 10 m.

To the south of the contact, at Le Pommier, the amphibolites can be seen to be cut by irregular sheets of tonalite (Figure 2.5) that greatly resemble the rock type of the main intrusion. These sheets are

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1. Also known as Gouiane Segat.

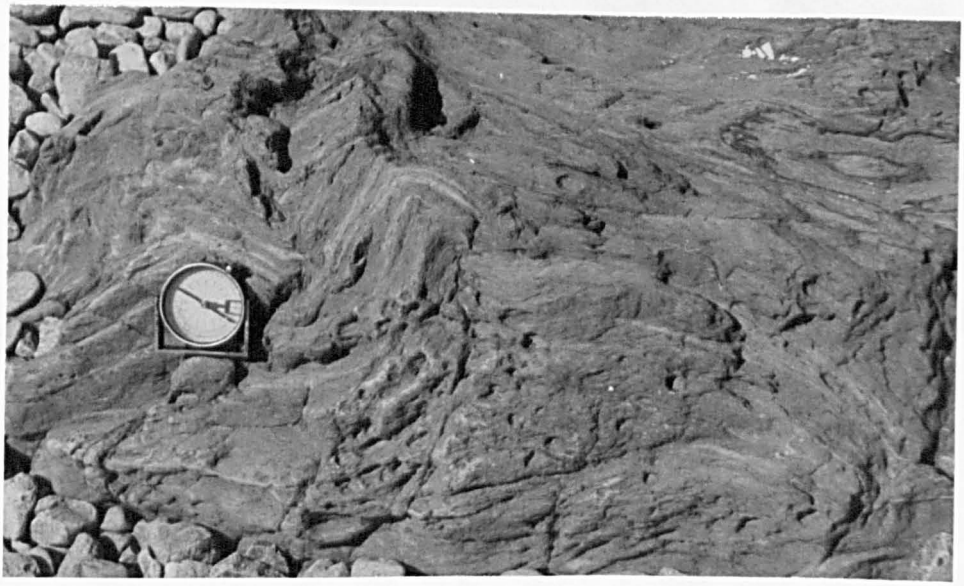
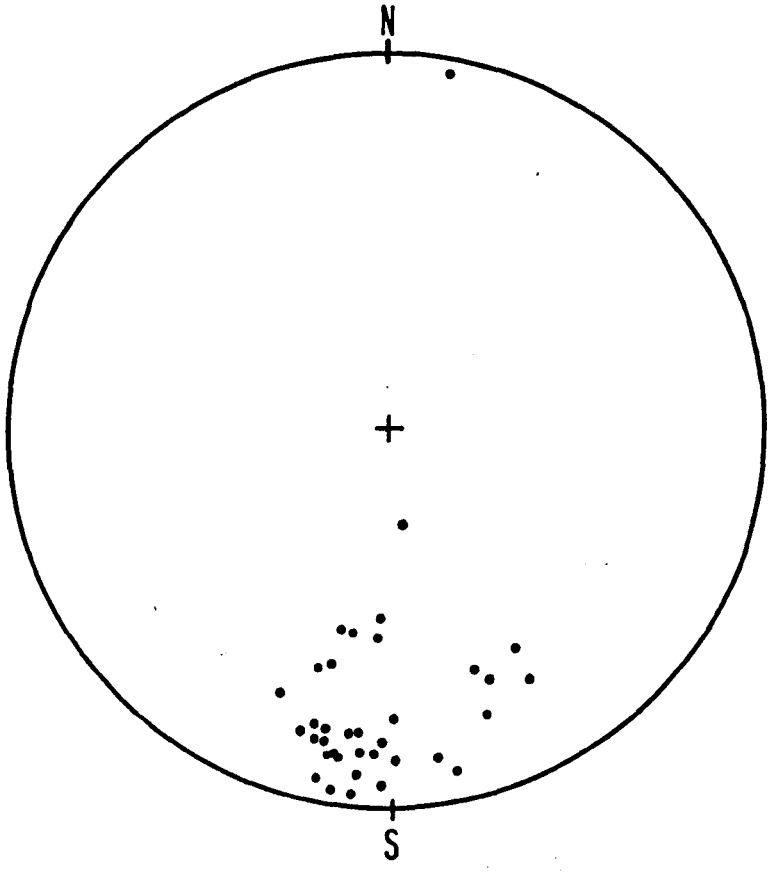


Plate 2.15. Folded retrogressed amphibolite dyke cutting Port Moguer tonalite at Quin Zegal.

Plate 2.16. Unaltered tonalite with xenoliths at Kerlohou quarry. Scale is in inches.



34 poles to Spm_1 (the majority of these readings were taken from the coastal section of the Port Moguer tonalite).

Figure 2.6. Stereographic projection showing the plots of 34 poles to the Spm_1 foliation within the Port Moguer tonalite.

slightly discordant to the foliation and the compositional banding of the amphibolites,but they are themselves foliated. This would suggest that the tonalite veined the country rock considerably at the margins and that the apparent simplicity of the contact is only due to subsequent faulting.

The tonalite is a white, yellow or pink coarse grained hypidomorphic rock that has a marked foliation. This foliation strikes east-west and dips steeply to the north (Figure 2.6). In the field the foliation is defined by the paralleism of micas and/or plagioclase laths, and the development of chloritised or quartz-rich shear zones. This foliation appears to die out as the centre of the body is approached.

The tonalite is cut by four phases of late aplite dykes and one phase of basic dykes. The latter are concentrated around the margins of the intrusion, particularly around Quin Zegal (Figure 2.5, Map 1). These are vertical and have an east-west strike. They are thoroughly retrogressed (Plate 2.15) and deformed, although their contacts with the tonalite are sharp and have not been disrupted tectonically. The first phase of aplitic dykes was intruded prior to the development of the foliation. Dykes of this generation have been broken up by the shearing that is associated with the development of the foliation and they now occur as trails of ellipsoidal bodies that have their long axes lying within the plane of foliation. The two subsequent phases that are found are seen to be generally parallel to the foliation within the tonalite, but they have been intruded after the development of this foliation and are not foliated. The earlier phase is made up of a yellow-white porphyritic aplite that in places may be seen to be cut by a later phase of pink porphyritic aplite that is sometimes

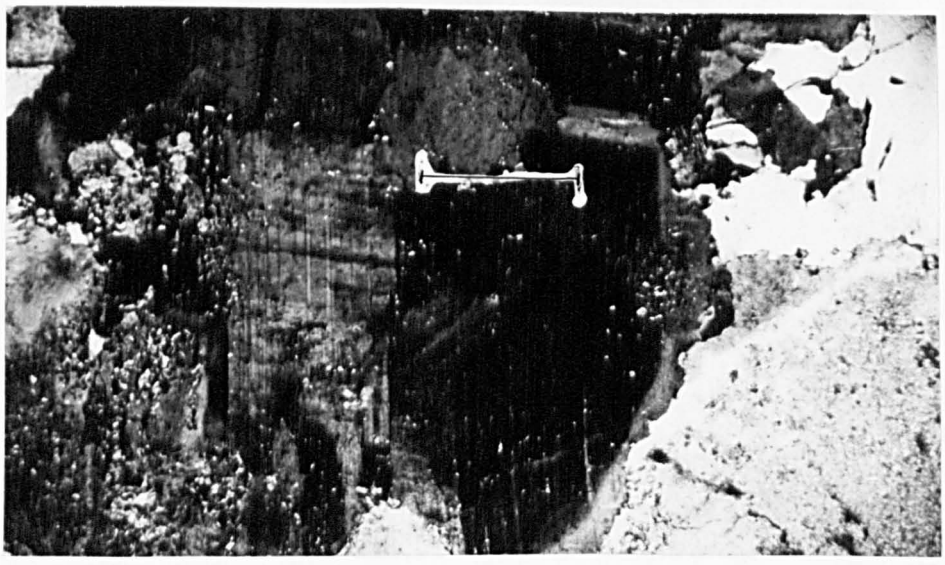


Plate 2.17. Photomicrograph (cn) of zoned plagioclase in tonalite from Kerlohou.
Scale 0.69 mm.

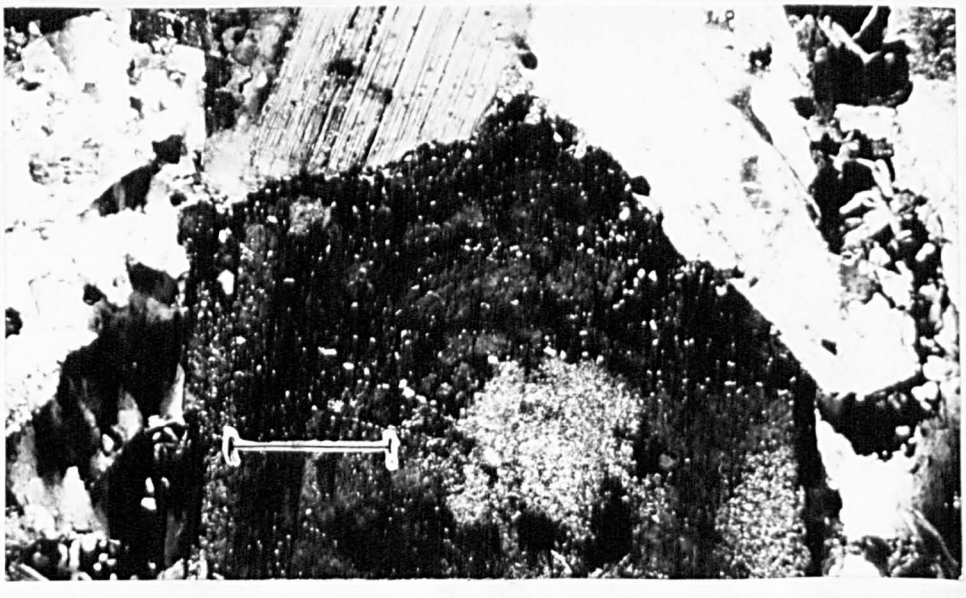


Plate 2.18. Photomicrograph (cn) of oscillatory zoning in plagioclase from tonalite at Kerlohou.
Scale 0.69 mm.

intruded along the same plane as the earlier aplite to form composite dykes. The last phase of intrusion is marked by irregulat thin veins of a very fine grained aplitic rock that may be seen to cut all the earlier phases of aplites and that are discordant to the foliation within the tonalite.

(d) The Original Nature of the Tonalite:

The nature of the original tonalite may be studied in the quarry at Kerlohou (Plate 2.16). At this locality the tonalite has not been sheared and is relatively fresh. It is a leucocratic coarse-grained hypidiomorphic rock comprised of quartz, plagioclase and biotite.

The plagioclase occurs as large 3-5 mm. subhedral laths that show well developed twinning according to the Carlsbad-Albite, Albite and Pericline laws. The Carlsbad twinning appears to be a primary growth twinning as the composition planes are irregular and occasionally show embayments. These plagioclases (An_{20-35}) show well developed broad euhedral oscillatory zones with very narrow rhythmic zones superimposed upon them (Plates 2.17 and 2.18). At the margins of these grains the last euhedral zone is overgrown by a zone of sodic plagioclase (An_{12},2V x 86^{o}-89^{o}) that apparently shows the same twinning as the rest of the grain. This zone varies in thickness from 0.05 -0.2 mm and shows ragged margins against quartz. Smaller equidimensional grains of plagioclase are found included poikilitically in quartz grains. These are found to display only the Carlsbad twin laws. Small anhedral grains of antiperthitic plagioclase up to 0.2 mm are found in the interstices between the large oligoclase grains and are enclosed poikilitically by quartz grains. Where these are in contact with quartz the contact is sharp but where in contact with the outer albitic rims of the plagioclase they are lobate and irregular. This would suggest that there had been

some reaction between these two phases. All the plagioclases are mildly seriticised.

The biotite is in the form of subhedral laths up to 3 mm. in length. These laths are elongate in form,with a length to breadth ratio of 2.5 to 1. The biotite shows a dark olive brown - dark brown pleochroism. They are often replaced by chlorite that grows along the cleavage.

Quartz occurs as large anhedral grains up to 5 mm. across, and as small interstitial grains between the crystal of biotite and plagioclase. They poikilitically enclose small grains antiperthitic andesine and sub poikilitically enclose biotite.

Small anhedral grains of magnetite are common. These may be seen to enclose grains of apatite that occur as a minor accessory. Very small grains of magnetite are enclosed poikilitically in the outer regions of the andesine grains.

The order of crystallisation of the primary igneous minerals in this tonalite is, in order of appearance, andesine, antiperthite, biotite, albite-oligoclase and quartz.

The fact that the euhedral zoning of the andesine is continuous and that there is no evidence of resorption or patchy zoning within these felspars would suggest that these crystals had grown slowly in the magma which had rested at one level. The growth of biotite and antiperthite would have also gone on at the same time but not to the same extent. The magma was then intruded to its present level and the more sodic felspars and quartz were the main phases to have crystallised from the liquid.

Deformation	Fold phase	Style	Lineation	Metamorphism	Mineral assemblages	Foliation
1	Fpg_1	isoclinal	....	Mpg_1	biotite + staurolite + plagioclase + quartz	Spg_1
2	Fpg_2	isoclinal to tight	....	....	.....	Spg_2
3	Fpg_3	isoclinal to tight	....	Mpg_2	biotite	Spg_3
4	Fpg_4	tight, angular	....	....	.....	....
5	Fpg_5	close to isoclinal, complex	....	Mpg_3	biotite	Spg_5 (75^o - 255^o)
....	....	.....	....	Mpg_4	quartz + andesine + biotite + andalusite + garnet (remobilised leucocratic portions of gneisses are intruded as veins parallel to Spg_5)	....
6	Fpg_6	tight	Lpg_6	....	.....	....
7	Fpg_7	close	....	....	.....	....

Table 2.1. Pentevrian structural and metamorphic history of the Port Goret gneisses.

C. The Pre-Brioverian Structural and Metamorphic History of the Pentevrian Basement.

1. Introduction.

The metamorphic and structural histories of the three Pentevrian groups will be dealt with separately. The following suffixes have been used to identify the group within which an event was identified: pg, Port Goret staurolite gneisses; ps, Plouha Series; pm, Port Moguer tonalite. Thus, for example, Fpg_1 is the first phase of folding recognised in the Port Goret gneisses and Mpm_3 is the third phase of metamorphism recognised in the Port Moguer tonalite.. An attempt to correlate these structural and metamorphic events within these groups will be made and a chronology of events during the Pentevrian era will be proposed.

2. Criteria for the evaluation of the structural histories.

The chronology of the folding has been evaluated by using the criterion of successive geometrical superpositions of folds of a later phase upon those of an earlier phase. Individual small scale structures have been assigned to a particular event when the associated fabric has been sufficiently distinctive to allow it to be differentiated from all other fabrics. Folds of a particular generation have not been recognised by their style as this is often varied by flattening during later events and this effect may not be constant over the whole region.

3. The structural and Metamorphic History of the Port Goret gneisses

(a) Introduction

These gneisses have been the subject of a special study as it is possible to enumerate which structures were developed prior to the deposition of the Brioverian. It has been possible to detect seven pre-Brioverian phases of deformation and four phases of associated metamorphism. These are summarised in Table 2.1.

Plate 2.19. Photomicrograph (ppl) of Mpg_1 staurolite in schists at Moulin plage. Relict Spg_1 (running from left to right) is enclosed in the staurolite. The Spg_1 foliation is crenulated in the matrix. Scale 0.69 mm.

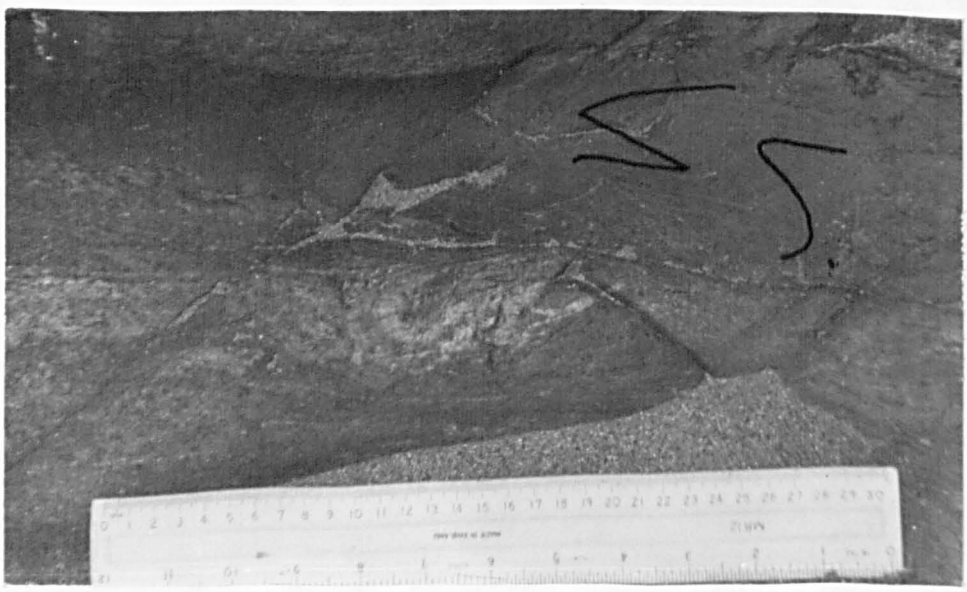


Plate 2.20. Fpg_1 folds at Moulin plage (in centre left of photo).

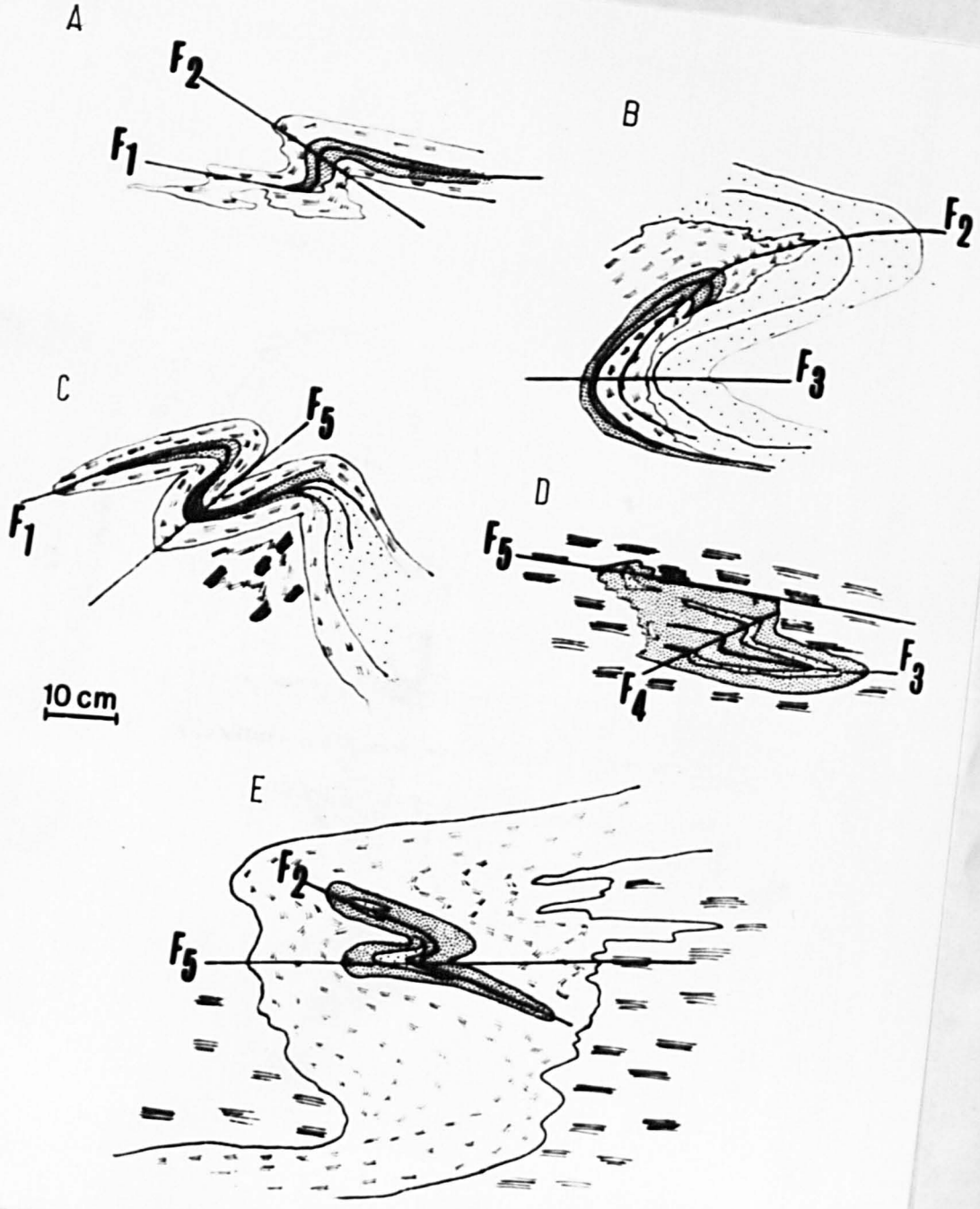

A
F2
F1
B
F2
F3
C
F5
F1
10 cm
D
F5
F3
F4
E
F2
F5

Figure 2.7. Sketches from notebook of interference structures found in the Port Goret gneisses. The hatched areas represent gneisses, the heavily stippled areas micaschists and the lightly stippled areas calc-silicate bands. The coarse hatching correspnds to rocks with a syn-F_{5p} fabric and the fine hatching to rocks with a syn-F_{1p} fabric.

The structural and metamorphic history presented below for these gneisses has been compounded from a study of the coastal exposures of the gneisses at Port Goret, Palus plage and Moulin plage. There are obvious disadvantages from using small outcrops to build up the structural chronology of such large area of rock, as the assumption must be made that all the structures within the Pentevrian are represented in the areas studied. The results obtained are for this reason not claimed to represent a full and complete account of the structural evolution of the Pentevrian basement. They are valuable however in that they show the Pentevrian to have a much more complex structural history than is suggested by some authors (e.g. Cogné, 1959 and Graindor, 1960).

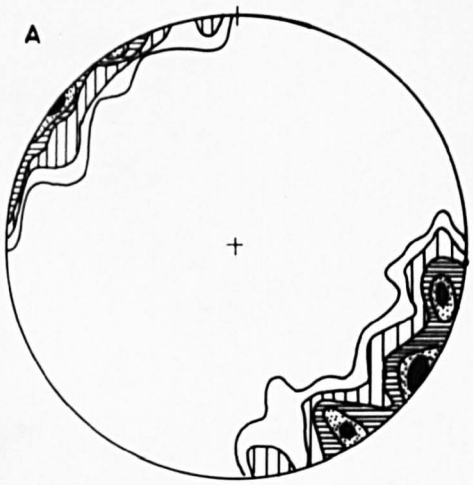
(b) First phase of folding Fpg_1 and associated metamorphism Mpg_1.

Isoclinal folds of this generation are found in the thinner bands of micaschist and calc-silicates at both Port Goret and Moulin plage (Plate 2.20 and Figure 2.7A,B and C). A penetrative micaceous foliation Spg_1 is developed that is parallel to the axial surfaces of these folds. This foliation is also developed in the bands of gneiss although no Fpg_1 fold closures have been recorded. This foliation is defined by parallel biotite flakes that are associated with the growth of staurolite porphyroblasts (Plate 2.19). These minerals were grown during the Mpg_1 phase of metamorphism.

Although the compositional banding is cut by Spg_1 in the hinge regions of the Fpg_1 folds, elsewhere it is parallel to Spg_1. This would suggest that any large scale folds of this generation are also isoclinal.

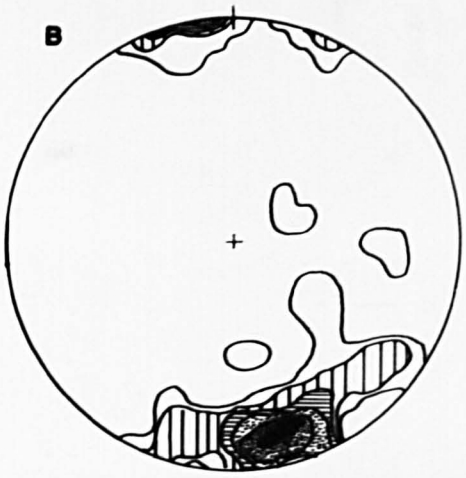
Small scale Fpg_1 fold closures are only preserved when the axial surface foliation Spg_1 is parallel or sub-parallel to the later foliation Spg_5 (Figure 2.8D). It would appear that all other Fpg_1 folds

A



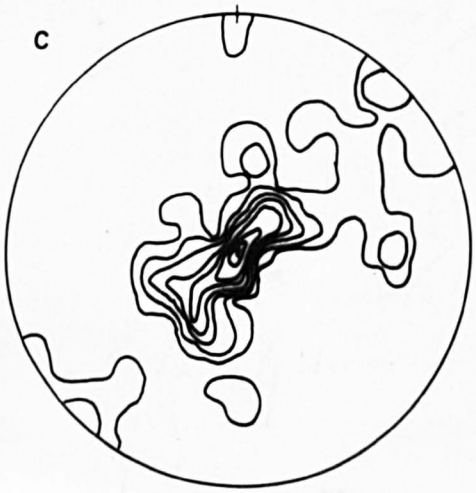
87 poles to Spg_5 at Port Goret
[contours at 1,3,5,8,11 %]

B



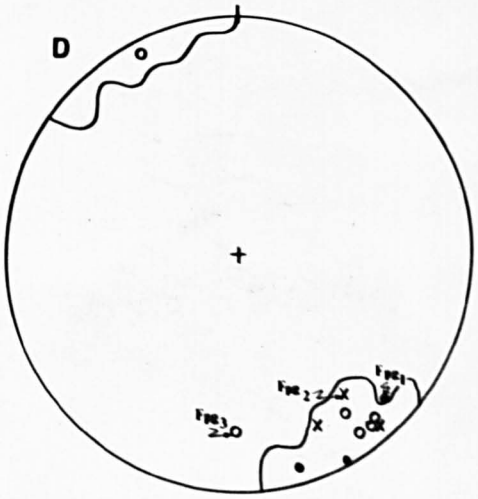
112 poles to Sps_4 [contours at 1,2,5,8,12,16 %]

C



69 axes small scale Fpg_5 folds
[contours at 1, 3, 5, 8, 10, 15%]

D



3% contour of Spg_5 in west of Port Goret and poles to axial surfaces early folds.

Figure 2.8. Stereographic projections of structures found within the Pentevrian: A) contoured plot to 87 poles to the Spg_5 foliation at Port Goret; B) contoured plot to 112 poles to the Spg_4 foliation within the Plouha Series; C) contoured plot og 69 axes of small scale Fpg_5 folds at Port Goret; D) 3% contour of poles to Spg_5 in the west of Port Goret and poles to the axial surfaces of earlier structures (closed circles = Fpg_1, crosses = Fpg_2 and open circles = Fpg_3).

that were of a different orientation had either been completely transposed during this later event or they had undergone rotation during the flattening that brought them into parallelism with Spg_5.

The Spg_1 foliation is the oldest penetrative foliation to be found within the gneisses. However this does not necessarily mean that there were no previous phases of folding, for it is possible that any earlier phase may not have had an associated penetrative fabric or if it had this fabric may have been transposed during the formation of the Fpg_1 folds and the Spg_1 foliation.

The textures and mineralogical assemblages that were developed during the Mpg_1 metamorphic event are not well preserved in the staurolite gneisses which have all undergone some degree of subsequent recrystallisation. However, these textures are preserved in bands of mica schist at Moulin plage (Plates 2.3 and 2.20). The mineralogical assemblage developed comprises quartz, oligoclase, biotite and staurolite. The quartz and the plagioclase form a granoblastic polygonal matrix of equant grains. The plagioclase has a composition of An_{28} and a $2V_x$ of 80^o to 84^o and shows rarely developed fine albite twin lamellae. The staurolites that are up to 1 cm in length are elongate in form and may occasionally poikiloblastically enclose quartz. They generally have an idioblastic to sub-idioblastic form often showing six sided basal sections with the {210} form much better developed than the {010} form. These porphyroblasts are usually oriented such that their axes lie within the plane of the foliation. The biotite which is elongate and exhibits a well defined foliation is concentrated in trails and the staurolites are often found in the intervening biotite poor regions. This concentration of biotite is due to a strain slip cleavage developed during the Fpg_2 phase of folding.

The same mineral assemblage appears to have been developed in the staurolite gneisses during this event. The schists differ, however, from the gneisses in the relative abundance of the constituent minerals. It has not proved possible to discover the mineral assemblages that were developed in the calc-silicate bands during this event. The mineral assemblages developed during this phase of metamorphism indicate that the amphibolite facies of regional metamorphism was attained.

(c) Second phase of folding, Fpg_2

These folds are found in both of the headlands. The closures are tight to isoclinal and are coaxial with the Fpg_1 folds whose limbs they fold, they also fold the foliation Spg_1. At Port Goret they are quite tight and are extensively developed as small scale structures but they do not have any associated axial surface foliation (Figure 2.7 A, B and E). In the south of the region at Moulin plage there has been a strong crinkling of the foliation Spg_1 during this phase. The structures that are developed are asymmetric with one limb extremely attenuated and a strain slip foliation Spg_2 parallel to the axial surfaces of these folds has begun to develop.

Although there is no penetrative axial surface foliation associated with the Fpg_2 folds throughout the area, the style of the folds and the fact that the strain slip foliation Spg_2 is not associated with any retrogression of the mineral assemblages formed during the Mpg_1 phase of metamorphism would suggest that the metamorphic conditions prevalent during Mpg_1 may have continued during Fpg_2, but no substantial recrystallisation took place after the cessation of Fpg_1.

(d) Third phase of folding Fpg_3 and associated metamorphism Mpg_2

Folds of this generation are found throughout the outcrop of the gneisses. They vary in style from isoclinal to tight structures with rounded closures. An associated foliation Spg_3, defined by biotite,

Plate 2.21. Closed Fpg_1 or Fpg_2/Fpg_3 interfernce structures at Moulin plage. The Spg_3 foliation is parallel to the ruler.

is developed parallel to the axial surfaces of these folds in the micaschists during the Mpg_2 phase of metamorphism (Plate 2.21). At Moulin plage remobilisation of the leucocratic portions of the rock has led to the injection of small tenuous veins of quartz and felspar parallel to the axial surfaces of these folds. These veins are usually only developed in the axial regions of these folds.

Where these folds are preserved their axial surfaces are often parallel or sub-parallel to the later transposing folation Spg_5 (Figure 2.8D). Fpg_3 folds refold the Spg_1 foliation and recognisable Fpg_2 folds (Figure 2.7B). This superposition of structures results in a variety of interference structures (e.g. Plate 2.21).

(e) Fourth phase of folding Fpg_4

A few small scale folds of this generation have been recorded at Port Goret. They have a wavelength of only a few centimetres and occur as close to tight asymmetric folds with rounded or angular closures upon the limbs of Fpg_3 folds (Figure 2.7D). The axial surfaces of these folds show a constant orientation with respect to Spg_3, always making an angle of approximatley 40° with this surface. There is no metamorphic fabric associated with these folds.

Fpg_4 folds are not associated with any major folds. They are not found elsewhere in the Port Goret gneisses and their equivalent is not seen in the other outcrops of Pentevrian. They are clearly only of local occurence and are not the product of any major Pentevrian deformation.

(f) Fifth phase of folding Fpg_5 and associated metamorphism Mpg_3

Small scale folds associated with this event are well developed throughout the gneisses. They vary greatly in style with both rock type and position but they may be easily identified as they are the last generation of small scale folds to have an associated axial planar

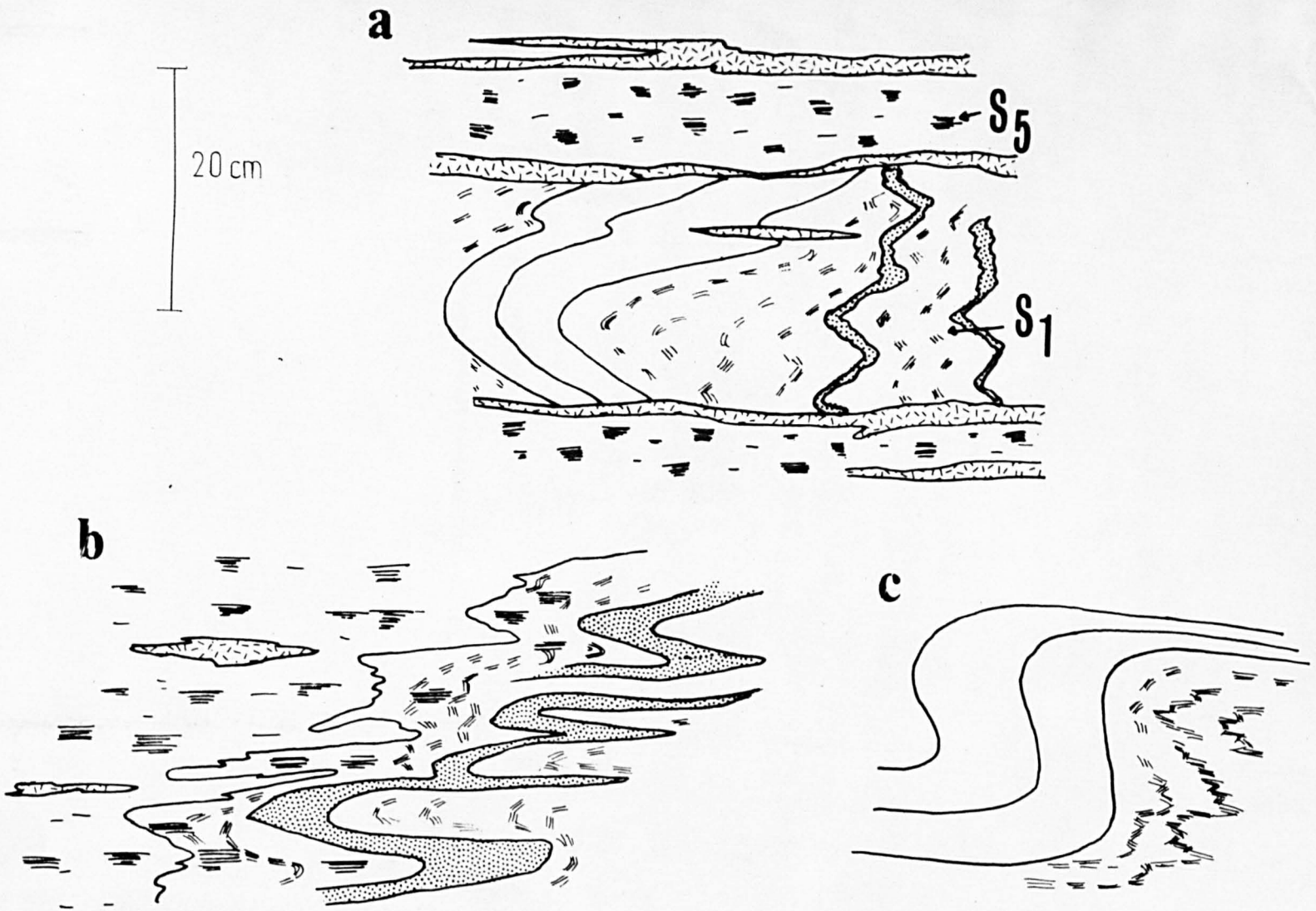

a
20 cm
S5
S1
b
c

Figure 2.9. Sketches taken from notebook illustrating the variation in fold style of the Fpg_5 folds at Port Goret; A) intrafolial fold within migmatised gneisses which exhibit the Spg_5 foliation; B) asymmetric isoclines in band of calc-silicate (stippled). Note the complexity of the contact within the gneisses; C) asymmetric close fold in banded gneisses. Note the marked change in limb thickness.

foliation Spg_5 which was developed during the Mpg_3 phase of metamorphism. This foliation is found as a penetrative fabric throughout the gneisses which often transposes earlier fabrics.

The small scale folds of this generation commonly have axes that are steeply inclined (Figure 2.8C) and their amplitudes or wavelengths are not in excess of a few tens of centimetres. Larger scale folds with wavelengths in excess of 30m may be identified at Port Goret on account of the change in symmetry of these small scale structures. A fold closure of thses larger folds is not seen, but the fact that the trend of the gneissic banding is always sub-parallel to the Spg_5 foliation would suggest that these folds are tight to isoclinal structures.

The style of these folds shows a marked variation, which is not only dependent upon the lithology of the band that is folded but is also controlled by the position of the fold in the gneiss outcrop. The folds are tighter and more flattened in the north than those in the south (Figure 2.9) there being a much greater attenuation of the fold limbs and hence an increase in the amplitude/wavelength ratio of these folds · This effect is associated with a change in the nature of Spg_5 which is a strain slip foliation in the south and a penetrative micaceous foliation in the north . The severity of the Mpg_3 recrystallisation that was associated with the development of this foliation in the north is indicated by the fact that there are many instances of intrafolial folds of micaschist or calc-silicate found in bands of gneiss (Figure 2.9). In the extreme north, near to the unconformity, earlier textures that were discordant to Spg_5 have been transposed, the only foliation found in the gneiss is Spg_5 while the compositional banding of the gneisses is only preserved where it is concordant with this foliation. Some of the earlier fabrics are preserved in the hinge regions of the larger scale Fpg_5 folds.

Within any one area the small scale Fpg_5 structures show a variation in style which is dependent upon rock type. Fold closures in the bands of gneiss are usually rounded although some display complex crenulations at the hinge region (Figure 2.9B), and do not show as much attenuation of the limbs as do those in the micaschist.Fold closures in the micaschists are complex and often angular. Folds in the calcsilicates exhibit rounded closures and extreme attenuation of the limbs so much so that they often become isolated (Figure 2.9C).

The mineral assemblages developed at Port Goret during the Mpg_3 event are quartz,plagioclase and biotite. The quartz and plagioclase form a polygonal granoblastic matrix and they show rational unilateral[1] boundaries with one another. The plagioclases are untwinned and their composition is approximately An_{20}. The biotite is in the form of elongate laths which define a foliation that is parallel to the axial surfaces of these folds. Biotite usually occurs at the contacts of the grains of the matrix and shows straight rational contacts with the surrounding grains. Occassionally, the biotite laths are enclosed subpoikiloblastically in quartz grains that display rounded irregular contacts, or they show serrated gradational contacts with plagioclase suggesting that there has been some reaction between these two minerals. These relationships would suggest that of these minerals, which were syntectonic and may have nucleated at the same time, plagioclase was the first to cease crystallisation and quartz the last. The retrogression of the staurolite porphyroblasts began during this event or possibly even earlier. At first they are replaced by a fine mesh of white mica at the margins which gradually spreads to replace the whole crystal. This white mica often pseudomorphs the staurolite, the original crystal outlines and even the cleavages are still discernible even in a completely replaced individual. As the staurolite is altered to white mica very fine granules of ore are exsolved. This mica although non-pleochroic

[1]Metamorphic textures are described using the terminology of Spry (1969).

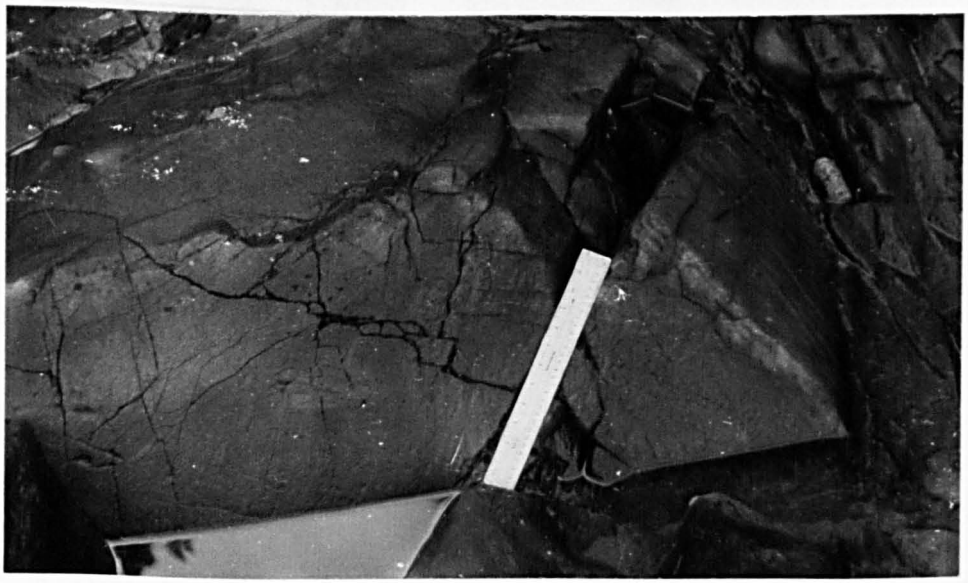


Plate 2.22 Fpg5 fold at Moulin plage. The ruler is parallel to the Spg_5 strain/slip cleavage.

Plate 2.23. Close up of Plate 2.22 showing the development of the Spg_5 strain/slip cleavage.

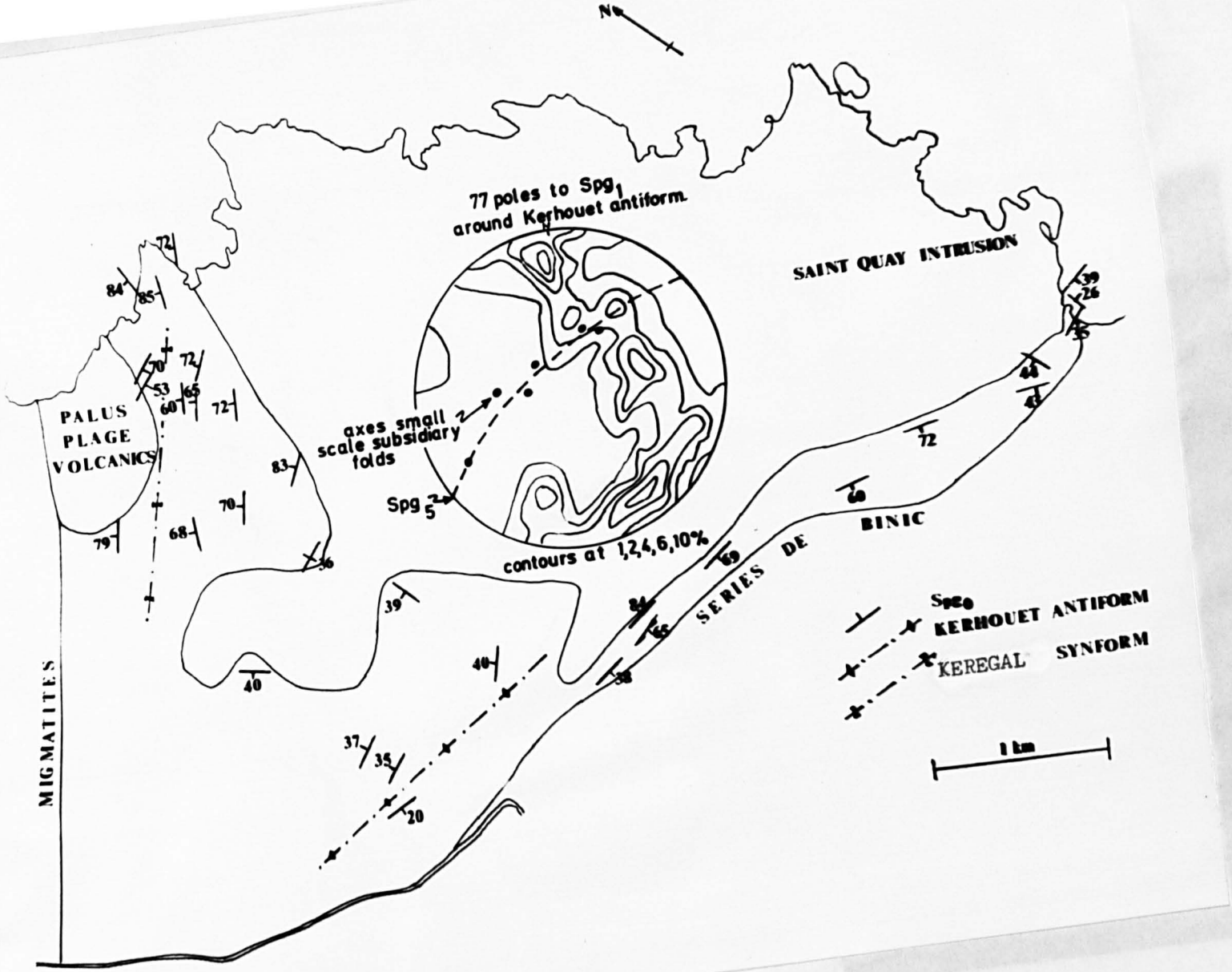
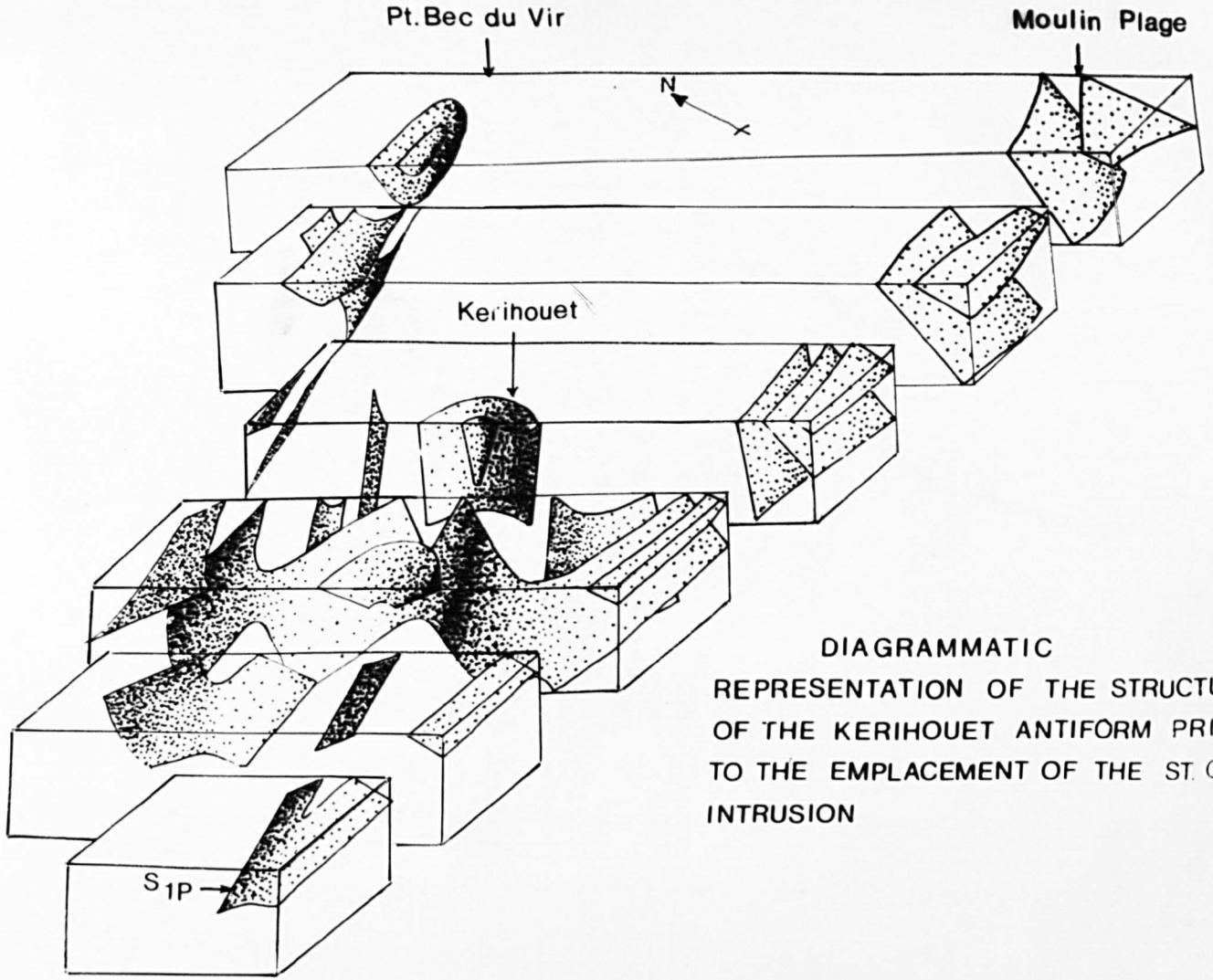

N
77 poles to Spg1
around Kerhouet antiform
SAINT QUAY INTRUSION
PALUS
PLAGE
VOLCANICS
axes small
scale subsidiary
folds
Spg 2
Spg 5
contours at 1,2,4,6,10%
SERIES DE BINIC
MIGMATITES
Spg1
KERHOUET ANTIFORM
KEREGAL SYNFORM
1 km

Figure 2.10. Structural sketch map of the Port Goret gneisses showing the attitude of the compositional banding Spg_0 and the location of the Kerhouet antiform and the Keregal synform. A contoured stereogram of 77 poles to Spg_1 (which is parallel to Spg_0 except at the rare Fpg_1 fold closures) measured around Kerhouet antiform shows the non-cylindroidal nature of the structure. Note that small subsidiary folds around this structure lie within Spg_5.



DIAGRAMMATIC REPRESENTATION OF THE STRUCTURE OF THE KERIHOUET ANTIFORM PRIOR TO THE EMPLACEMENT OF THE ST. QUAY INTRUSION

Figure 2.11. Sketch which attempts to reconstruct the form of the Kerhouet antiform and the Keregal synform S_{1p} prior to the emplacement of the Saint Quay intrusion.

is usually yellow in colour.

Complete recrystallisation did not take place during this event in the south of the region. The Fpg_5 folding produced tight asymmetric small scale folds with angular closures one limb of which has become attenuated to produce a strain slip foliation (Plates 2.22 and 2.23). At Moulin plage complete recrystallisation did not take place and a new generation of biotite that defines a foliation Spg_5 parallel to the axial surfaces of these folds has begun to grow, but only a few small individuals are developed at the hinge regions of these folds. In these rocks the staurolites are only partially retrogressed. A white fibrous mica is seen to grow around the margins of the grains. A phase of injection of quartz veins took place during this event. These veins which are found in the hinge regions of the Fpg_5 folds often cut across the hinges of these folds and are either partially folded or display ptygmatic structures.

A study of the compositional banding except at Fpg_1 closures, has shown that the majority of the outcrop of the Port Goret Staurolite gneisses is taken up by a large antiform, the Kerhouet antiform. The limbs of this structure dip away from the core, the northern limb strikes NE-SW and dips more steeply than the southern limb which strikes WNW-ESE to E-W. This non-cylindroidal fold has two hinge zones, one at Froidville (093886) and one at Kerlan (088897) as shown in Figures 2.10 and 2.11. In spite of the geometrically complex nature of the fold the axes of the individual closures fall upon a plane that is parallel to the axial surface of this structure (Figure 2.10 and 2.11).

To the north of the Kerhouet antiform there is a tight synform, the Keregal synform, whose vertical axial surface strikes ENE-WSW parallel to the Spg_5 foliation. The Keregal synform,unlike the neighbouring

antiform, is a simple symmetrical fold with both the northern and the southern limbs dipping steeply towards the core, its statistical axis plunges at 35° towards 245° east of north.

These folds do not affect the attitude of the small scale Fpg_5 folds (the last major penetrative Pentevrian fold phase) and were therefore formed during or prior toFpg_5. From the evidence available it appears that the axial surfaces of these major structures are sub-parallel to a later foliation Spg_5. Also,since the major structures have not undergone major refolding, they are thought to be of the same generation as the Fpg_5 small scale folds and were therefore the product of the last major Pentevrian fold phase to affect the region.

A tentative attempt to reconstruct the form of these folds is given in Figure 2.11. This diagram is only schematic and is solely intended to demonstrate the form envisaged for these folds in the light of the present evidence.

The non-cylindroidal nature of these folds must be attributed to a previous phase of deformation prior to the formation of the Fpg_5 Kerhouet antiform and the Keregal synform. As the Fpg_1 folds were isoclinal the pre-Fpg_5 major folding must have taken place during any of the Fpg_2, Fpg_3 or Fpg_4 phases of folding. The small scale structures associated with the Fpg_2 folding are everywhere isoclinal and coaxial with the Fpg_1 structures. The Fpg_4 folds are not widespread and are therefore unlikely to be associated with the development of large scale folds, thus it is probable that the non-planar form of the compositional banding prior to Fpg_5 was in the main attributable to the major phase of folding immediately prior to this event, that is Fpg_3. Although little can be deduced about the form of the Fpg_3 folds, the reconstruction of the form of the Spg_1 surface proposed in Figure 2.11 would suggest that their axes were approximately horizontal.

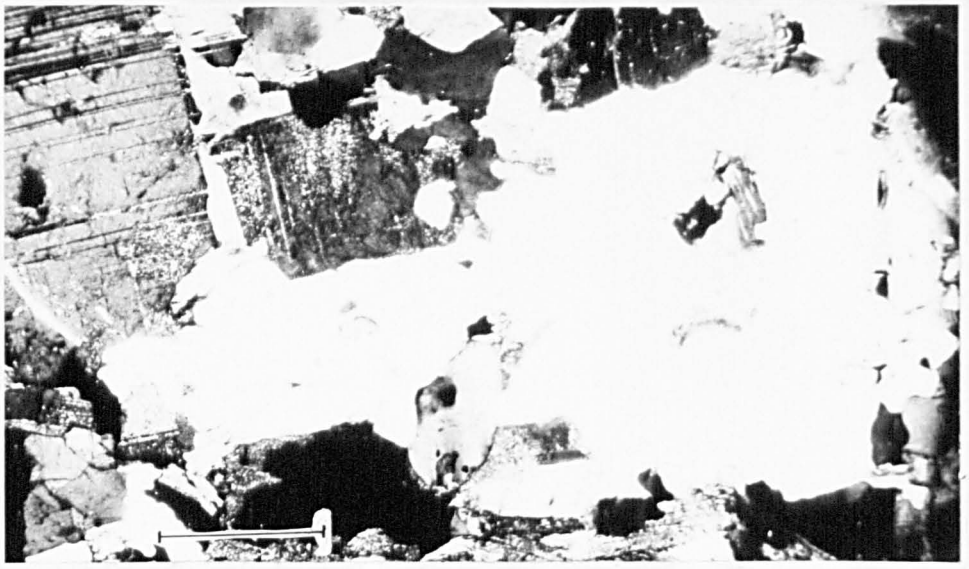


Plate 2.24. Photomicrograph (cn) of oligoclase and quartz in the remobilised portion of the gneisses at Port Goret. Scale 0.69 mm.

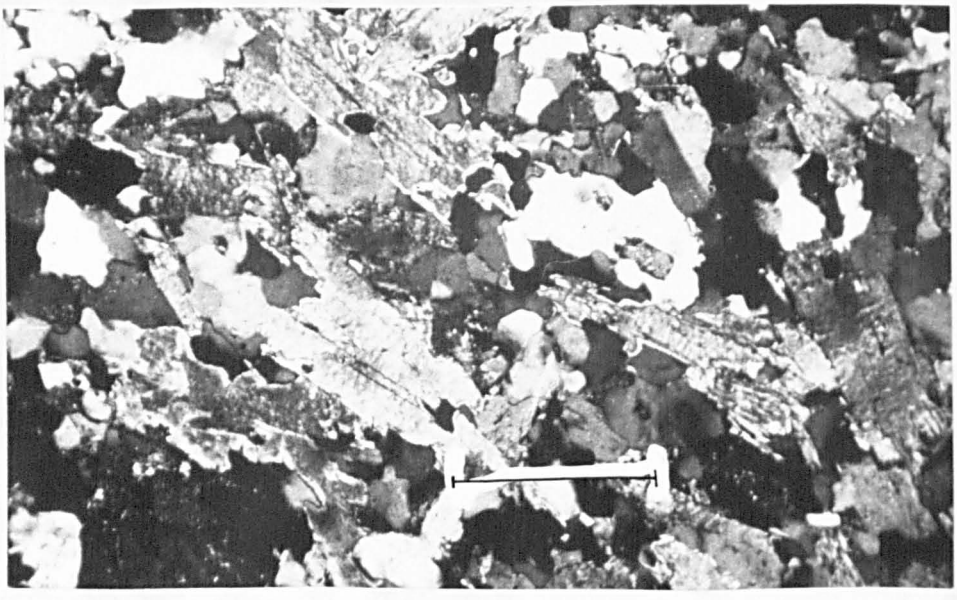


Plate 2.25. Photomicrograph (cn) of Mpg_4 static biotites in Port Goret gneisses at Palus plage. Scale 19 mm.

Plate 2.26. Photomicrograph (ppl) of Mpg_4 static biotites in gneisses at Port Goret. Scale 0.32 mm.

(g) The Mpg_4 phase of static regional metamorphism

This was a phase of static metamorphism that affected both the gneisses and the micaschists throughout the region. The mineralogical assemblages developed during this event are quartz + plagioclase + biotite + garnet + andalusite in the south at Moulin plage and quartz + plagioclase + cordierite + andalusite in the north by the unconformity at Palus plage. This event has also been associated with the remobilisation and injection of the leucocratic portions of the gneiss as veins that are parallel or sub-parallel to the axial surfaces of the Fpg_5 folds, produced during the previous phase of metamorphism. Recrystallisation and the growth of new minerals takes place to a much greater extent in the hinge zones of these folds and elsewhere.

The quartz recrystallised from small polygonal granoblastic grains to much larger irregular poikiloblastic grains with irregular lobate margins that form embayments in the plagioclase and that often include small rounded embayed plagioclase crystals (Plate 2.24).

The plagioclase also recrystallised to form larger crystals (Plate 2.24). These are poikilioblastic to very small inclusions of quartz that occur only in the centre of the plagioclase, and also to grains of biotite that are only found in the outer parts of the grains. These grains have irregular form and lobate margins with quartz and with other plagioclase. These plagioclases show well developed twinning according to the Albite and Pericline laws.

The biotites grew as static decussate overgrowths upon the earlier nematoblastic biotites (Plates 2.25 and 2.26). These are usually of similar size to the earlier biotites but they show a different pleochroic formula. Often an earlier nematoblastic biotite with well developed cleavages can be seen to be replaced mimetically by a later static biotite that grows in optical continuity with it. The later biotite

Plate 2.27. Photomicrograph (cn) of Mpg_4 garnet (centre right) remobilised portion of the gneisses at Port Goret. Scale 0.69 mm.

Plate 2.28. Photomicrograph (cn) of Mpg_4 garnet replacing a retrogressed Mpg_1 staurolite in micaschists at Port Goret. Scale 0.69 mm.

shows a different pleochroism, less well defined cleavage and inclusions of small,high relief,acicular crystals that are aligned along three directions that are at 120° to one another. These later biotites show irregular creulate margins with all the other minerals indicating that they have replaced these minerals. All biotites show pleochroic haloes around minute zircon crystals.

Subhedral garnet porphyroblasts (5mm across) occur throughout the gneisses (Plates 2.27 and 2.28). However they are best developed in the areas where remobilisation has taken place (Plate 2.27) or replacing the altered staurolites (Plate 2.28). Very small grains of andalusite (0.02mm across) are often associated with these garnets. At Port Goret the altered staurolite porphyroblasts have acted as a centre of nucleation for cordierite porphyroblasts (5mm across) that show sector twinning (Plate 2.29) and are full of inclusions of quartz, plagioclase and mica.

There has been a remobilisation of the leucocratic portions of the gneiss during this phase of metamorphism. This appears to have taken place only in the hinge zones of the Fpg_5 folds that were developed in the gneisses during the preceding phase of metamorphism. The remobilised portion of the gneisses is often intruded as leucocratic veins that are sub-parallel to the axial surfaces of these folds. This remobilisation is first marked by the growth of large poikilitic porphyroblasts of quartz. These generally start as several discrete grains that all have parallel extinction. At a further stage these grains are seen to coalesce and to replace both biotite and plagioclase. They are often filled with small embayed inclusions of plagioclase and their margins are irregular and lobate, particularly when they are in contact with the non-recrystallised plagioclase. This growth of quartz porphyroblasts is followed by the growth of irregular poikiloblastic

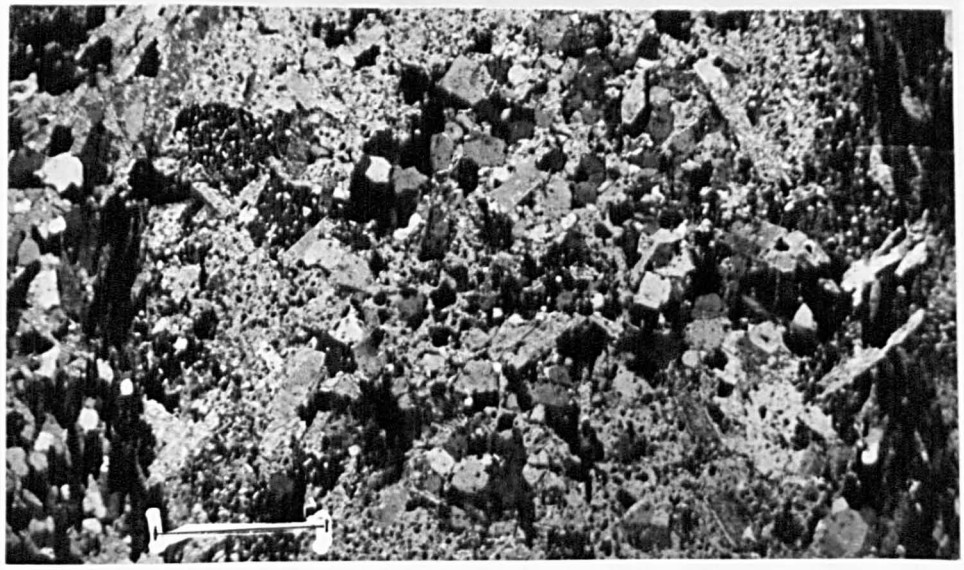


Plate 2.29. Photomicrograph (cn) of Mpg_4 cordierite in micaschists at Palus plage. Scale 0.69 mm.

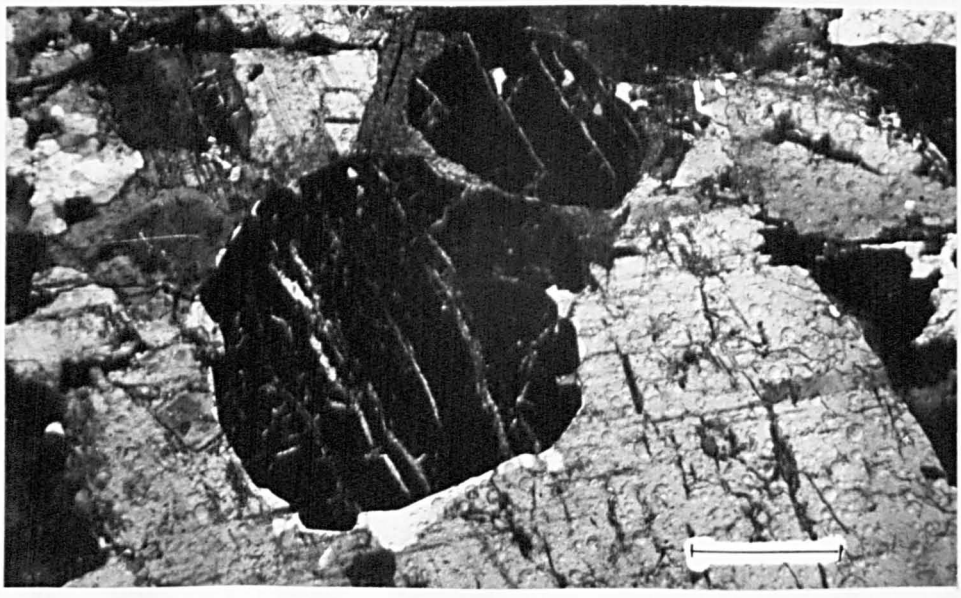


Plate 2.30. Photomicrograph of Mpg_4 garnets shown in tonalite veins which cut the Port Goret gneisses. Scale 0.19 mm (cn).

porphyroblasts of oligoclase An_{20-22},$2V_x 86^o$, which show twinning according to both the Albite and the Pericline Laws. (Plate 2.24). Each porphyroblast appears to have nucleated as a single grain that has grown outwards incorporating all other minerals. The quartz is apparently absorbed and then later exsolved as small square shaped,oriented inclusions within the plagioclase. The plagioclases have irregular lobate margins and the twinning is much more well developed than that of the plagioclase that grew during the previous phase of metamorphism. These new minerals coalesce into very fine veinlets in the hinge regions of the small scale folds. The veinlets appear to coalesce in their turn to form larger veins, 3-7 cm across, that are intruded sub-parallel to the axial surfaces of the F_{5p} small scale folds. These veins are generally irregular in thickness and often bifurcate but they may be up to 1m in length.

The tonalite veins that cut the gneisses in the north of their outcrop (Figure 2.1 and Map 1) and are probably associated with the Port Moguer tonalite are thought to have been intruded prior to this phase but post-Mpg_3. They show growth of decussate biotite flakes and garnets (Plate 2.30) in shear zones and replacing the igneous biotites. Also quartz-plagioclase intergrowths are developed at the margins of the igneous plagioclases.

(h) Sixth phase of folding Fpg_6

At Port Goret both the Spg_5 foliation and the leucocratic bands parallel to it are crenulated. These microcrenulations (Fpg_6), rarely greater than 1cm in amplitude and 2.5 cm in wavelength, are of irregular form and form a marked lineation (Lpg_6). This lineation is not associated with the development of any other large or small scale structures.

(i) Seventh phase of folding, Fpg_7

The Spg_5 foliation and the Lpg_6 lineation may be seen to be gently

Deformation	Fold phase	Style	Lineation	Metamorphism	Mineral assemblage	Foliation
1	Fps_1	isoclinal	....	?	(quartz + andesine + garnet + apatite ?)	Sps_1
2	Fps_2	isoclinal	....	Mps_1	quartz + oligoclase + biotite + hornblende + garnet	Sps_2
3	Fps_3	isoclinal to close	Lps_3	Mps_2	quartz + biotite + muscovite + andesine + hornblende + garnet	Sps_3
4 (south)	Fps_4	isoclinal to tight	Lps_4	....	.....	Sps_4 (crenulation)
4 (north, early)	Fps_4	cataclasis	....	....	.....	Sps_4 (mylonitic)
4 (north, late)	....	.....	Lps_4	Mps_3	quartz + oligoclase + hornblende	Sps_4 (penetrative)
....	....	.....	....	Mps_3 (south)	quartz + oligoclase + biotite + garnet + andalusite + hornblende + staurolite	....
5	Fps_5	gentle to open	....	....	.....	....

Table 2.2. Pentevrian structural and metamorphic history of the Plouha Series.

Metamorphic events:	Port Goret gneisses				Plouha Series (pelites)			Plouha Series (basites)			Port Moguer tonalite	
local	Mpg_1	Mpg_2	Mpg_3	Mpg_4	Mps_1	Mps_2	Mps_3	Mps_1	Mps_2	Mps_3	Mpm_1	Mpm_2
regional	M_{1P}	M_{3P}	M_{4P}	M_{5P}	M_{2P}	M_{3P}	M_{5P}	M_{2P}	M_{3P}	M_{5P}	M_{5P}	M_{6P}
Minerals:												
Sphene										X		
Magnetite		X							X		X	
Epidote											X	
Garnet			X	X			X		X			
Cordierite				X	X							
Andalusite				X			X					
Staurolite	X						X					
Hornblende								X	X	X	X	
Muscovite		X				X						
Biotite	X	X	X	X	X	X	X				X	
Oligoclase	X	X	X	X	X	X	X	X	X	X	X	
Microcline												X
Quartz	X	X	X	X	X	X	X	X	X	X	X	

Table 2.3. Mineral assemblages developed within the Pentevrian basement during the various Pentevrian metamorphic events.

folded by late folds Fpg_7 (Figure 2.8A) which have an axial surface that strikes 130°-310° east of north and dips at 87° to the south west. The axes of these folds plunge at 81° towards 74° east of north at Port Goret and at 26° towards 84° east of north Moulin plage. Fpg_6 fold closures are not exposed at Port Goret but they are found exposed on the beach at Moulin plage. The folds are gentle, the dihedral angle between the two limbs being in the order of 120°. There are no small scale folds r axial planar foliation associated with these folds, which have wavelengths of not less than 50m, although a mullion lineation is developed parallel to the axes of these folds at Moulin plage.

The pre-Brioverian structural and metamorphic history of the Port Goret gneisses is summarised in Table 2.1.

3. The structural and Metamorphic History of the Plouha Series.

(a) Introduction

The Plouha Series has not proved suitable for structural analysis as it is poorly exposed inland where it is often impossible to identify individual structures. As a result no major structures have been evaluated in this series. A structural and metamorphic chronology has been established however from a study of the rocks that are exposed on the coast between Palus plage and Port Logot, where the structural pattern is well preserved on account of the inhomogeneity of the Plouha series in this region. Elsewhere this series appears to be structurally very simple due to severity of a late cataclastic deformation which has resulted in the transposition of all pre-existing structures and metamorphic textures.

Five pre-Brioverian phases of small scale folding, Fps_1 to Fps_5 and three associated metamorphic events Mps_1 to Mps_3 have been recognised in this area, these are reviewed in Tables 2.2 and 2.3.

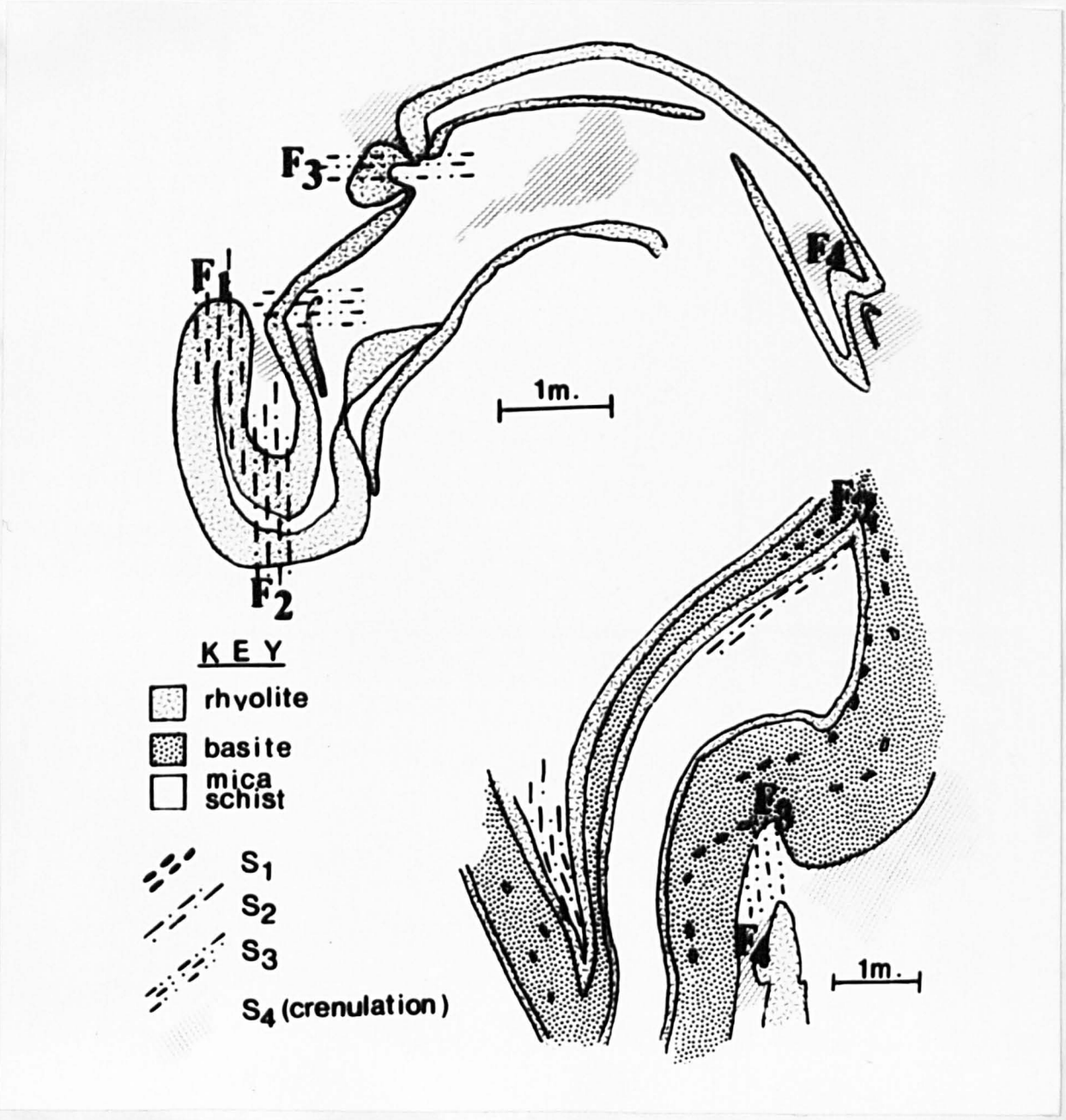

F3
F1
F4
1m.
F2
KEY
rhyolite
basite
mica schist
S1
S2
S3
S4 (crenulation)
F3
F2
1m.

Figure 2.12. Sketches taken from notebook showing the form of two complex interference structures found in the Plouha Series exposed to the north of Palus plage. Both the sketches were drawn looking westwards onto a vertical north-south cliff face.

Plate 2.31. F_{ps1} folds in metarhyolites at Palus plage. Field of view 20 cm.

(b) First phase of folding Fps_1

these folds are best preserved in the interbanded acid and basic sheets, where they are not uncommon (Figure 2.12A, Plate 2.31). No fold of this generation has been found in the pelites. They are isoclinal and show extreme attenuation of the limbs and a very large amplitude to wavelength ratio. They are always refolded by the later Fps_2 folds. In the basic lavas the amygdales are flattened and define a foliation that is folded by the Fps_2 folds and it is therefore thought to be associated with the Fps_1 folds.

The preservation of the foliation that is defined by the alignment of the ellipsoidal amygdales must indicate that these became structurally inert after the first phase of folding. This would suggest that these amygdales, that were originally filled with quartz, zeolites and chlorite, as may be deduced from their mineralogy (see page 2.9), underwent metamorphic recrystallisation during the Fps_1 event, and that the new minerals grown led to the amygdales becoming less ductile that the surrounding rock, and hence able to preserve this earlier texture. The garnet + quartz + apatite + andesine and andesine + quartz + apatite assemblages developed in these amygdales may therefore have been grown during a metamorphic event that accompanied the Fps_1 folding. However as no other textures that could have been associated with such an event are found it is felt that there is insufficient evidence to propose this possible event as a distinct phase of metamorphism (Table 2.2).

(c) Second phase of folding Fps_2 and associated metamorphism Mps_1

The Fps_2 folds are isoclinal and show severe attenuation of the limbs. Where they refold an Fps_1 structure the resultant interference structure is of type 3 (Ramsay 1967) indicating that the two phases of folding were coaxial (Figure 2.12A). A metamorphic foliation Sps_2 which is defined by biotites grown during Mps_1 and is parallel to the axial surfaces of

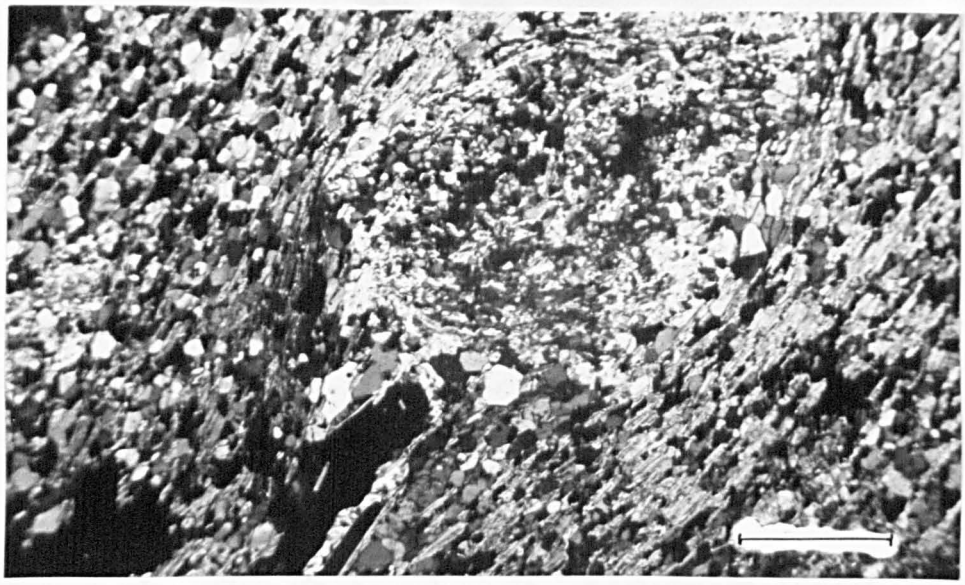


Plate 2.32. Photomicrograph (cn) of a partially retrogressed Mps_1 cordierite with a poor sygmoidal internal foliation (Sps_1 ?) in foliated (Sps_2) metasediments east of Plouha. Scale 0.69 mm.

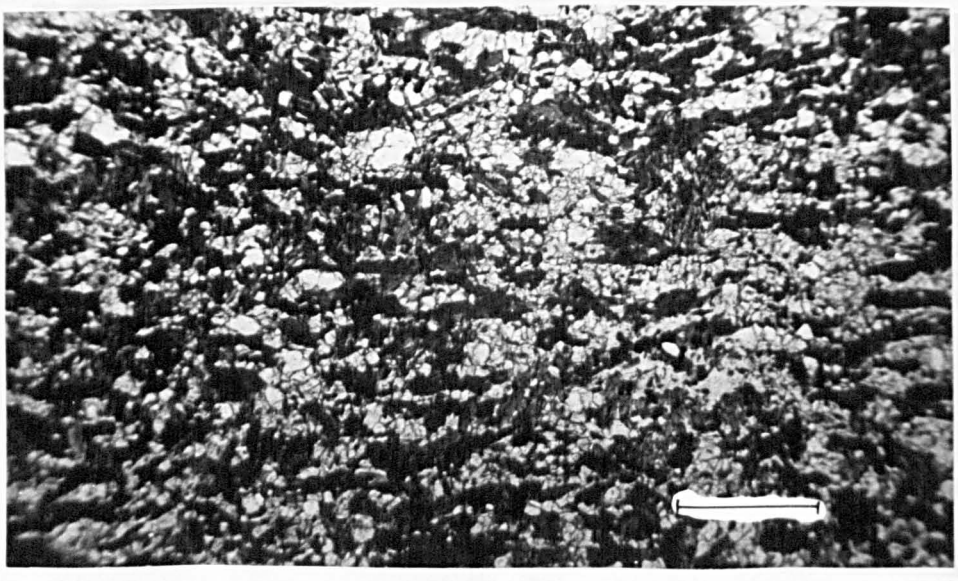


Plate 2.33. Photomicrograph (ppl) of metabasalt with relict Sps_3 foliation defined by Mps_2 hornblendes that are replaced mimetically by Mps_4 hornblended. Scale 0.69 mm.

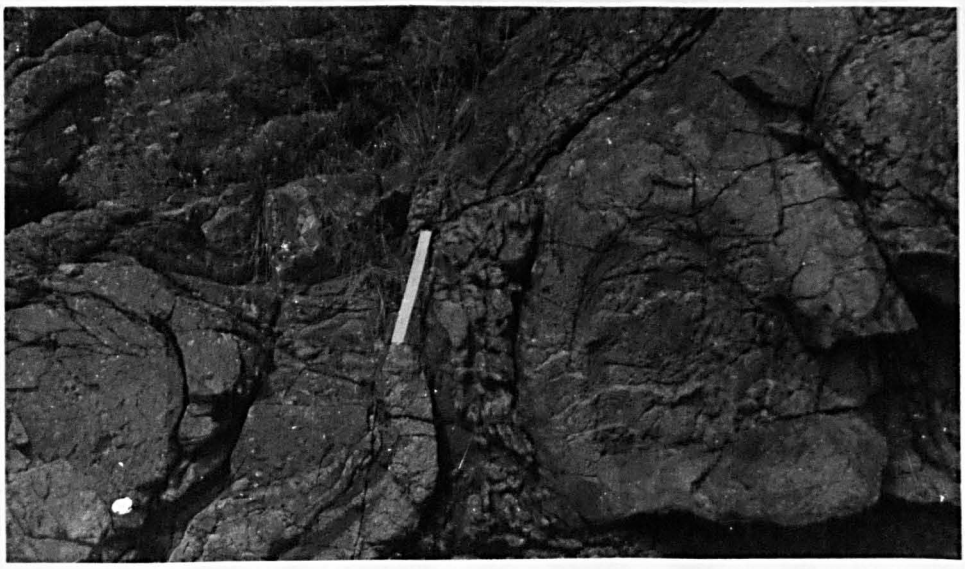


Plate 2.34. Fps_2/Fps_3 interference structures at Palus plage. Scale 30cm.

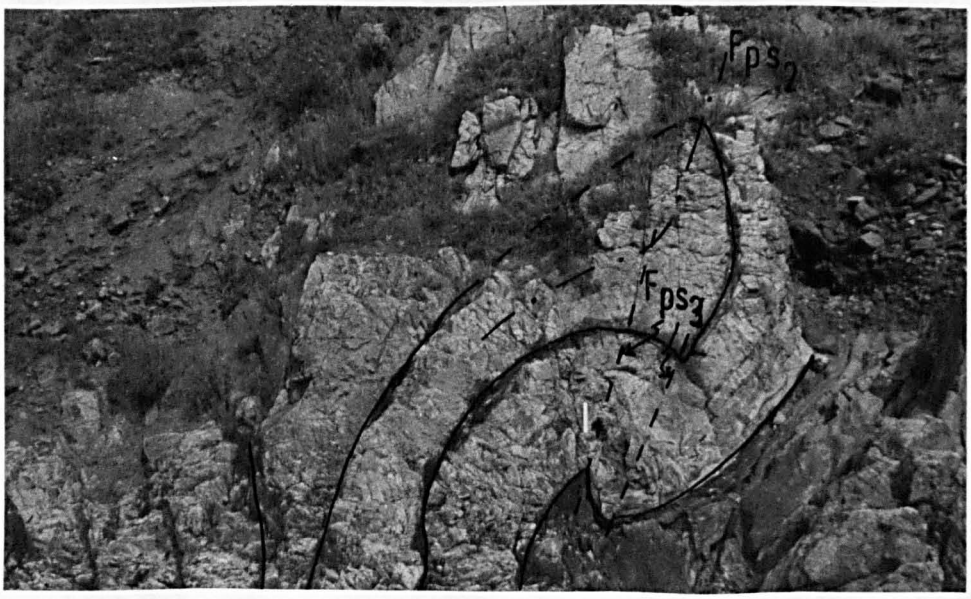


Plate 2.35. Fps_2/Fps_3 interference structure at Palus plage shown in Figure 2.12B. Scale 30cm.

of these folds, is found in the metasediments. This is the earliest recognisable Pentevrian metamorphic fabric within this sequence. Syntectonic poikilitic porphyroblasts of cordierite which contain sigmoidal trails of inclusions of quartz and ore needles were also grown in the metasediments during Mps_1 (Plate 2.32, Table 2.3). Occasionally a relict foliation parallel to Sps_2 which is defined by hornblende or biotite is found in Fps_2 closures in the metabasalts and metarhyolites respectively. Also in the metarhyolites, the amygdales are flattened and define a foliation that is parallel to Sps_2. The preservation of the earlier Sps_1 foliation by the amygdales in the metabasalts is presumably due to the fact that these were flattened and metamorphosed during Fps_1 and that the metamorphic assemblage developed at this time, resisted recrystallisation during Mps_1. This would mean that these amygdales were structurally inert during Fps_2, the fold phase associated with Mps_1. Quartzo-felspathic veins are found in both the metabasalts and the meta-rhyolites that are parallel to Sps_2.

(d) Third phase of folding Fps_3 and associated metamorphism Mps_2

Fps_3 folds are variable in style from tight to isoclinal. They are developed throughout this sequence of rocks and have a penetrative foliation developed parallel to their axial surfaces, Sps_3. This foliation is defined by the parallelism of biotite and hornblende crystals which were grown during Mps_2 (Plate 2.33) and constitutes the major metamorphic fabric of this series between Palus plage and Port Logot. Sps_3 is generally low lying or horizontal, the axes of the associated folds being horizontal with an east-west trend. Where these folds refold either Fps_1 or Fps_2 (Plates 2.34 and 2.35) they are coaxial with each of the two preceding phases, and in fact Fps_1, Fps_2 and Fps_3 are all coaxial. Where larger scale folds of this generation are observed they are isoclinal and recumbant with an amplitude of 10 m and a wavelength of 8m. The bands of basic lavas and of pelites within the cores of these folds are

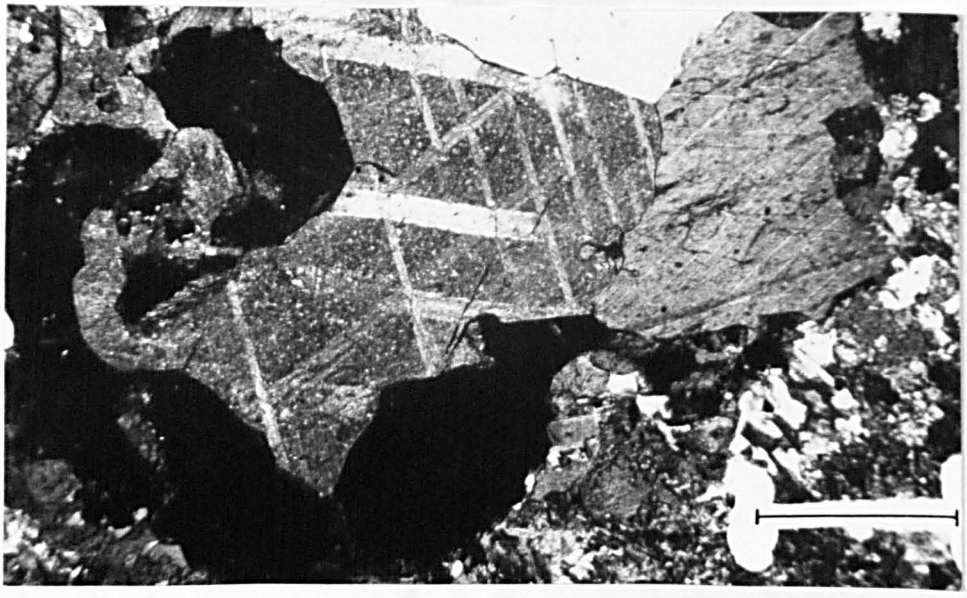


Plate 2.36. Photomicrograph (cn) of amygdale in metabasalts containing Mps_2 quartz and garnet which are replaced by Mps_4 calcite. Scale 0.69 mm.

Plate 2.37. Complex interference structure (outlined) in metasediments at Palus plage. Field of view 10 m.

well foliated and all the previous foliations are transposed, whereas the poor micaceous foliation Sps_2 found within the acid bands is not, and is folded into angular small scale folds whose axial surfaces are parallel to those of the larger scale Fps_3 folds.

Where the Sps_2 foliation is not transposed on the limbs of these folds it is crenulated, the axes of these crenulations defining a lineation Lps_3 that is parallel to the axes of the Fps_3 folds.

The Mps_2 metamorphism led to the development of a new biotite foliation, Sps_3, in the metasediments and the replacement of the Mps_1 cordierites by an agregate of quartz + plagioclase + white mica + biotite (Table 2.3). In the metabasalts a hornblende + andesine + garnet + quartz + magnetite assemblage was developed (Table 2.3). The acicular needles of hornblende (0.3mm) lie within the plane of the Sps_3 foliation, and smaller (0.1 mm - 0.2 mm) grains of andesine and subiodioblastic magnetite grains form the matrix (Plate 2.33). The amygdales have been replaced by either garnet + quartz + apatite or by quartz + andesine (An_{34}) + apatite (Plate 2.36). This variation must reflect the original composition of the amygdales which are ellipsoidal in form and often rimmed by quartz that is concentrated in pressure shadows. Textures associated with this event have not been recognised in other lithologies.

Deformation in this area was very complex and some of the resultant interference structures are difficult to interpret. The interference structures shown in Plates 2.34 and 2.37 only show fabrics which are associated with Fps_1, Fps_2 and Fps_3. However it is not possible to produce such structures from 3 phases of cylindroidal folding which the majority of

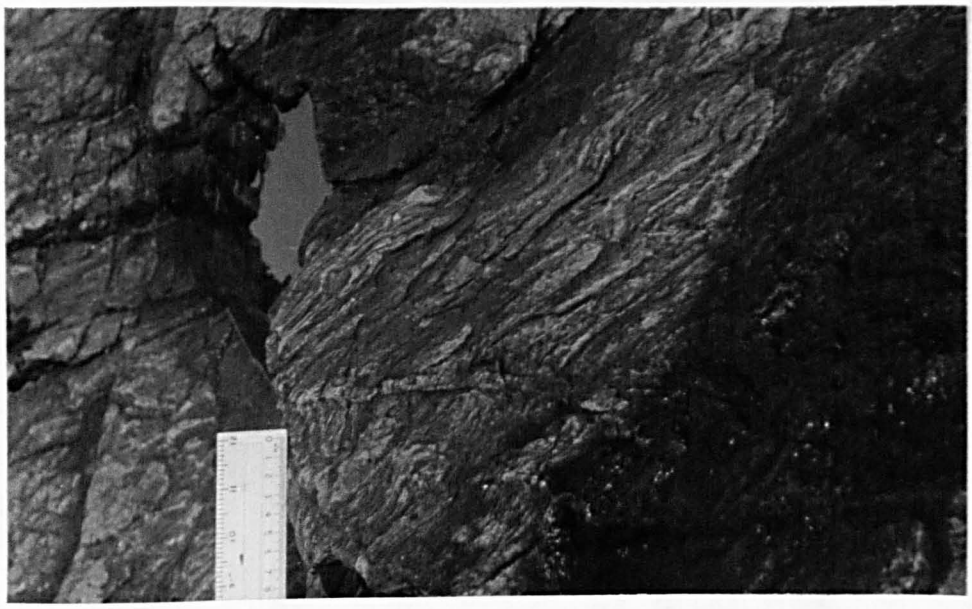


Plate 2.38. Asymmetric small scale Fps_4 folds which fold the Sps_3 foliation at Palus plage.

Plate 2.39. Folded Lps_3 lineation at Palus plage. Scale in cms.

structures suggest were coaxial. Such structures can only be interpreted as being the result of these phases of folding if, either locally the strain involved in these fold phases was inhomogenous, or there was some primary contortion of the banding. There still remain some structures that have not been fully interpreted and the sequence of events here proposed has been deduced from interference structures where individual fabrics have been recognised. No structures or fabrics have been found which suggest that a further event has been missed.

(e) Fourth phase of deformation Dps_4 and associated folding Fps_4.

Few large scale folds of this generation are seen although the Sps_3 foliation is strongly crenulated (Plate 2.38) and a good crenulation cleavage Sps_4, which has an east-west strike and dips at a moderate angle to the north is developed, which is found everywhere along the coast between Palus plage and Port Logot. The axes of these crenulations define a lineation Lps_4 that is variable in attitude but is always parallel to the axes of the neighbouring large scale Fps_4 folds. These larger scale folds have amplititudes of up to 10m and wavelengths of up to 20m, are tight to isoclinal in form and have been responsible for controlling the attitude of the structures in this region. Folding about the east-west striking axial surfaces has rotated all previous structures to their present east-west orientation.

It appears that one limb of the Fps_3 folds sometimes contained the "a" kinematic axis of the Fps_4 folds since, although these limbs are still planar, the Lps_3 lineation which they contain has been deformed (Plate 2.39). This also indicates that the folding, Fps_4, took place as a result of simple shear rather than flexural slip (Ramsay 1967).

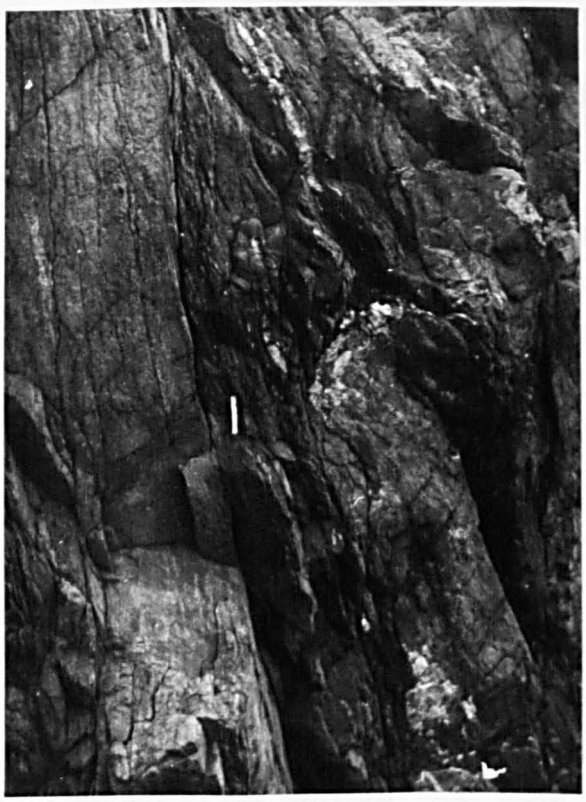


Plate 2.40. Sheared Plouha Series (banding dips steeply to the north) at Bonaparte plage. A late Cadomian flexure occurs in centre of photograph. Scale 30 cm.

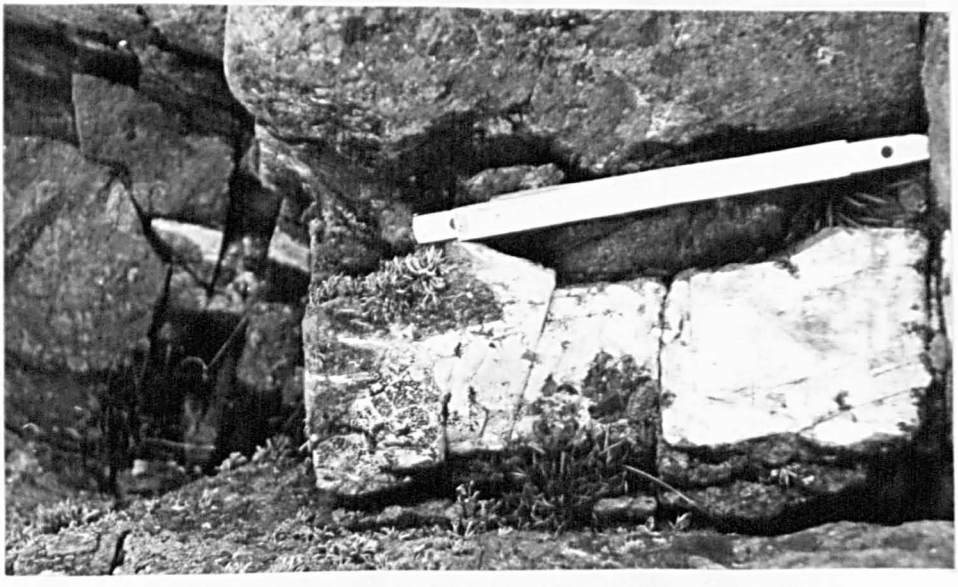


Plate 2.41. Small scale Fps_4 fold with comples closure in aplite at Pointe Plouha.

Plate 2.42. Small scale Fps_4 fold with angular closure in aplite at Pointe Plouha.

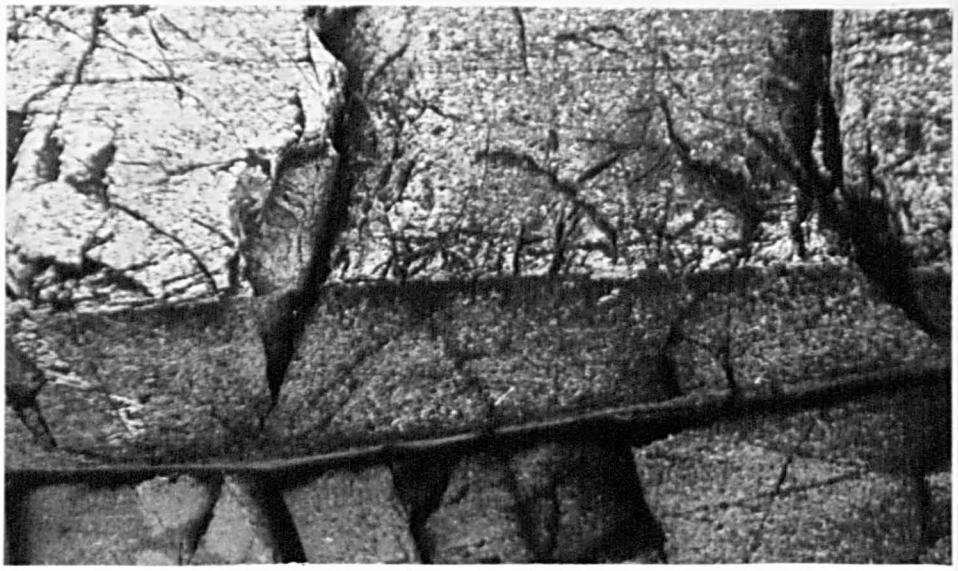


Plate 2.43. Sharp contact between the aplites and the sheared metabasalts (darker coloured) in the Plouha Series at Pointe Plouha. Field of view approximately 30 cm.

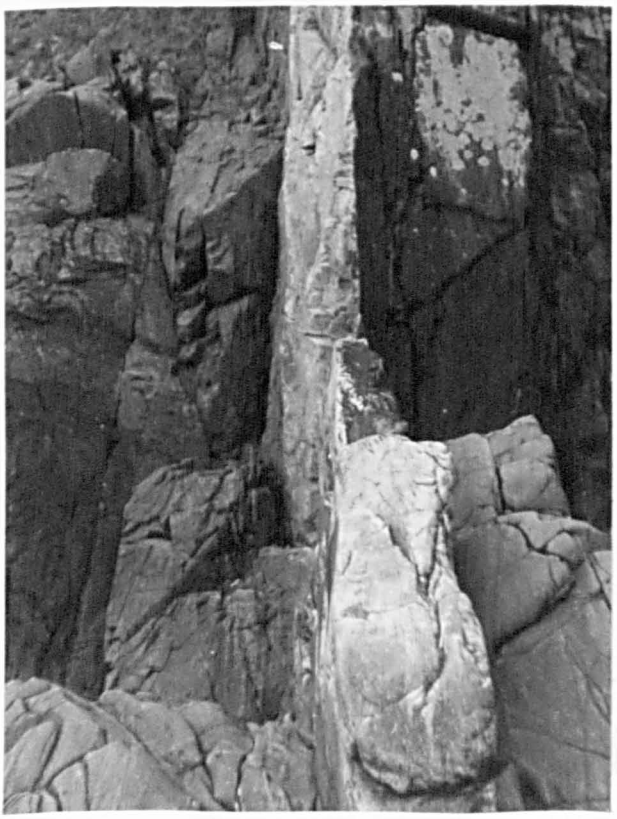


Plate 2.44 Vertical aplite vein cutting the Plouha Series at Pointe Plouha. The vein is parallel to the Sps_4 foliation and is approximately 25 cm wide.

To the north of Port Logot the style of deformation changes. The major penetrative fabric is a mylonitic foliation that transposes all previous structures. This foliation strikes 75^{o}-255^{o} east of north and is vertical or dips steeply to the south (Figure 2.8B). This foliation is correlated with Sps_4 in the south on the grounds that: 1) it has not been subjected to any major folding, late warps being the only subsequent structures to be developed; and 2) the rocks in this region have undergone a late to post-deformational metamorphic event Mps_3 which has affected the rest of the Plouha Series (Tables 2.2 and 2.3). This metamorphic event always occurs as a late tectonic to post-tectonic event, closely related to the last major phase of Pentevrian deformation Dps_4.

In the cataclased Plouha Series (Plate 2.40) north of Port Logot, the Sps_4 foliation is parallel to the axial surfaces of the rare Fps_4 fold closures that occur (Plates 2.41 and 2.42). Fold closures that may be attributed to an earlier phase of deformation are absent in this area. Those Fps_4 folds which are preserved are tight to isoclinal with angular closures (Plates 2.41 and 2.42) and axes of variable orientation. They occur where thick bands of acid material, which are surrounded by massive amphibolites, are folded. It is thought that the less competent amphibolite protected the more competent acid bands from the effects of the cataclastic deformation. Bands of relatively unsheared acid material occur which are always oriented parallel to the foliation. It is thought that these were originally concordant with the cataclastic foliation and therefore did not themselves undergo such severe deformation during this event (Plates 2.43 and 2.44).

A discussion on the variation in the nature of the Dps_4 deformation is given on page 2.43.

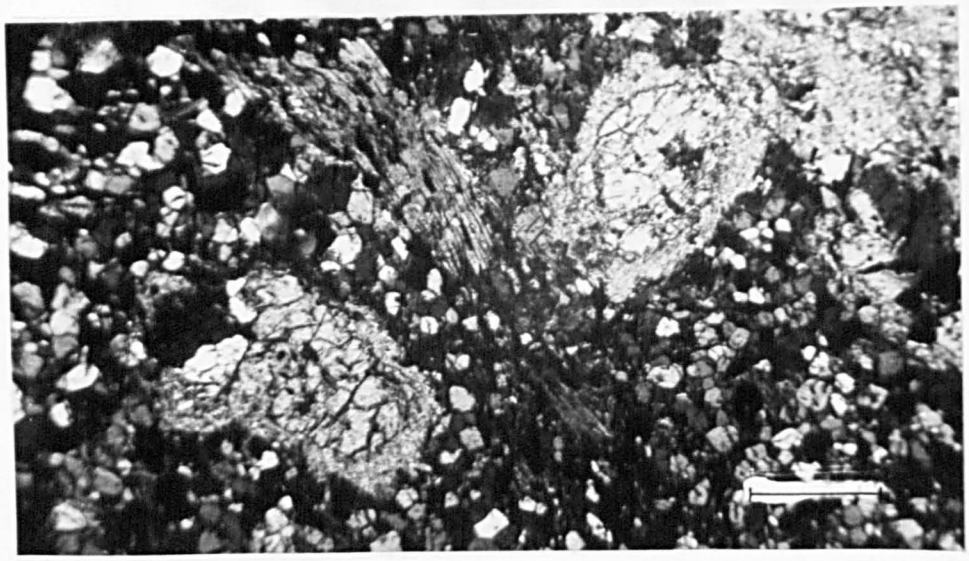


Plate 2.45. Photomicrograph (cn) of partially retrogressed Mps_3 staurolites in the metasediments to the north of Palus plage. Scale 0.69 mm.

Plate 2.46. Photomicrograph (cn) of a sheared porphyroblast now replaced by irregular mica plates in the metasediments at Pointe Plouha. The foliation seen in the photograph is Sps_4. Scale 0.69 mm.

(f) Third phase of metamorphism Mps_3

This phase of late to post-tectonic metamorphism led to the development of amphibolite facies assemblages and static metamorphic textures throughout the Plouha Series (Table 2.3). Within the metabasalts static porphyroblasts of hornblende are well developed in the more sheared bands and in the regions between the Sps_4 crenulation cleavage planes, in the less sheared bands. Mimetic hornblendes that lie within the Sps_4 foliation are grown in bands of sheared metabasalt between Port Logot and Pointe de la Tour. Hornblende also replaces the margins of the garnets that occur in the amygdales. Sphene occurs in the matrix as small (0.2mm) sub-idioblastic wedge shaped grains. In the metasediments a staurolite + quartz + plagioclase + andalusite ± garnet assemblage was developed during Mps_3 (Plate 2.45). The matrix of the metasediments has been recrystallised to a polygonal equigranular aggregate of quartz and plagioclase whilst staurolite porphyroblasts that may be up to 2cm across are seen to either replace the Mps_1 cordierite directly or to replace altered cordierite. The garnet grows exclusively in the altered cordierites. Andalusite replaces both the biotite in the matrix and the white mica that replaces the cordierite. To the north of Palus plage large retrogressed porphyroblasts of andalusite up to 5cm across are developed.

To the north of Port Logot, where the effects of the cataclastic deformation Dps_4 are well developed, all previous textures have been obscured and the metasediments are represented by fine grained quartz + oligoclase + biotite schists, no porphyroblasts being developed (Plate 2.46). This would suggest that the pre-existing cordierite porphyroblasts acted as a centre of nucleation for the later minerals and that where these cordierites had been destroyed during the

Plate 2.47. Late Fps_5 flexure in metabasalts at Palus plage. This photograph was taken from the north. Scale 30cm.

Deformation	Foliation	Metamorphism	Mineral assemblage
		....	.....
Dpm_1	Spm_1 (cataclastic)		
Dpm_1	Spm_1 (metamorphic)	Mpm_1	Biotite, quartz, oligoclase, epidote, hornblende, magnetite ± garnet.
....	....		
....	....	Mpm_2	Metasomatic muscovite

Table 2.4. Pentevrian Structural and Metamorphic History of the Port Moguer tonalite.

cataclasis, nucleation of such minerals as staurolite, andalusite and garnet did not take place.

The quartz + andesine + biotite assemblage found in the acid igneous rocks, the aplites and the granite gneisses, were developed during this event. The matrix of these rock types, where they have not been sheared, is comprised of a polygonal aggregate of quartz + andesine + biotite. The biotite grows as decussate plates.

(g) Fifth phase of folding Fps_5

This is a late phase of folding about axial surfaces that strike ENE - WSW and dip at a moderate angle to the SSE. These folds are gentle to open (Plate 2.47) and have no associated metamorphic fabric. They can be seen to fold the Sps_4 foliation and were therefore developed after the Fps_4 phase of folding.

4. The structural and metamorphic history of the Port Moguer tonalite

(a) Introduction

The Port Moguer tonalite has undergone at least two phases of Pentevrian metamorphism subsequent to its intrusion and solidification, which have resulted in a variety of mineral assemblages being formed. Its structural history is simple with only one penetrative foliation developed. The sequence or events is reviewed in Table 2.4.

(b) Cataclasis Dpm_1 and formation of Spm_1 foliation

Subsequent to the injection of aplite dykes the tonalite underwent a phase of cataclasis Dpm_1 which resulted in the formation of the Spm_1

Plate 2.48. Photomicrograph (cn) of a plagioclase grain in the sheared tonalite at Port Moguer. Scale 0.69 mm.

Plate 2.49. Photomicrograph (cn) of a shattered and strained quartz grain in the blastomylonitic tonalite. Scale 0.69 mm.

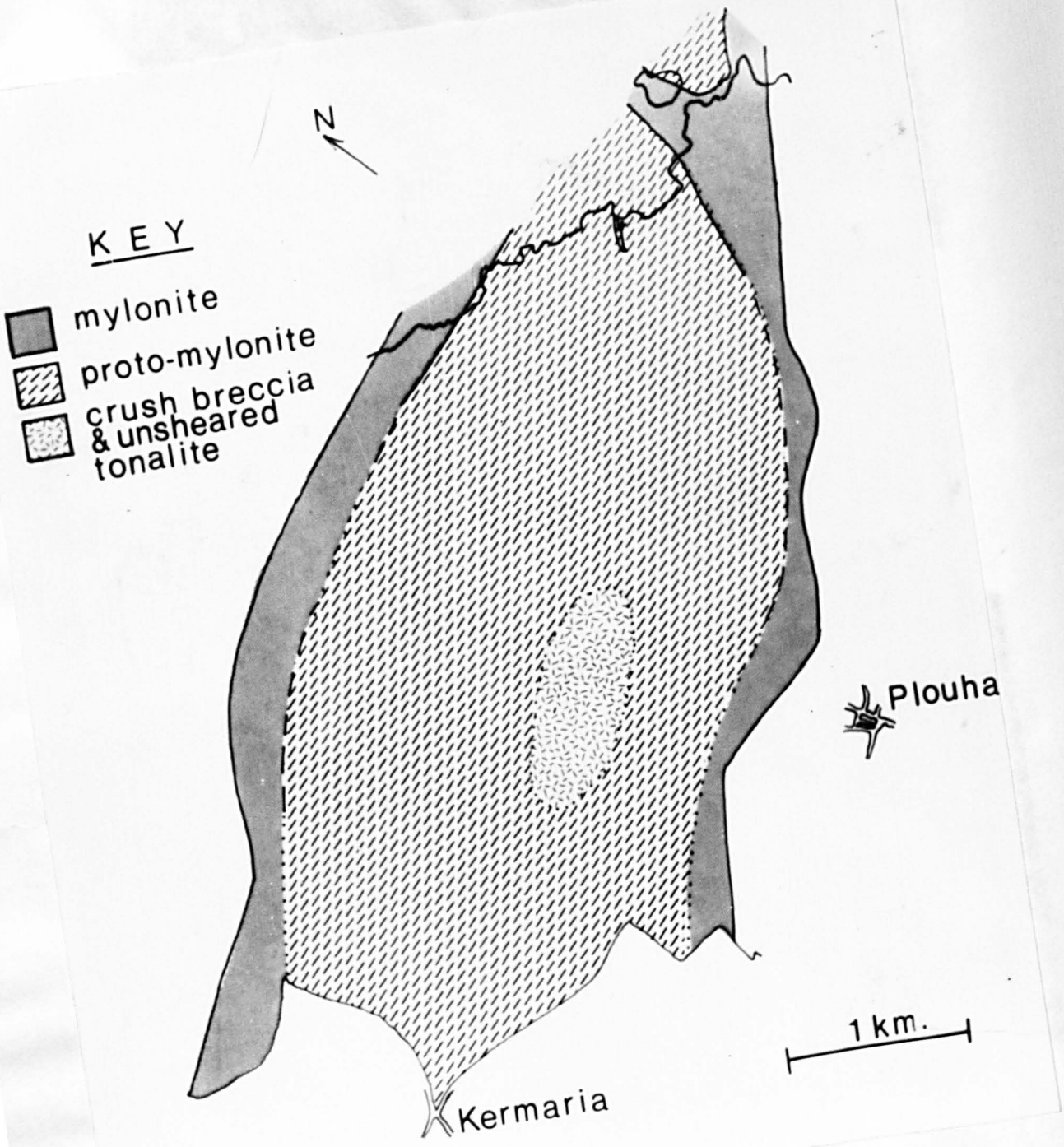

N
KEY
mylonite
proto-mylonite
crush breccia & unsheared tonalite
Plouha
1 km.
Kermaria

Figure 2.13. Sketch geological map of the Port Moguer tonalite showing the varying degree of cataclasis within the body.

foliation. This foliation has an almost east-west strike and dips steeply to the north (Figure 2.6). As it is unlikely that the tonalite would have undergone any appreciable flattening or rotation after this event because of its size and as the later static recrystallisation resulted in this body becoming a homogenous rigid body, this orientation of Spm_1 may be taken as the original attitude of this foliation. The extent to which the tonalite has been affected by this event appears to decrease as the centre of the body is approached (Figure 2.13). The margins of the intrusion are comprised of mylonites with 60% to 90% of crushed matrix. Elongate porphyroclasts of sericitised plagioclase lie sub-parallel to the mylonitic foliation Spm_1 within the matrix. These plagioclases are often bent and display a marked development of deformation twinning. Plagioclase laths whose long axes are not parallel to Spm_1 are much less sericitised than those whose long axes lie within Spm_1. This may be due to the fact that the less sericitised plagioclases lie in a less sheared portion of the tonalite as they have not been rotated into parallelism with Spm_1. The age of this sericitisation is not clear. Only the original igneous plagioclases are sericitised, subsequent overgrowths are not. This could indicate that either this was associated with the earliest event Dpm_1 or that it took place later but only affected the more calcic primary plagioclase.

The central two thirds of the intrusion, and the region around Quin Zegal that is rich in xenoliths, are made up of protomylonitised tonalite with only 10% to 50% of the original tonalite being reduced to a crushed matrix (Plates 2.48,2.49). In some instances the protomylonites are replaced by proto-cataclasites that show no foliation. As previously mentioned, the tonalite in the centre region of the intrusion at Kerlohou has not been cataclased to any great extent. The large quartz grains all show strained extinction and are

Plate 2.5O. Photomicrograph (cn) of crushed tonalite showing lighter oligoclase rims on the plagioclases and decussate biotites replacing the igneous biotites (centre). Scale 0.69 mm.

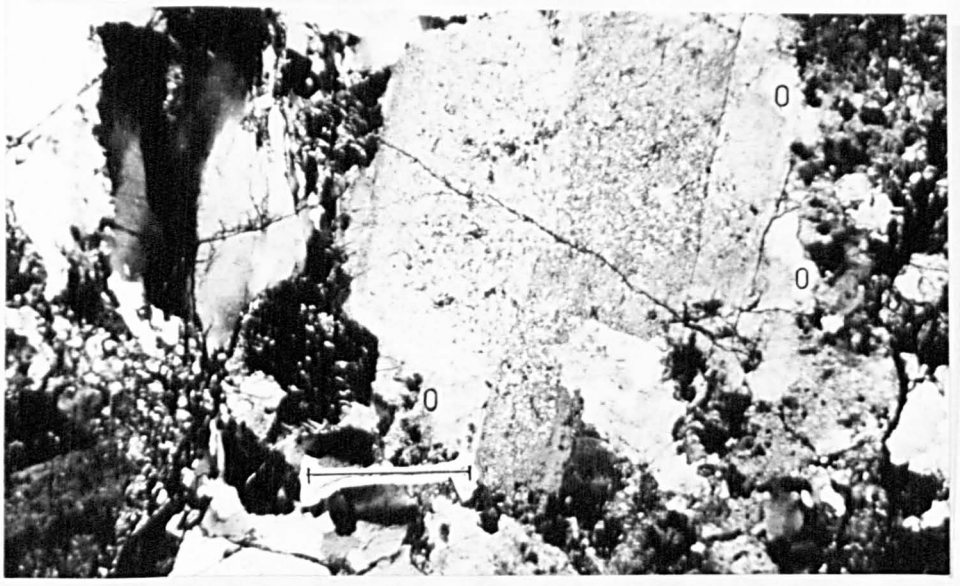


Plate 2.51. Photomicrograph of a relict igneous plagioclase rimmed by Mpm_2 oligoclase (o). Scale 0.69 mm, (cn).

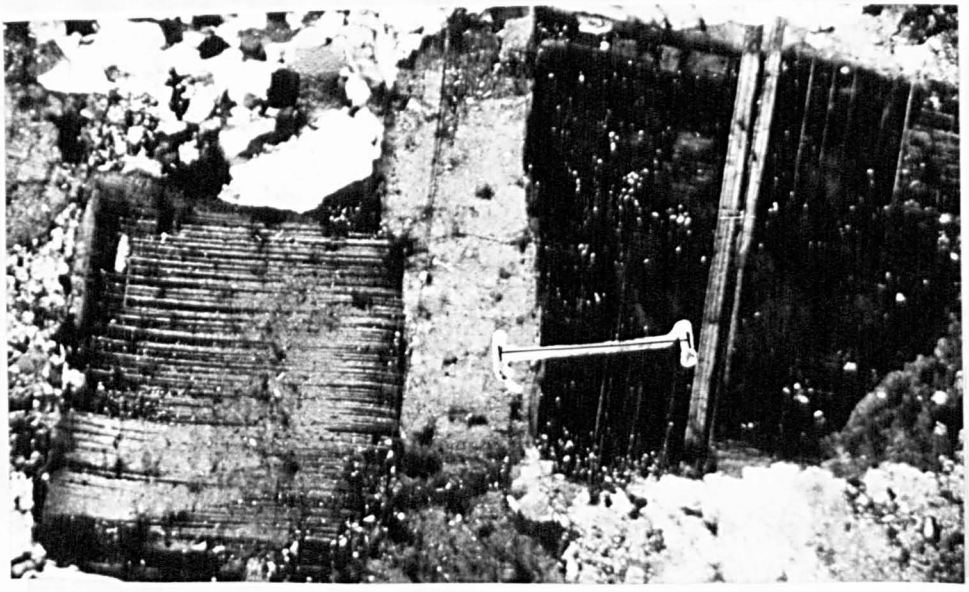


Plate 2.52. Photomicrograph (cn) of shattered igneous plagioclase healed by a later growth of Mpm_2 oligoclase. Scale 0.69 mm.

often cut by microshears that are filled with finely crystalline quartz. The biotite laths are often kinked.

(c) Prograde metamorphism Mpm_1

This metamorphism postdates the cataclastic events and has produced a granoblastic texture throughout the crushed matrix of the mylonites, resulting in the development of blastomylonites .

Biotites exhibit a decussate texture. In the less sheared areas of the tonalite the large relict igneous biotite laths are replaced by fine aggregates of small decussate biotites (Plate 2.50). Biotite also occurs as trails in the crushed matrix where it is particularly associated with the crushed grains of magnetite. Plagioclase is also replaced by biotite, but this is not common and could be due to grains of ore within the plagioclase being replaced. In the central regions of the body where the rock is less sheared the biotite shows a dark brown pleochroism, whereas at the more sheared margins of the intrusion the biotite shows a green brown to yellow pleochroism.

The oligoclase felspar that is grown during this phase of metamorphism is developed as rims around the original igneous felspars (Plate 2.51) and also cements fragments of crushed igneous plagioclases (Plate 2.52). The grains of igneous plagioclase are also replaced by spongy albite/ quartz intergrowths. The original igneous andesine appears to have undergone recrystallisation as a result of which the zoning disappears and twinning becomes less distinct. Small irregular needles of ore (1 mm x 5 mm) that are found in the unaltered igneous andesine have apparently become resorbed

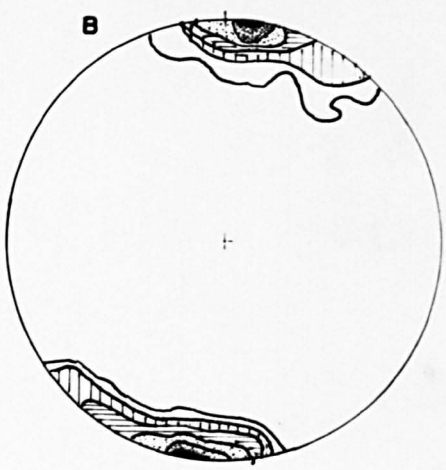
Epidote replaces the uncrushed igneous plagioclases, often being developed in trails that follow the euhedral zones. It is, however, more commonly found growing in association with the biotite. In those rocks where the biotite and the hornblende define a foliation Spm_1 the epidote replaces the plagioclase porphyroclasts as a radial aggregate. This suggests that in these rocks the epidote grew after the deformation, whereas the biotite and the hornblende grew during the deformation, and that although the epidote is in close association with the biotite it had in fact continued to after the biotite, which it may even replace in some instances.

Quatrz occurs as equidimensional granoblastic grains that are coarser in the pressure shadow regions of the plagioclase porphyroclasts than in the matrix. Some of the large grains of igneous quartz are not crushed, but may show marked undulose extinction and the development of Börn strain lamellae. These grains are often cut by microshears that are filled with very fine granular quartz.

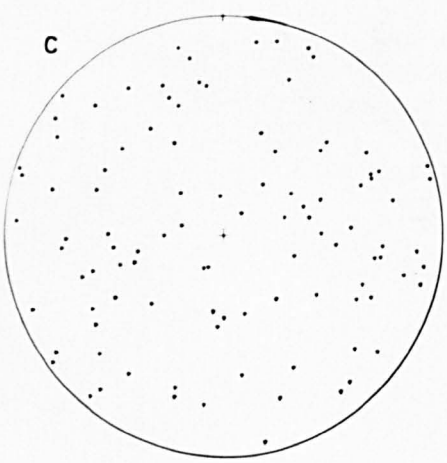
Small crystals of garnet grow in the plagioclase porphyroclasts and in the matrix where they are usually in association with ore or biotite. These grains are small, rarely exceeding 0.1mm. They are anhedral but not poikilitic and are not commonly developed in these sheared rocks.

Elongate needles of hornblende that are aligned parallel to the mylonitic foliation are developed in both the xenoliths and the tonalite surrounding them. These appear to have grown whilst the rock was still undergoing deformation, although it is possible that they could owe their orientation wholly or in part to a mimetic mode of crystallisation.

100 poles to biotite cleavage
[contours at 1,3,5,8%]



100 poles to biotite cleavage
[contours at 1,5,10,15,20%]



100 quartz C axes

100 quartz C axes
[contours at 1,2,3,5%]

Figure 2.14. Petrofabric diagrams from the Port Moguer tonalite: A) and C) 100 poles to biotite cleavage and 100 quartz C axes respectively taken from a specimen that did not undergo syn-Mpm_1 shearing; B) and D) 100 poles to biotite cleavage and 100 quartz C axes respectively taken from a specimen that underwent syn-Mpm_1 shearing. Both specimens were collected 50 m. south of the harbour wall at Port Moguer.

Magnetite recrystallises as trails of anhedral grains in the matrix or, more rarely, as euhedral grains that are cubic in form.

In certain discrete zones shearing took place during this event. One such zone is 200m to the north of the harbour wall at Port Moguer. Figures 2.14A and B are plots of poles to Mpm_1 biotite cleavages from the blastomylonitic tonalite and the syn-Mpm_1 shear zone respectively. Figure 2.14C and D are plots of quartz C axes from the same specimens. The biotite defines a very weak girdle and the quartz C axes are almost spherically symmetrical in the blastomylonitic tonalite (Figures 2.14 B and D), whereas the biotite defines a strong foliation with an associated triclinic quartz girdle in the syn-Mpm_1 shear zone (Figures 2.14 A and C). The foliation in the shear zone is parallel to this zone. Within the shear zone the quartzofelspathic matrix is finer than in the surrounding blastomylonitic tonalite and grains show irregular sutured contacts with one another.

The metamorphic assemblage developed within the toanlite and its cataclased derivative comprises biotite + quartz + albite + epidote $\pm$ garnet $\pm$ hornblende, typical of the upper greenschist facies.

(d) Potassium metasomatism Mpm_2

This event, postdating the phase of prograde regional metamorphism, is marked by the growth of microcline throughout the body. The microcline is generally seen to replace the albitic rims of the igneous plagioclases that grew during the previous phase of metamorphism. It is also seen to display a variety of replacement textures within the igneous plagioclases. Often lenses or stringers of microcline grow inwards from the margin of

Pentevrian	Port Goret gneisses	Plouha Series	Port Moguer tonalite
D_{1P} F_{1P} S_{1P} ... M_{1P}	.... Fpg_1 Spg_1 .... Mpg_1	.... Fps_1 Sps_1	....
D_{2P} F_{2P} S_{2P} ... M_{2P}	.... Fpg_2 Spg_2	.... Fps_2 Sps_2 .... Mps_1	....
D_{3P} F_{3P} S_{3P} L_{3P} M_{3P}	.... Fpg_3 Spg_3 .... M_{pg_2}	.... Fps_3 Sps_3 Lps_3 Mps_2	....
D_{4P} F_{4P}	.... Fpg_4	....	....
D_{5P} F_{5P} S_{5P} L_{5P} M_{4P}	.... Fpg_5 Spg_5 .... Mpg_3	Dps_4 Fps_4 Sps_4 Lps_4	Dpm_1 .... Spm_1 ....
... ...?M_{5P}?	.... Mpg_4	.... Mps_3	.... Mpm_1
D_{6P} F_{6P} ...L_{6P} ?M_{6P}	.... Fpg_6 .... Lpg_6	....	....?Mpm_2?
D_{7P} F_{7P}	.... Fpg_7	....	....

Table 2.5. Correlation of the Pentevrian Structural and Metamorphic events recorded in the area studied. The left hand column gives an overall synthesis for the Pentevrian in the area studied. The three other columns list the individual deformations, fold phases, foliations, lineations and metamorphisms for each of the three Pentevrian units.

the plagioclase crystal. In one instance microline is developed along one half of a Carlsbad twinned individual, the other half of the individual is completely replaced by secondary mica. It is common for microcline to grow along certain twin individuals in one grain. Microline also replaces the igneous plagioclase along the euhedral zones and often it is the outer zone of an individual that is partly or wholly replaced.

Microcline grows along the contact of quartz veins and also across them. Often, several of these patches of microcline that replace one quartz vein are in optical continuity with one another. The age of this event is unknown.

5. Correlation of the various Pentevrian structural and metamorphic events.

A correlation of the various structural and metamorphic episodes described above is proposed in table 2.5. Fpg_1 and Fps_1 are correlated in that theyare the earliest structures seen in both the Port Goret gneisses and the Plouha series. The folds are isoclinal and both fold phases are followed by two coaxial phases of folding which produce isoclinal folds Fpg_2, Fps_2, $Fpg_3$and Fps_3. The second and third phases of folding in the two regions are also correlated. The Fpg_5, Fps_4/Dps_4 and Dpm_1 structures are all correlated as they are the last penetrative structures to be developed. The associated foliations Spg_5, Sps_4 and Spm_1 all trend approximately ENE-WSW and all these events were followed by a static phase of regional metamorphism,Mpg_4 Mps_3 and Mpm_1 respectively. The Fpg_7 and Fps_5 events are correlated in that these folds are of the same style and orientation, however the age of this event is unknown. A Complete structural and metamorphic history for the Pentevrian is proposed in Table 2.6.

Temporal and Spatial Relationships of M_{4P}, M_{5P}, and D_{5P}.

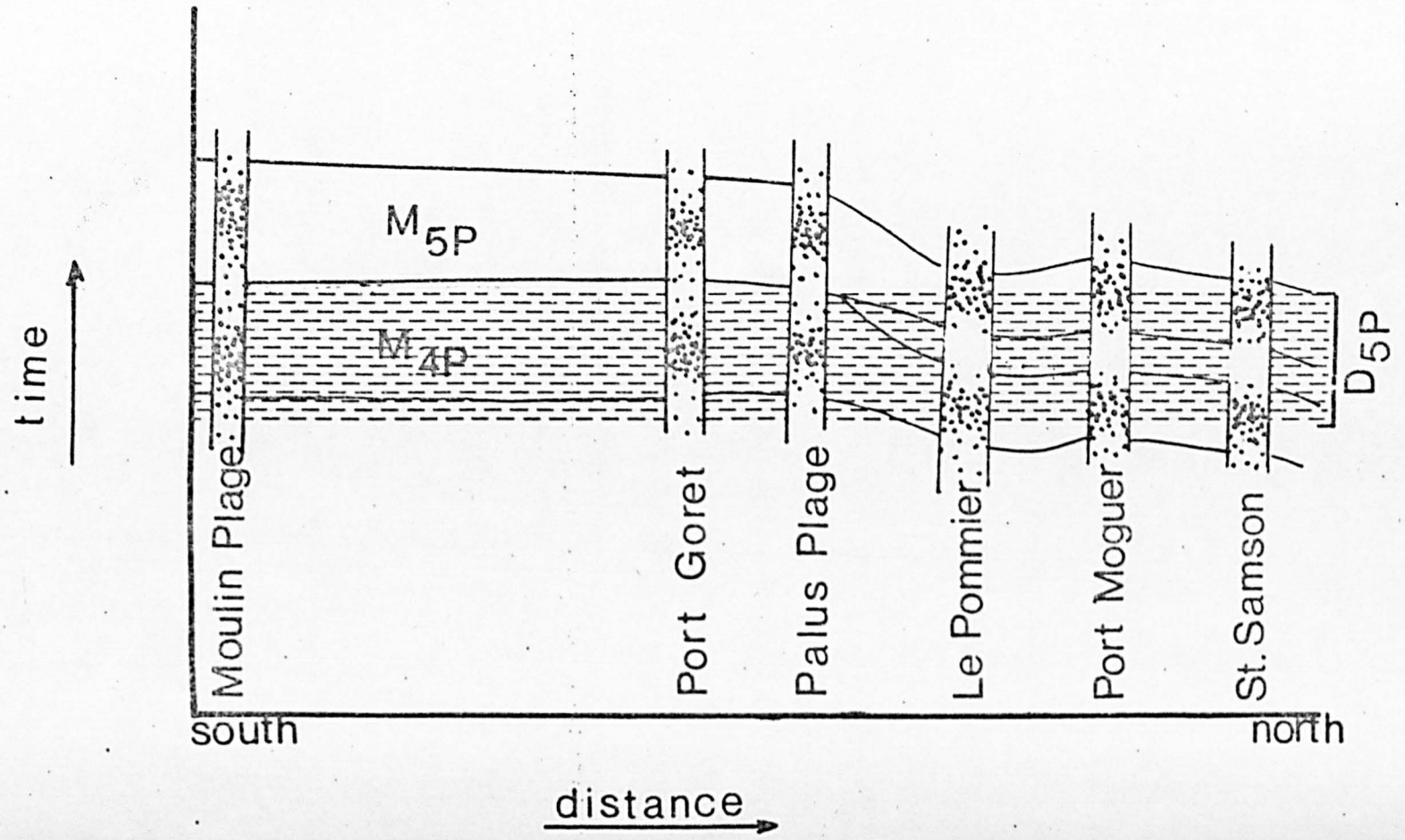


Figure 2.15. Diagram showing the possible temporal and spatial relationships between D_{5P}, M_{4P} and M_{5P}. It is suggested that M_{4P} was synchronous with D_{5P} in the south. However, M_{4P} either died out or preceded D_{5P} where this event was associated with cataclasis in the north. The subsequent metamorphic event M_{5P} postdated D_{5P} in the south but was still associated with shearing and the development of S_{5P} in the north.

6. Discussion.

The variation in the nature of the D_{5P} deformation, with F_{5P} folds being developed to the south of Port Logot and a cataclastic foliation S_{5P} being formed to the north, could be due to one or more of the following factors: a variation in temperature during this event; a variation in strain rate; a variation in the timing of the associated metamorphic events. One possible explanation is outlined in Figure 2.15. In the south between Moulin plage and Palus plage the F_{5P} folding was associated with the M_{4P} metamorphism. Between Palus plage and Port Logot no recrystallisation was associated with the F_{5P} folds although the style of the folds would suggest that the rocks were fairly hot at this time. In the area to the north of Port Logot the D_{5P} deformation may have acted on rocks that were a good deal cooler than those in the south and thus they yielded by cataclasis. This suggests that the M_{4P} metamorphic event was less important in the north than in the south. Subsequent to the D_{5P} deformation a static phase of metamorphism M_{5P} affected all the Pentevrian. This event was post-tectonic in the south of the area, but was associted with some late shearing in the north. Thus it is suggested that whilst the M_{4P} event accompanied D_{5P} in the south, it either died out or preceded D_{5P} in the north (Figure 2.15) and that the M_{5P} event was post-tectonic in the south but late-tectonic in the north (Figure 2.15). This explanation does not take into account differing strain rates but may in part account for the above mentioned variation in the nature of D_{5P}.

This study has study has shown that the structural and metamorphic history of the Pentevrian on the French mainland is complex. At the present time similar studies are being undertaken in the Pentevrian basement regions of Cap de la Hague, Guernsey, Jospinet and Saint Malo

Deformation	Fold phase	Foliation	Lineation	Metamorphism	Metamorphic grade
D_{1P}	F_{1P}	S_{1P}	...	M_{1P}	Amphibolite facies
D_{2P}	F_{2P}	S_{2P}	...	M_{2P}	Amphibolite facies
D_{3P}	F_{3P}	S_{3P}	L_{3P}	M_{3P}	Amphibolite facies
D_{4P} (Local)	F_{4P}	...	...	...	.....
D_{5P} (South)	F_{5P}	S_{5P}	L_{5P}	M_{4P}	Upper greenschist facies
D_{5P} early (North) late	F_{5P}	S_{5P}	...	???	.....???.....
...	...	...	L_{5P}	M_{5P}	Amphibolite facies
D_{6P} (Local)	F_{6P}	...	L_{6P}	...	.....
D_{7P}	F_{7P}	...	...	...	.....

Table 2.6. Pre-Brioverian Structural and Metamorphic History of the Pentevrian Basement.

and Saint Cast migmatite belts (R.A.Roach, M.Brown and G.Power - personal communication). There is a possibility, therefore, that some tentaive structural correlation may be made between these regions.

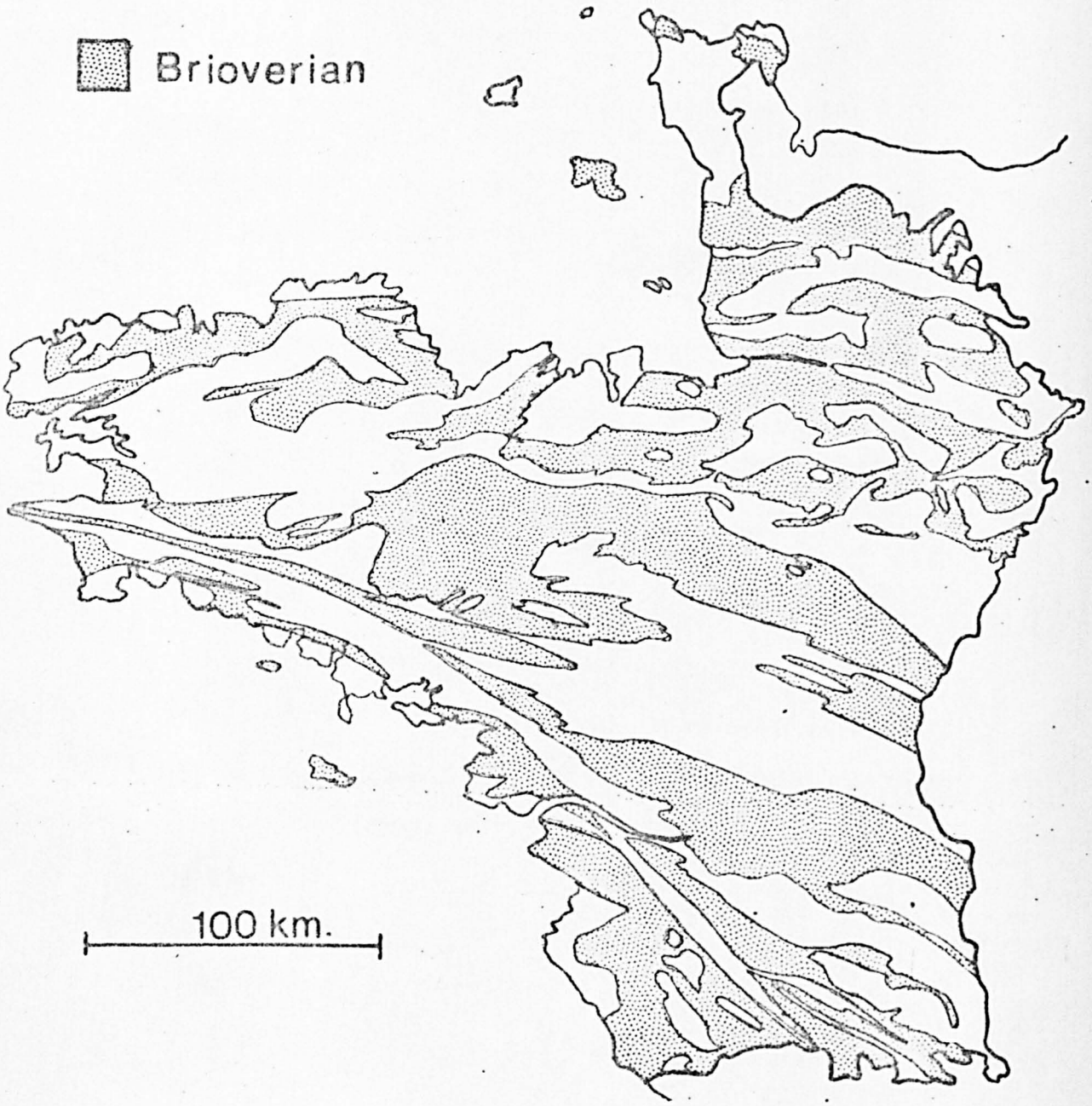
It should be noted that the description of the Pentevrian in the type area by Cogne (1959) has led many other authors to treat the Pentevrian as a pre-Brioverian, highly metamorphosed basement that has a predominantly north - south trending foliation. However, certain authors have gone even further and have taken high metamorphic grade and a penetrative north - south foliation as being typical criteria for recognising Pentevrian basement e.g. Graindor 1960, Shelley 1966, Rast and Crimes 1969. This has led to subsequent misidentification of Brioverian rocks as Pentevrian, and also to Pentevrian rocks (that do not show these features) being assigned to the Brioverian.

7. Conclusions.

The existence of three previously unreported bodies of Pentevrian age, the Port Goret gneisses, the Plouha Series and the Port Moguer tonalite has been established. These are comprised of paragneisses, metasediments, metavolcanics and metatonalite. Although each body shows different structural and metamorphic patterns, an overall correlation is proposed that suggests that the Pentevrian basement in this area underwent at least 7 phases of folding and 5 metamorphic events prior to the deposition of the Brioverian. These are reviewed in Table 2.6.

CHAPTER III

THE BRIOVERIAN



Distribution of Brioverian Sediments in the Massif Armoricain
after Cogné 1962, modified.

Figure 3.1. Map of the Armorican Massif showing the outcrop of the Brioverian (stippled) after Cogne 1962 (modified).

A. Introduction

The term Brioverian was first used by Barrois in 1895 as a system name for the vast sequence of sedimentary Precambrian rocks that outcrop over the whole of the Armorican Massif (Figure 3.1) and had hitherto been known as the "Schists de St. Lô". For the purpose of this study the author has taken the term Brioverian to imply a late Precambrian, post-Pentevrian, supracrustal sequence of geosynclinal sedimentary and volcanic rocks that were laid down in the Armorican Massif between 1000-7000 m.y. ago. All Brioverian rocks in the Armorican Massif have been affected to some degree by the late Precambrian Cadomian orogeny that occurred between 690-600 m.y. ago. (Roach et al 1972).

Although the rocks of this area that are considered to be Brioverian are not seen to be covered unconformably by the Cambrian, they are assigned to the Brioverian for the following reasons:

1. They rest unconformably upon a pre-1030 m.y. gneissose basement (Leutwein 1968, see Page 1.7 and Table 1.5 no. 7), which represents the Pentevrian as defined by Cogné (1959)

2. They have only been subject to one orogenic phase, which the radiometric dates published for the area show to have occurred pre-570 m.y. (see Page 1.5 and Table 1.3 no. 3) but post-1030 m.y. (see above). This is considered to be the Cadomian orogeny (Leutwein 1968).

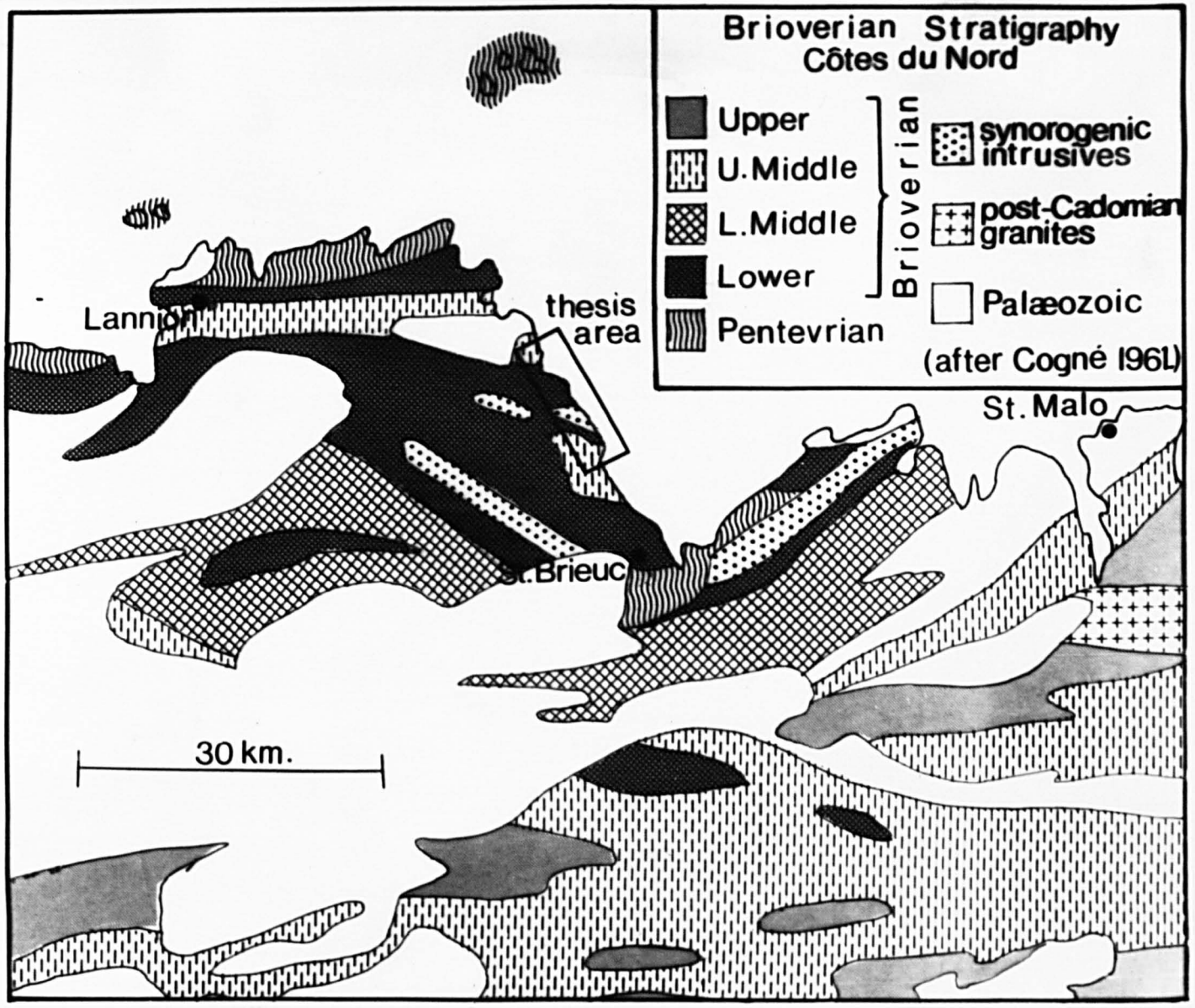

Brioverian Stratigraphy
Côtes du Nord
Upper
U.Middle
L.Middle
Lower
Pentevrian
Brioverian
synorogenic intrusives
post-Cadomian granites
Palæozoic
(after Cogné 1961)
thesis area
St.Malo
30 km.

Figure 3.2. Outline geological map of the area around the Baie de Saint Brieuc showing the stratigraphy of the Brioverian, after Cogné 1962.

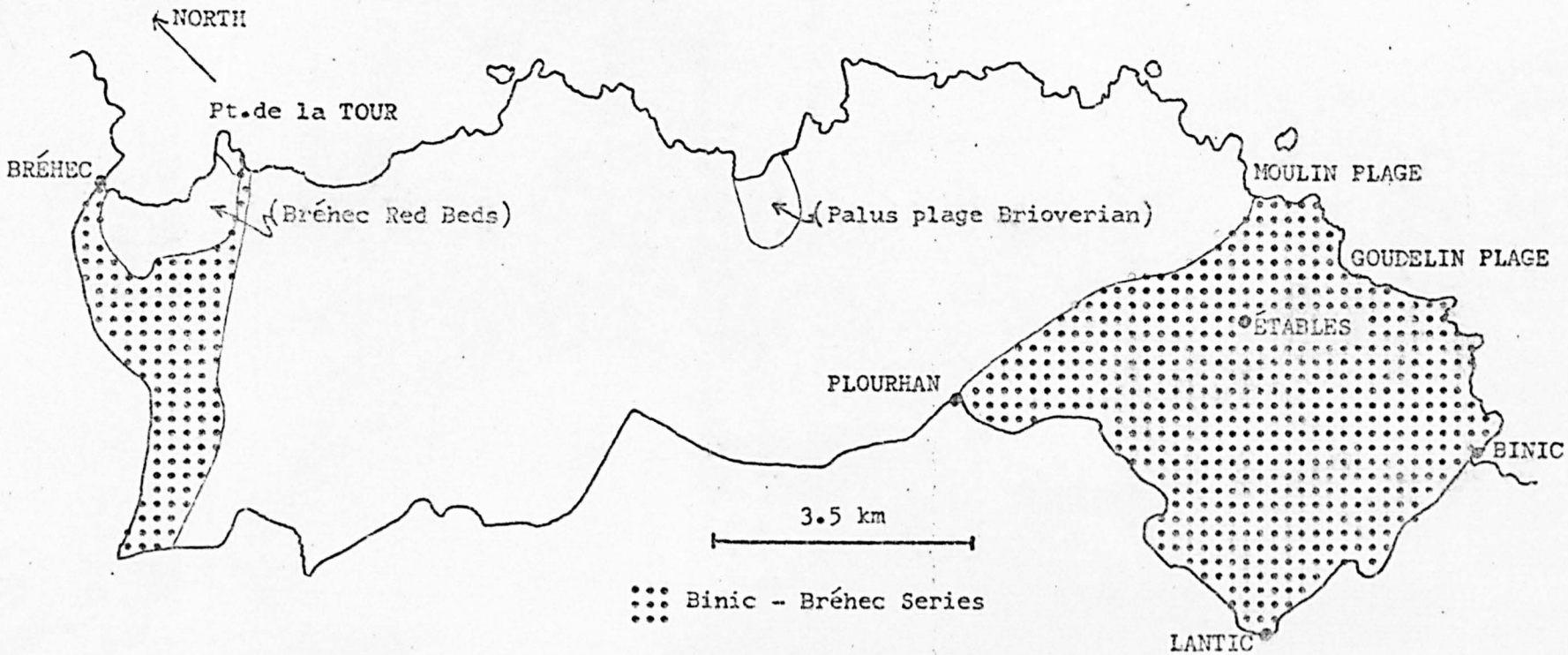

NORTH
Pt.de la TOUR
BRÉHEC
(Bréhec Red Beds)
(Palus plage Brioverian)
MOULIN PLAGE
GOUDELIN PLAGE
ÉTABLES
PLOURHAN
BINIC
3.5 km
Binic - Bréhec Series
LANTIC

Figure 3.3. Sketch geological map showing the outcrop of the Binic-Bréhec series (stippled) in the area mapped.

Since these sediments were deposited upon an older Precambrian basement, are Precambrian in age and have been affected only by the Cadomian orogeny, they may be regarded as Brioverian.

These sediments were first described as Brioverian by Barrois (1896) who referred to the "Massif (now 'Series') de Binic", which he later correlated with the "Schistes et Phtanites de Lamballe" (Barrois 1934 and 1938a) as they contained bands of phtanite. The Series de Binic has been assigned to the Middle Brioverian as it contains phtanites (Cogné 1962, 1964, Figure 3.2) and also to the Upper Brioverian as it is said to rest discordantly upon the Lower and Middle Brioverian of Rosaires plage. The Brioverian of Pointe de la Tour and Bréhec is placed in the Lower Brioverian along with the Port Goret gneisses and the Plouha Series by Cogné (1962).

The Brioverian sediments of the area studied may be divided into three separate sequences. That in the north of the area, comprising the Brioverian of Bréhec and Pointe de la Tour, outcrops on the coast as far south as Pointe de la Tour (052966) and extends northwards past Bréhec port (039974) (Figure 3.3). At Bréhec it can be seen to be covered unconformably by a sequence of red beds. (Map 1). The southern contact of the Brioverian with the Pentevrian runs east-northeast to west-southwest and has been traced inland as far as Kertidic (008948). The ground occupied by these sediments rises steeply from the coast to a plateau around 80 m. in altitude. A second sequence in the centre of the area is composed of volcanic rocks that are seen to rest unconformably upon the

Pentevrian basement. These rocks, the Palus plage metasediments and metavolcanics, outcrop on the southern flank of the Grève de Palus (088915 to 094914) and extend inland as far as Keregal (Map 1). Another limited outcrop of a very similar sequence of volcanics is found to the north of Plouha (052917). In the south of the area a third sequence consists of a great thickness of clastic sediments, the "Series de Binic" (Barrois 1896). These occupy a rectangular area that is bounded by the town of La Bourdonniere (077880) and Moulin plage (128872) in the north, and the towns of Lantic (086838) and Binic (134834). The outcrop of this series continues to the south of the area studied as far as the beach at Les Rosaires where it is in contact with a sequence of older metamorphic rocks. The land occupied by the Series de Binic rises from the coast as low cliffs 10m. to 20m. in height to an inland plateau about 80m. in height which is disected by a few east-west river valleys.

The Series de Binic and the Brioverian of Bréhec and Pointe de la Tour are very similar in litholigies and will be treated together and termed the Binic - Bréhec Series.

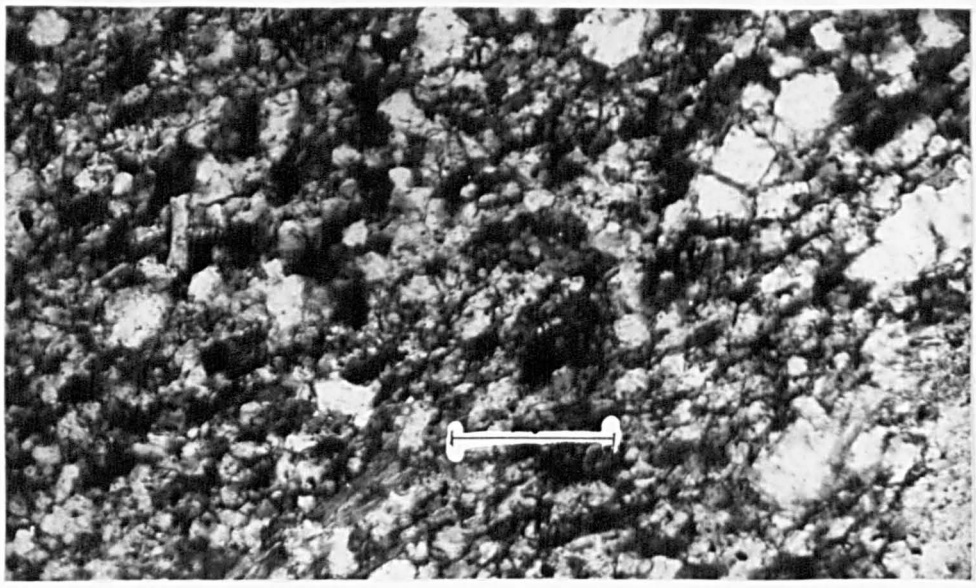


Plate 3.1. Photomicrograph (ppl) of the calc-siltstones of Pointe de la Rougnouse, consisting of "clastic" quartz grains in a zoizite, biotite matrix.
Scale 0.19 mm.

Plate 3.2. Parallel flute casts in Series de Binic in quarry $\frac{1}{2}$km west of Binic on the Binic-Lantic Road. Field of view is approximately 3m.

B. The Binic-Bréhec Series

1. Introduction

The Binic-Bréhec series is comprised of an interbedded sequence of sandstones, siltstones and mudstones. The sandstone units may be up to several metres in thickness whereas the finer material may occur in laminations that are less than 1 mm. in thickness. Individual beds are very constant in thickness and even the finest of these may be traced with no variation for a considerable distance. Many of the coarser beds show graded bedding. Similar sediments are found elsewhere in the Brioverian, e.g. between Granville and Saint Pair and along the Élorn. However, only a few detailed studies on their sedimentology have been carried out (Graindor 1957, 1964; Dangeard, Dorét and Guignot 1961; Winterer 1967; Bradshaw, Renouf and Taylor 1967; Bishop, Bradshaw, Renouf and Taylor 1969).

There is some variation in the nature of the sediments that make up the Binic-Bréhec series. At Pointe de la Rougnouse (Map 1) there is a band 110 m. thick, that is comprised of calc-sandstones and siltstones (Plate 3.1). These sediments show much less variation in grain size than the rest of the sequence and are made up of beds of 1 - 3.5m thick are much richer in quartz.

A study of the nature of the Brioverian exposed on the coast between Moulin Plage (132872) and Pointe de Trouplet (137848)

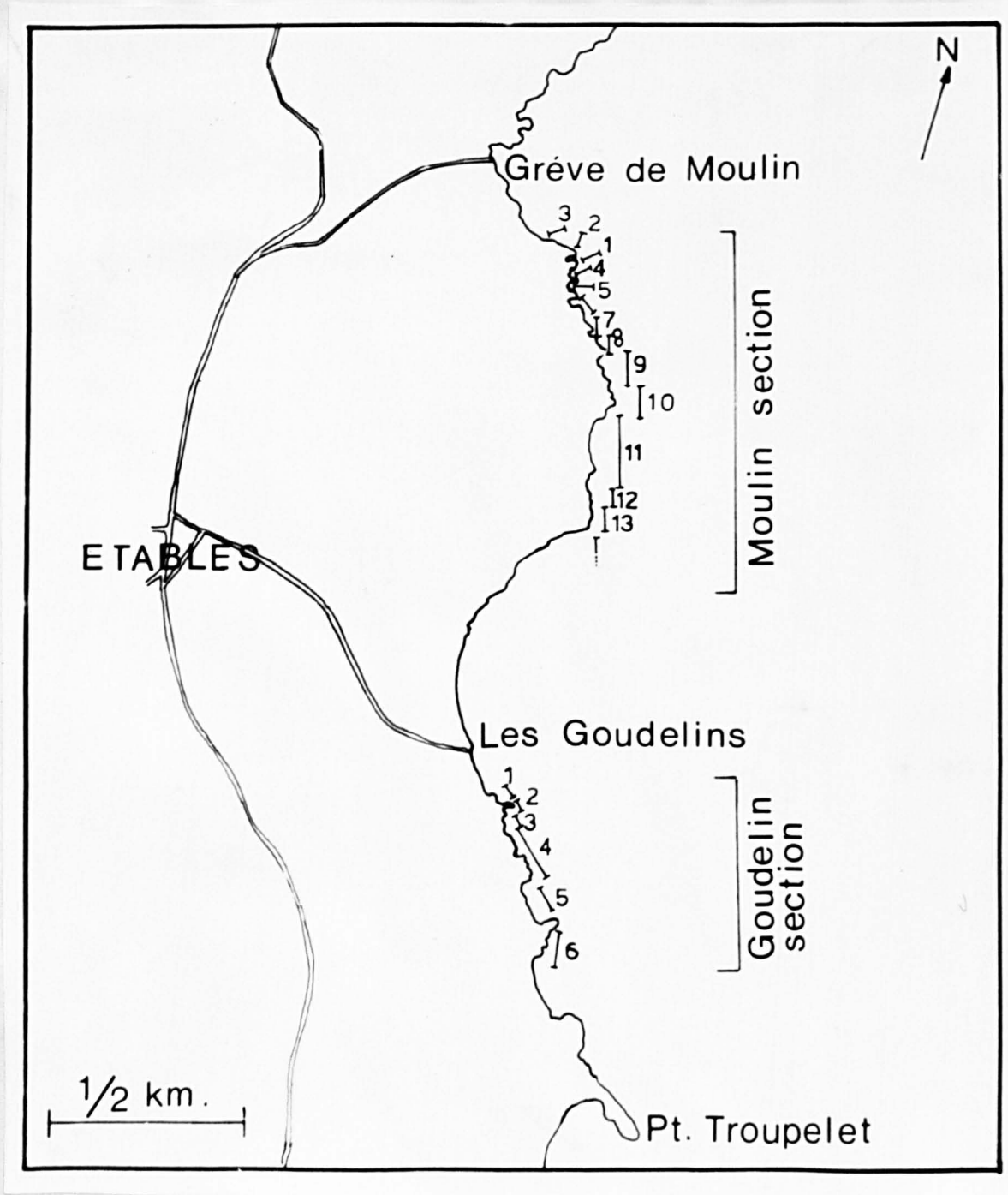

N
Gréve de Moulin
3
2
1
4
5
7
8
9
10
11
12
13
Moulin section
ETABLES
Les Goudelins
1
2
3
4
5
6
Goudelin section
1/2 km.
Pt. Troupelet

Figure 3.4. Map of the Moulin and Goudelin plages showing the location of the sections recorded. The numbers on the sections for Moulin and Goudelin plages correspond to those on figures 3.10 and 3.14. respectively.

Plate 3.3. Bifurcating ripple marks in the Series de Binic in quarry 3 km west of Binic on the Binic-Lantic road. Field of view is approximately 3 m.

Plate 3.4. Graded bedding in lithofacies M1. Grading (the fine sediments are darker than the coarser) indicates that the sequence is the right way up. Scale 30 cm.

has been carried out in order that something may be learned of the mechanism and environment of deposition of these sediments (Figure 3-4). In this study no regard has been paid to the relatively few directional sedimentary structures (Plates 3-2 and 3-3) preserved in these sediments as it is felt that the complexity of the Cadomian deformations and the lack of knowledge of the exact orientation, type and mechanism of formation of structures associated with the early phase of folding would make any attempt at calculating the original attitude of the bedding very inaccurate.

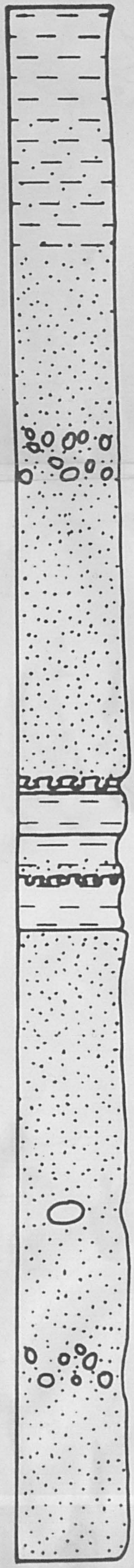
2. The Brioverian of Moulin plage.

(a) Introduction.

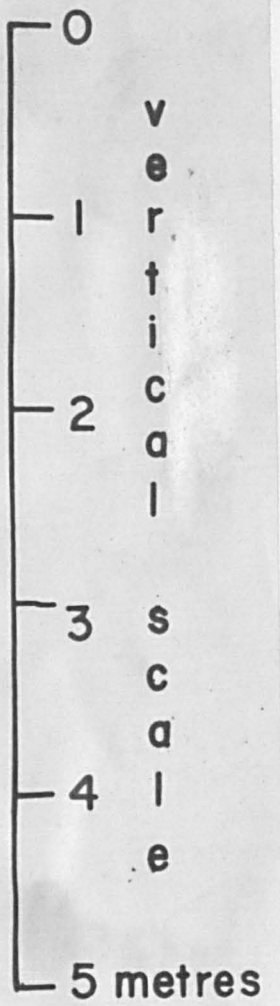
Four distinct lithofacies have been recognised within the Brioverian of this section (Figure 3.4). These are: lithofacies M1, massive nodular sandstones; lithofacies M2, graded sandstones and sandstones with banded mudstones; lithofacies M3, banded mudstones; and lithofacies M4, graded siltstones and sandstones with banded mudstones. These lithofacies are often found in a constant stratigraphic order with lithofacies M1 at the base and M4 at the top. All four lithofacies comprise a unit of sedimentation which is repeated cyclically at least six times within this section (Figures 3.10 and 3.11). The thickness of one such cyclic unit varies from 12.00-30.5m with a mean value of 19.5m.

(b) Lithofacies M1.

This is comprised of thick units of massively bedded greywackes that are from 0.7-9.4m thick, the mean being 3.9m



M1



KEY

sandstone

siltstone

laminated mudstone

mudstone

sharp contact

gradational contact

disrupted or slumped beds

load casts

calcareous nodules

Figure 3.5. Section through lithofacies M 1 taken from section no.3, Moulin plage. The key in this figure is also used for Figures 3.7., 3.8., 3.9. and 3.12.

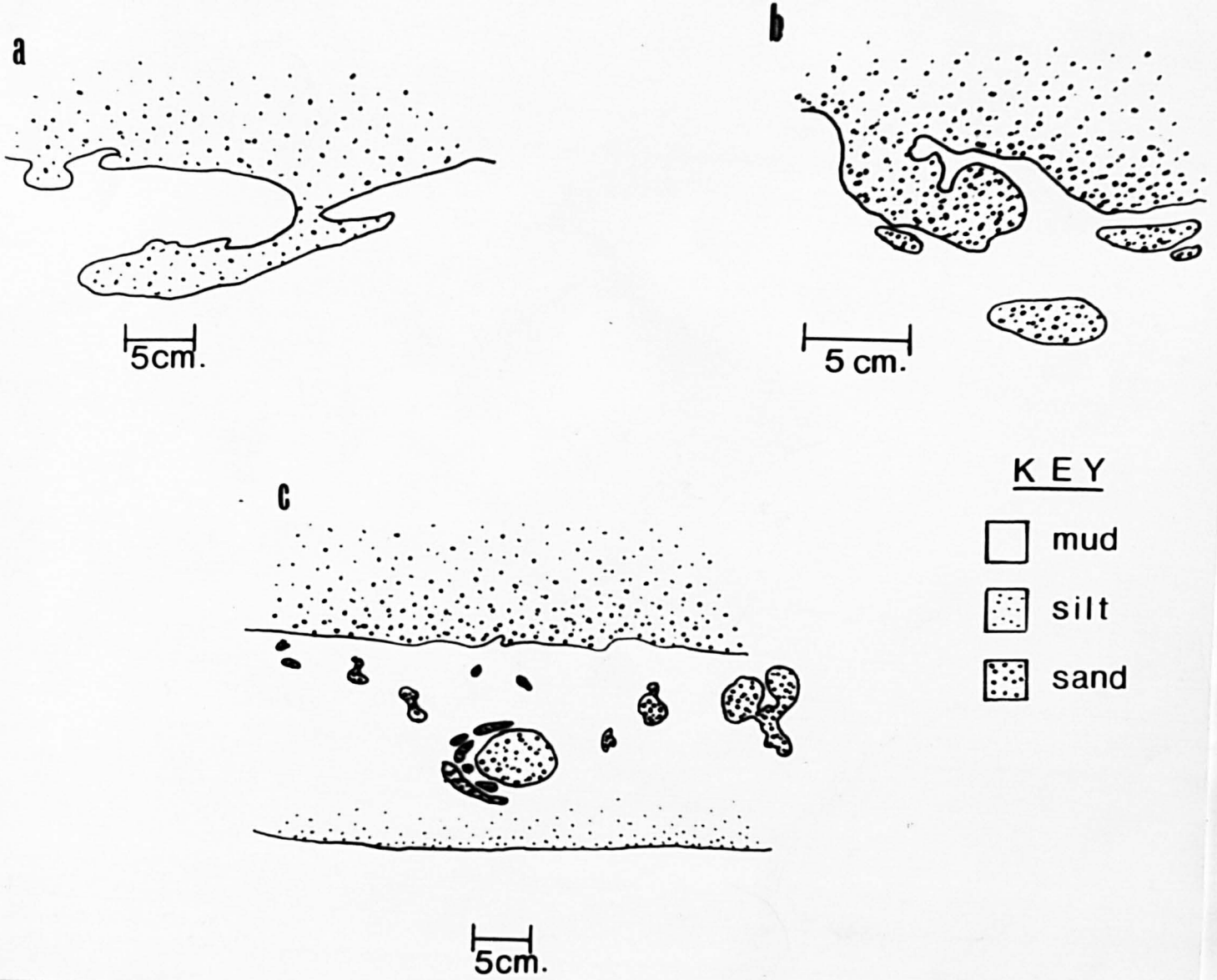

a
5cm.
b
5 cm.
c
5cm.
KEY
mud
silt
sand

Figure 3.6. Sedimentary structures found in lithofacies M 1: a) deformed load structure at the base of sand unit 2m thick; b) Load cast with overturned mud plume and possible "ball and pillow" structures. Balls of mud are contained in bed of mudstone.

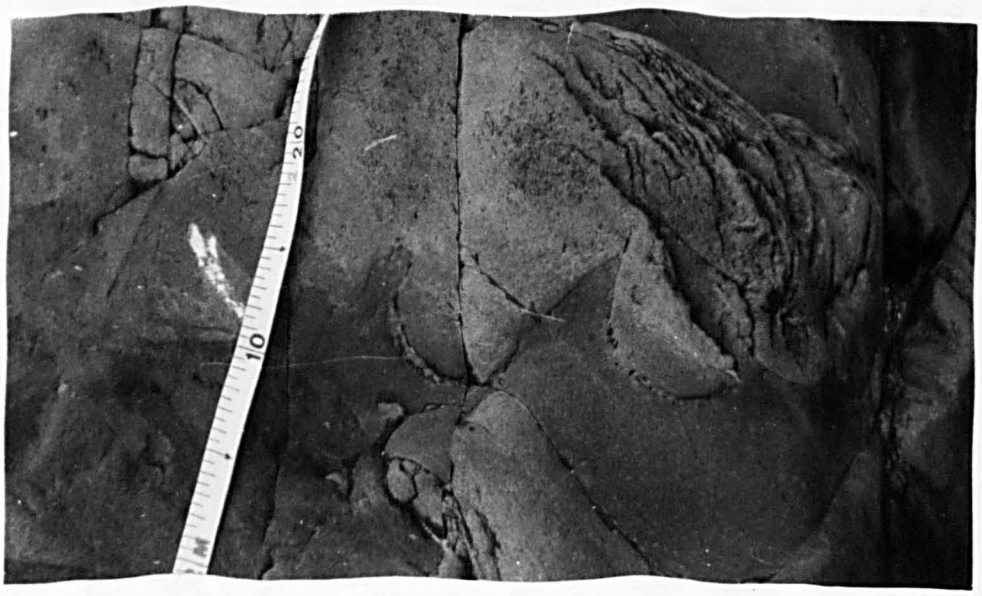


Plate 3.5. Well developed load structures at the base of a graded unit in Lithofacies M1. Scale in cm.

Plate 3.6. Disrupted mud bank (dark coloured) near the base of a graded unit in lithofacies M1. Scale in cm.

Plate 3.7. Thick graded unit in lithofacies M1 with flattened clacareous nodules aligned parallel to the cleavage S_{2C} (which is also parallel to the hammer).

Plate 3.8. Calcareous nodule in greywacke, lithofacies M1. Scale in cms.

(Figure 3.5, Plate 3.4). There may be up to three such beds in any of the units of this lithology which are from 3.3-15.4m thich with a mean of 6.2m. The greywackes are medium grained and show little variation in grain size, except at the top of a unit where beds are often well graded. The grain size at the base of a graded bed is coarser than that of the rest of the unit. Individual beds of greywacke are often separated by thin bands of finely interbedded siltstones and mudstones that are 0.1-0.4m thick (Figure 3.5). The base of the overlying bed shows well developed load and flame structures and ball and pillow structures (Figure 3.6 and Plate 3.5) while the bedding in the mud and siltstones is often severely disrupted (Plate 3.6).

The thick greywacke beds are characterised by the occurrence of distinct horizons that are rich in calcareous nodules (Plates 3.7 and 3.8), which are 0.07-0.5m thick. Several such horizons may be found in one bed of greywacke. The nodules are in the form of ellipsoids whose longer axes lie within the plane of the foliation S_{2C} (see Chapter IV, page 4.4). The principal axes of these ellipsoids vary from X:Y:Z := 0.8m:0.6m:0.3m to X:Y:Z = 0.05m:0.04m:0.03m and the ratio of the long to short axes varies from 1:1 (or circular) to 20:1. These nodules make up between 5% and 20% by volume of the nodular horizons. The banding within these nodules is concentric and they are thought to be concretionary in origin. In some instances the nodules do not occur in distinct horizons but are disseminated throughout the bed of sandstones.

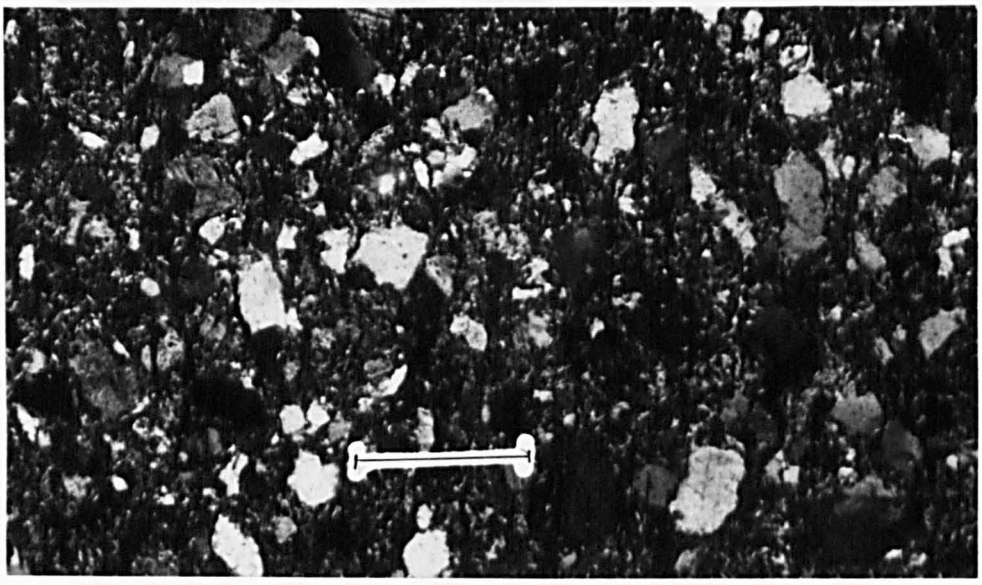


Plate 3.9. Photomicrograph (cn) of greywacke from base of graded unit at Binic harbour wall. The clastic grains still exhibit some original texture. Scale 0.63 mm.

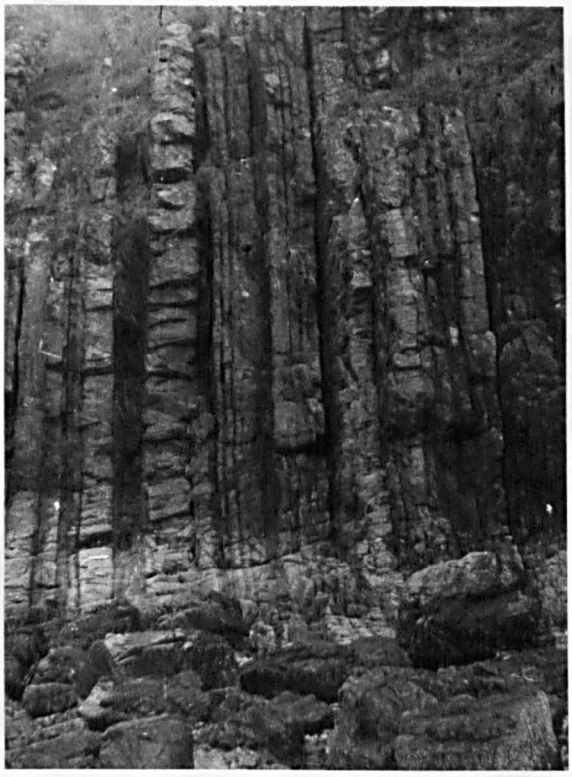
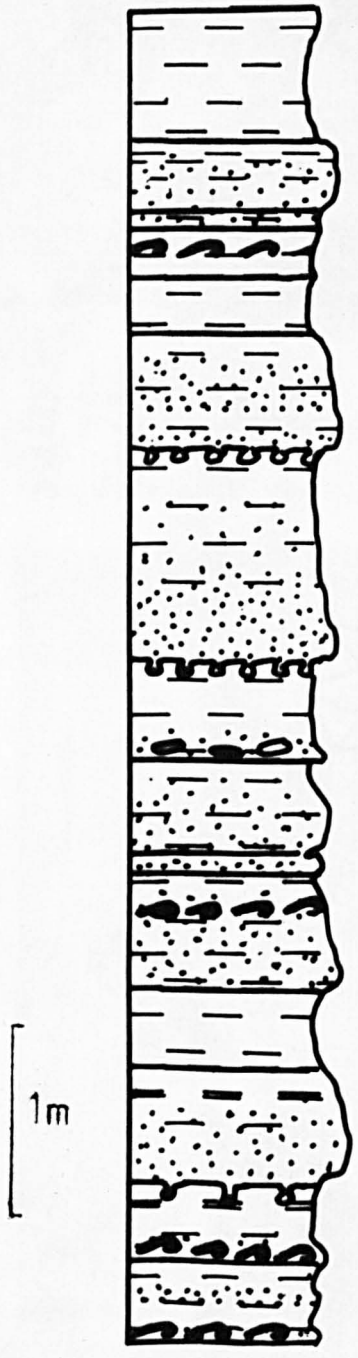


Plate 3.10. Bedding in lithofacies M2. Field of view is approximately 8m.



M2

Figure 3.7. Section through lithofacies M 2 taken from section no. 3, Moulin plage. (Key as in figure 3.5.)

Petrologically it is difficult to assess the actual abundances of the original constituents of these greywackes, particularily the labile constituents, as these rocks have undergone metamorphic recrystallisation. Fortunately all original textures have not been lost and in the greywackes the detrital fragments still preserve their angular form (Plate 3.9). The relative abundances of these fragments are quartz > felspar > lithic fragments. These rocks appear to have contained a good deal of matrix since metamorphic biotite, which has presumably grown at the expense of the matrix, is ubiquitous and never falls below 15% of the mode even in the most coarse grained rocks. These sandstones may therefore be classified as greywackes (Pettijohn 1957). It is remarkable that there is very little variation in the mineralogical composition of these greywackes in the sequences studied and the above observations hold true for the whole Binic-Bréhec Series.

(c) Lithofacies M2

This consists of beds that grade from sandstone at the base to mudstone at the top, and that are interbedded with thinner beds containing many thin bands of mudstone that grade to siltstone at their base (Figure 3.7). This lithofacies ranges from 9.7-3.1m in thickness with a mean thickness of 6.9m (Plate 3.10).

The graded beds range in thickness from 0.1m to 1.1m with a mean of 0.4m. The base of these beds is made up of a sandstone that is usually massive, although it does sometimes contain fine

Plate 3.11. Graded units in lithofacies M2 with load structures at the base. Scale in cms.

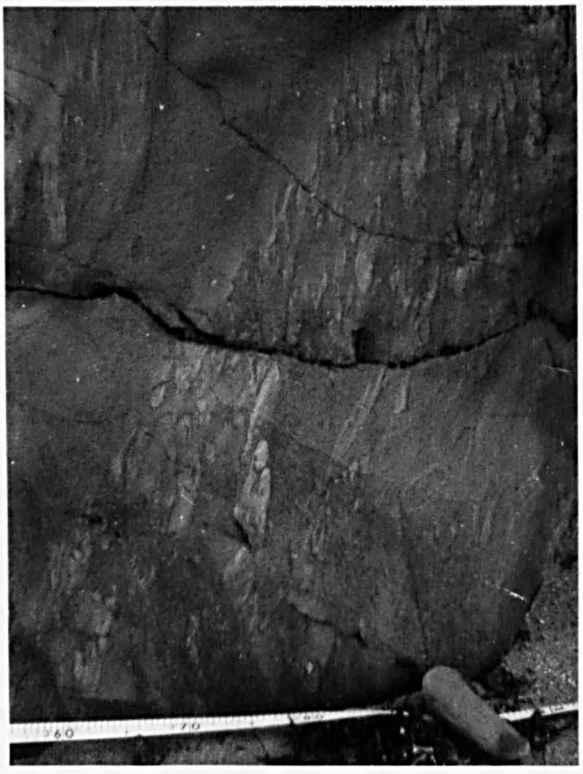


Plate 3.12. Disrupted silt bands (lighter colour) at the top of a 1.2 m graded unit in lithofacies M2. Field of view 50 cm.

bands of siltstone. Load casts and flame structures are well developed at the base of these beds (Plate 3.11). The sandstone at the base often contain mudflake conglomerates that appear to have been derived from the underlying beds. As the top of the bed is approached, the grain size changes to that of siltstone and then to mudstone. The ratio of sandstone to mudstone in any one bed is variable, although it appears that as the top of this facies is approached the amount of mudstone increases and the grain size of the coarser material at the base of the bed decreases. Occasionally bands of disrupted siltstone occur at the top of a graded unit (Place 3.12).

The beds of banded mudstone range in thickness from 0.2-0.7m with a mean of 0.3m. These are comprised of many thin beds of mudstone, usually of 1cm to 5cm in thickness, that grade to siltstone at their very base. The ratio of mudstone to siltstone is very large, the siltstone never comprising more than 20% of one unit. Occasionally, there appears to be a very fine lamination within the graded unit. Calcareous nodules are rarely developed within these beds and tend to be a good deal more elongate than those in the thick beds of sandstone.

Beds of medium to fine-grained sandstone that have no internal structure and sharp bases and tops occur within this sequence. They range in thickness from 1.1m to 0.5m with a mean of 0.9m.

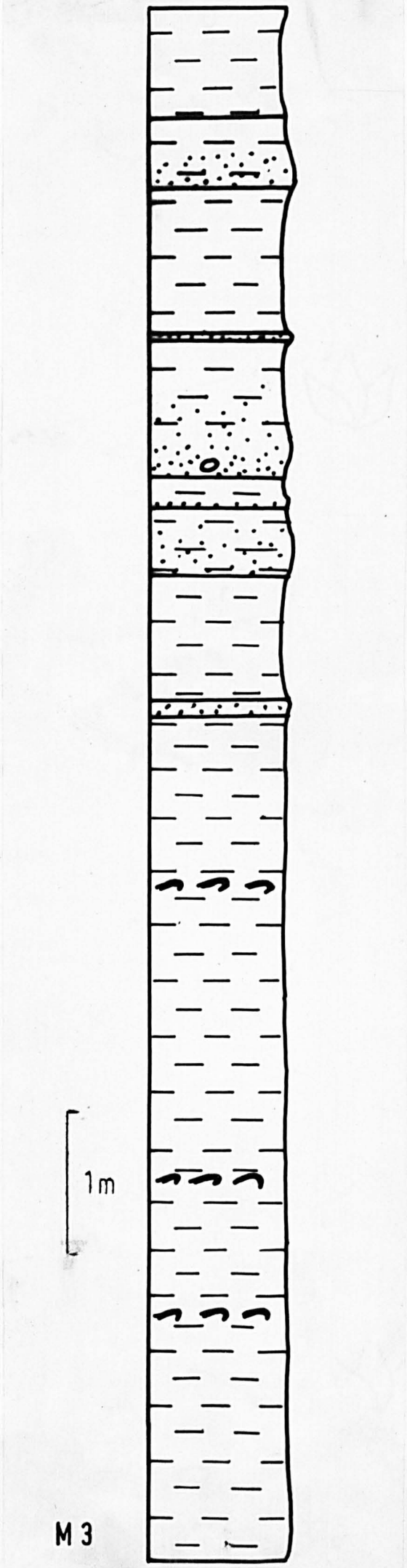
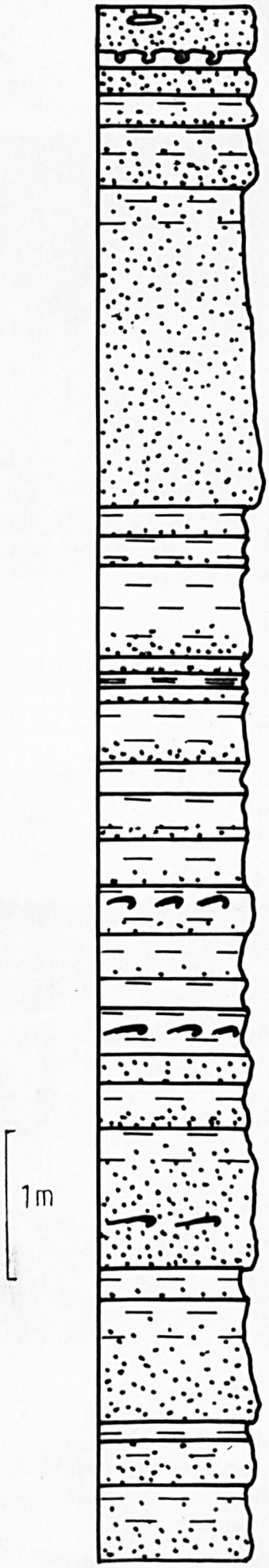

1m
M 3

Figure 3.8. Section through lithofacies M 3 taken from section no. 3, Moulin plage. (Key as in figure 3.5.)

Plate 3.13. Bedding in lithofacies M3. Scale 3cm wide.

Plate 3.14. Ball and pillow structures in silt band (lighter colour) which is enclosed by mudstones of lithofacies M3. Scale in cms.



M4

Figure 3.9. Section through lithofacies M 4, taken from section no. 12, Moulin plage. (Key as in figure 3.5.)

(d) Lithofacies M3

This is comprised of beds of massive mudstones that are interbedded with units of laminated mudstones and siltstones (Figure 3.8, Plate 3.13). This lithofacies is up to 10.5m thick in the north of the section but is only 2.1-0.5m thick in the south where no beds of massive mudstones are seen. The thickness of the massive mudstone units varies from 6.0-0.1m but in general it is close to the mean value of 1.3m. These units are generally featureless except for very occasional bands of siltstone (1-2cm thick) that are often disrupted (Plate 3.14). These mudstones do not contain nodules. The rhythmically interbedded mudstones and siltstones are composed of beds of mudstone (5-30cm thick) that are interbedded with siltstones (1-5cm thick). The contacts between the beds of mudstone and siltstone may be either sharp or gradational. Occasionally these beds may exhibit a very fine lamination of order of thickness less than 1 mm. The interbedded mudstones and siltstones are 0.1-0.9m thick with a mean of 0.4m. Rare beds of sandstone that do not exceed 0.3m in thickness occur within this lithofacies. They have both sharp tops and bases.

(e) Lithofacies M4

This lithofacies, which varies in thickness from 1.9-10.2m with a mean value of 5.2m, is comprised of graded beds with mudstone at the top and siltstone or fine grained sandstones at the base (Figure 3.9). The beds that grade down into siltstone are 0.1-0.6m thick with a mean of 0.25m. The silt fraction occupies on average approximately 60% by volume of these beds, although it may vary from 10%-90% of any one bed. These

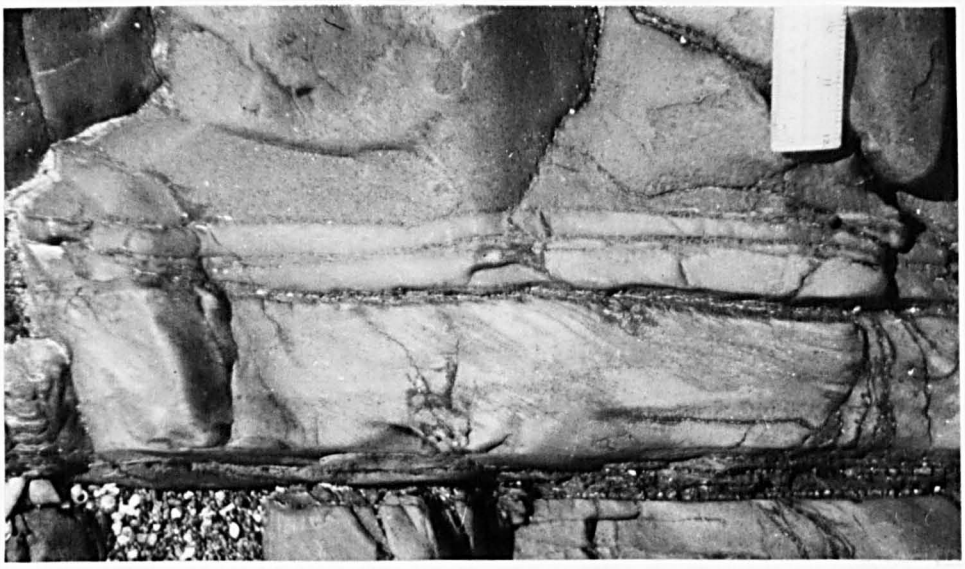


Plate 3.15. Cross lamination in siltstone band in lithofacies M4 Scale in cms.

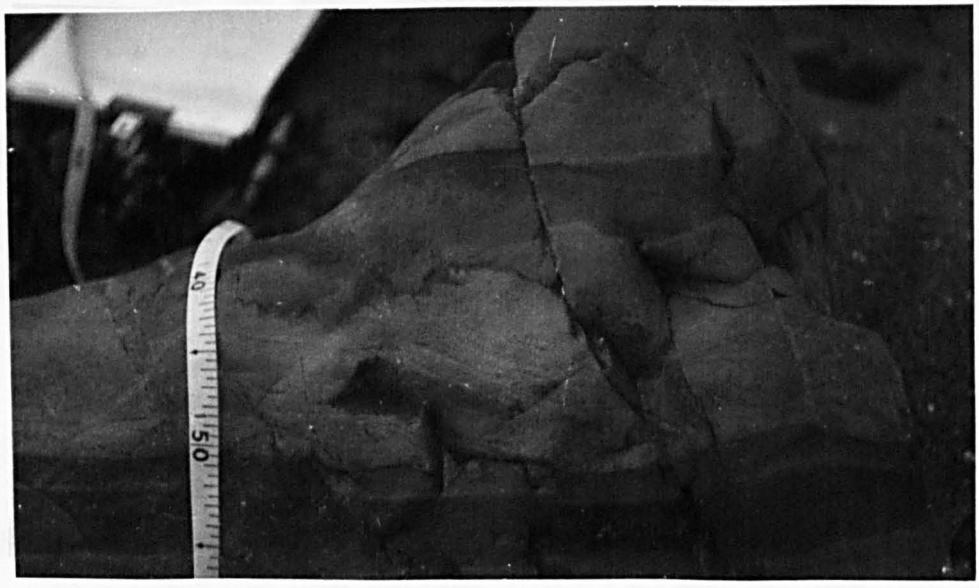
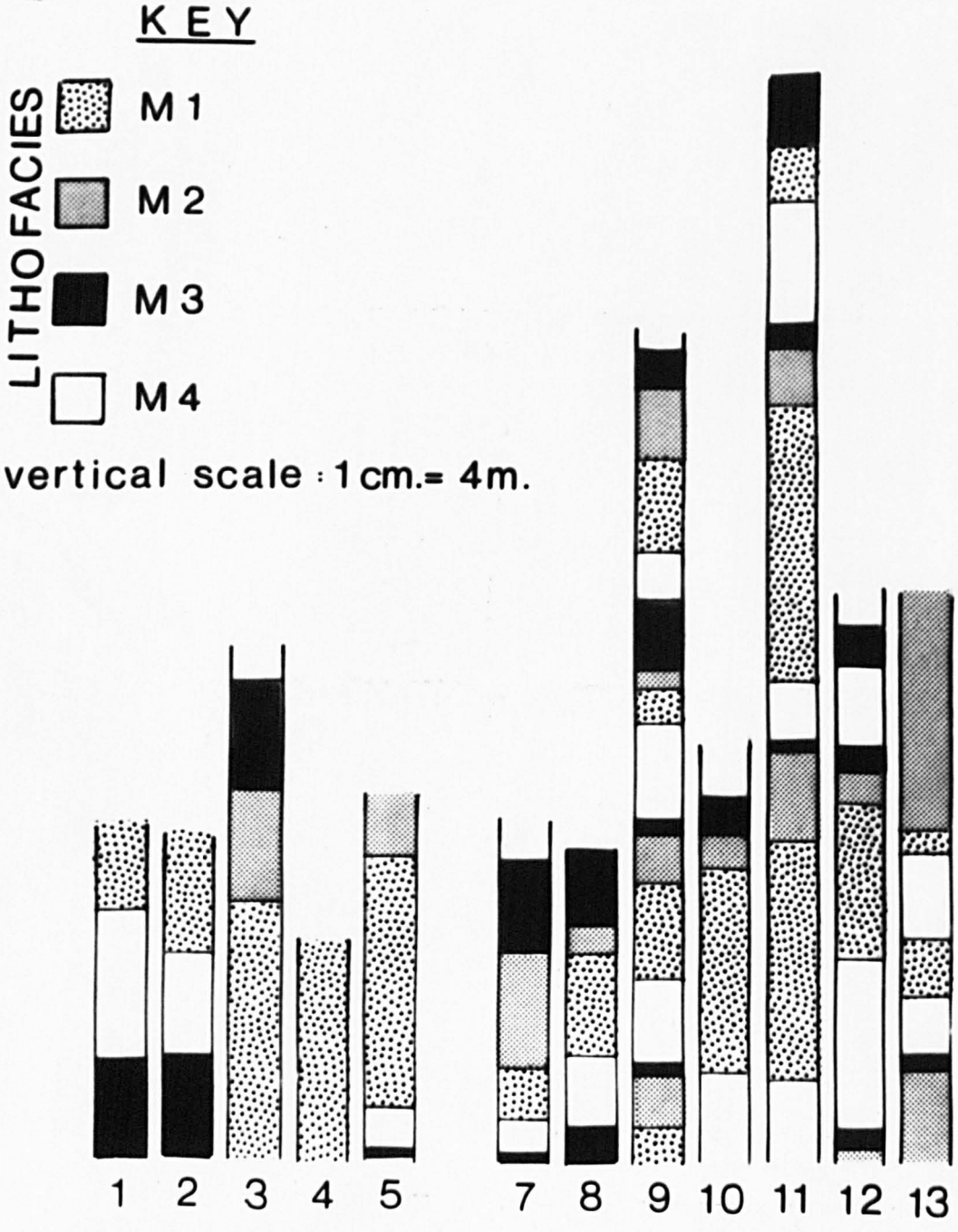


Plate 3.16. Cross lamination in siltstone band in lithofacies M4. Scale in cms.



Measured Sections, Moulin Plage.

Figure 3.10. Diagram to show the distribution of the lithofacies M 1, M 2, M 3, M 4 as recorded in the various sections measured at Moulin plage. Their cyclic arrangement can be clearly seen. The numbers on the sections correspond to those on the Moulin plage section shown in figure 3.4.

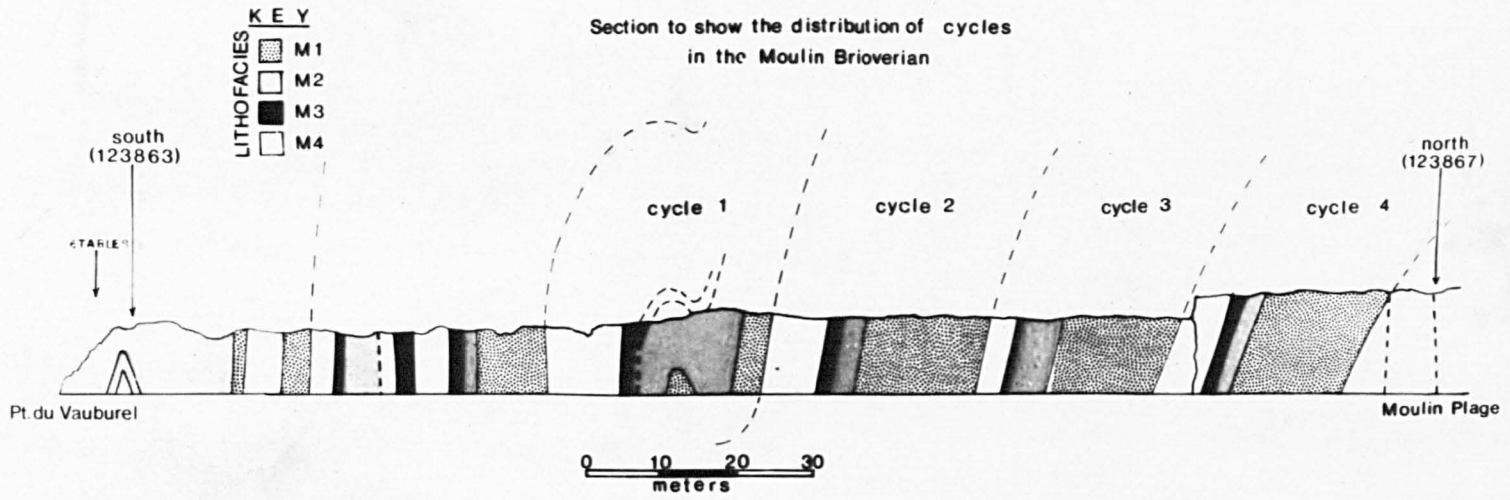

KEY
LITHOFACIES
M1
M2
M3
M4
Section to show the distribution of cycles
in the Moulin Brioverian
south
(123863)
north
(123867)
cycle 1
cycle 2
cycle 3
cycle 4
Pt.du Vauburel
Moulin Plage
0 10 20 30
meters

Figure 3.11.A cross section showing the distribution of the lithofacies M 1, M 2, M 3 and M 4 as recorded in the southern portion of the Moulin plage section. The diagram is compiled from sections numbers 10, 11, 12, and 13 (see also Figures 3.4 and 3.10).

siltstones show rare cross lamination (Plates 3.15 and 3.16). The beds that grade down into fine sandstone are common near the top of this lithofacies and are 0.2-1.7m thick with a mean value of 0.6m. The sandstone fraction occupies the lower 10%-30% of any one bed. Load structures are developed at the base of these beds which, near the top of the lithofacies, become so exaggerated that ball and pillow structures are developed. Towards the base of this lithofacies horizons of interbedded mudstones and siltstones are found which comprise 8% by volume of this lithofacies. The beds of mudstone and siltstone are usually of equal thickness which varies between 1cm and 5cm.

(f) Summary

The distribution of the lithofacies described above is summarised in Figure 3.10. The rhythmic repetition of the individual lithofacies in a given order may be seen in Figure 3.11. Generally it appears that within a rhythmic unit thick beds of coarse sediments are found at the base and finer sediments in a thinner beds are found at the top. These thinner beds then grade gradually upwards into thicker coarser beds.

3. The Brioverian of the Goudelin plage section

(a) Introduction

The Brioverian sediments of this section may be divided into two distinct lithofacies G1 and G2. Lithofacies G1 is comprised mainly of arenaceous sediments and lithofacies G2 is comprised mainly of argillaceous sediments. The succession here

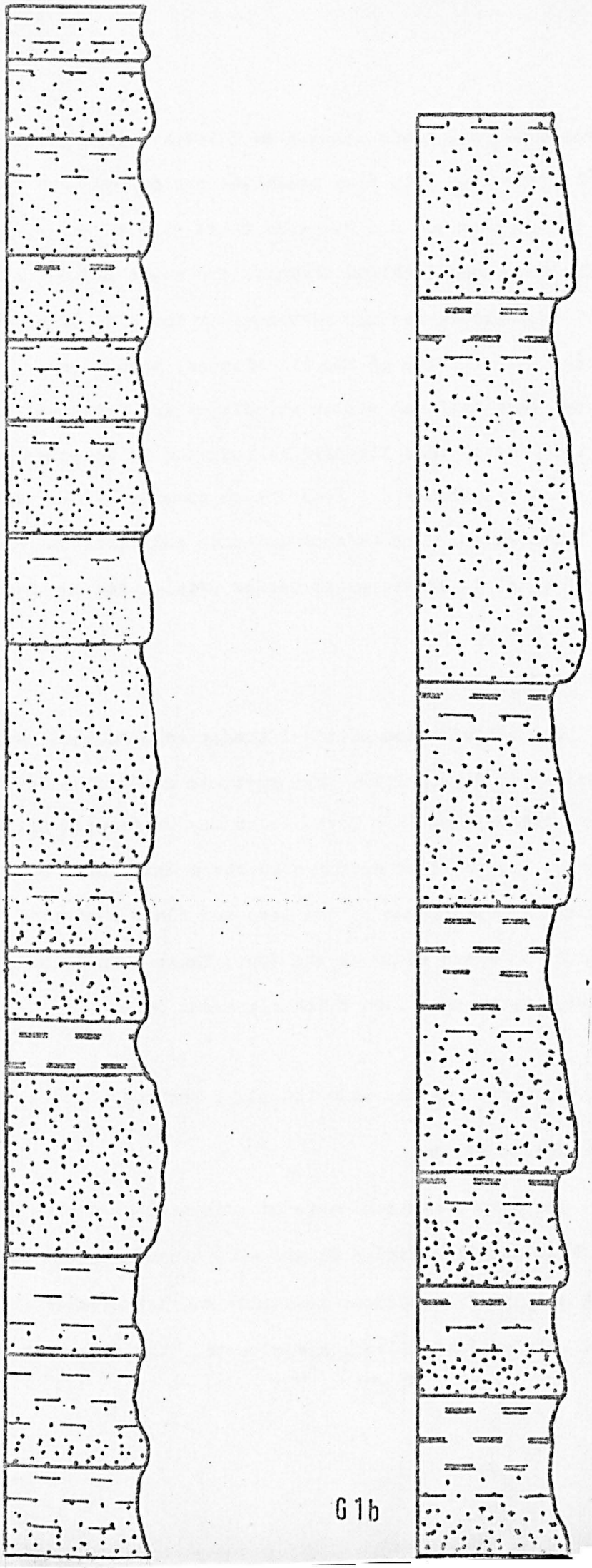

1m
G 1a
G 1b

Figure 3.12. Section through lithofacies G1a and G1b taken from Goudelin plage section no.2. (Key as in figure 3.5.)

is of broadly similar composition to the Moulin plage section being made up of clastic sediments, the only major variation being that the calcareous nodules are not found within the sandstones of this succession. The relative distribution of the different rock types in the various lithofacies is however greatly different to that of the Moulin plage section. The sandstone beds are always graded and are much thinner that those of the Moulin plage succession, there being no equivalents to the intermediate lithofacies M2 and M4, also there is a much greater abundance of finer grained sediments.

(b) Lithofacies G1

This lithofacies is comprised of graded units 0.4-2.8m thick. These are mainly comprised of sandstone, usually have sharp bases and grade into siltstone or mudstone towards the top. This lithofacies is further subdivided on account of the nature of the finer fraction of the graded beds into lithofacies G1a and G1b. Lithofacies G1a is comprised of beds of sandstone that grade upwards into the siltstones and mudstones that are 0.3-2.2m thick with a mean value of 0.8m. These beds all have sharp bases and they all show some degree of grading. In the thicker beds only the top 10% is occupied by the finer fraction, whereas in the thinner beds the finer fraction may comprise up to 50% of the whole. Mudstones that are 0.1-0.8m thick are interbedded with these graded beds. These mudstones are massive, grading into siltstone at their base. These mudstones

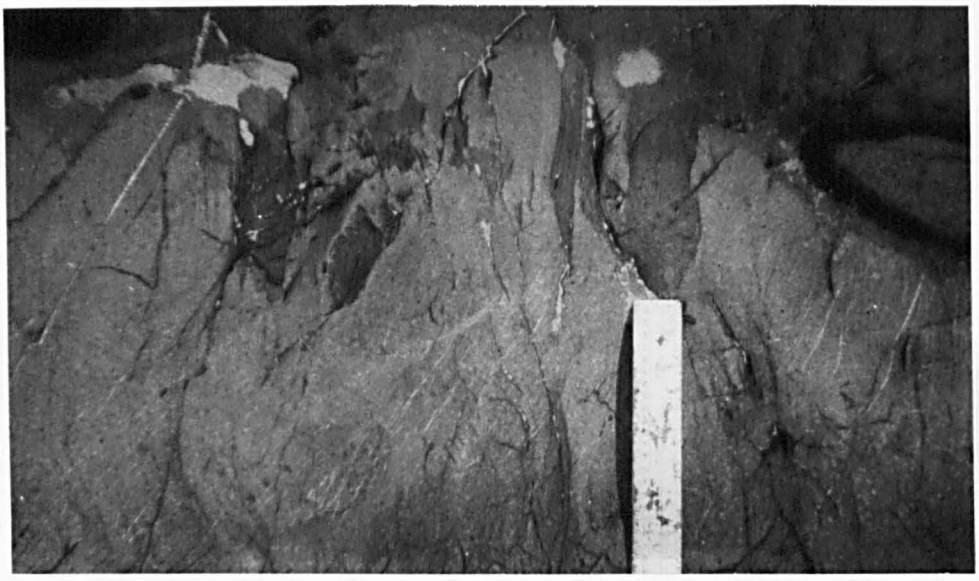


Plate 3.17. Disrupted mudstone (dark coloured) at the top of a sandstone unit in lithofacies G1a.

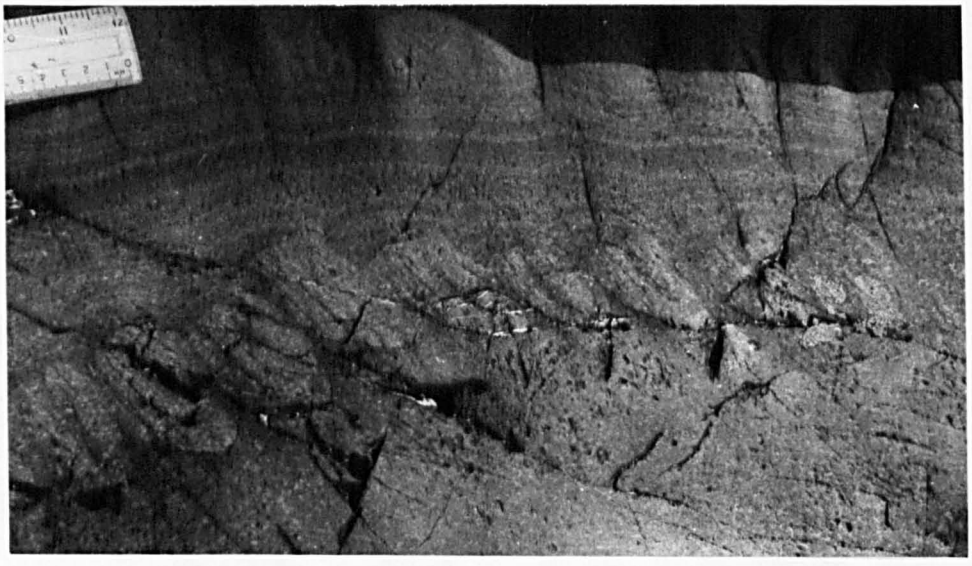
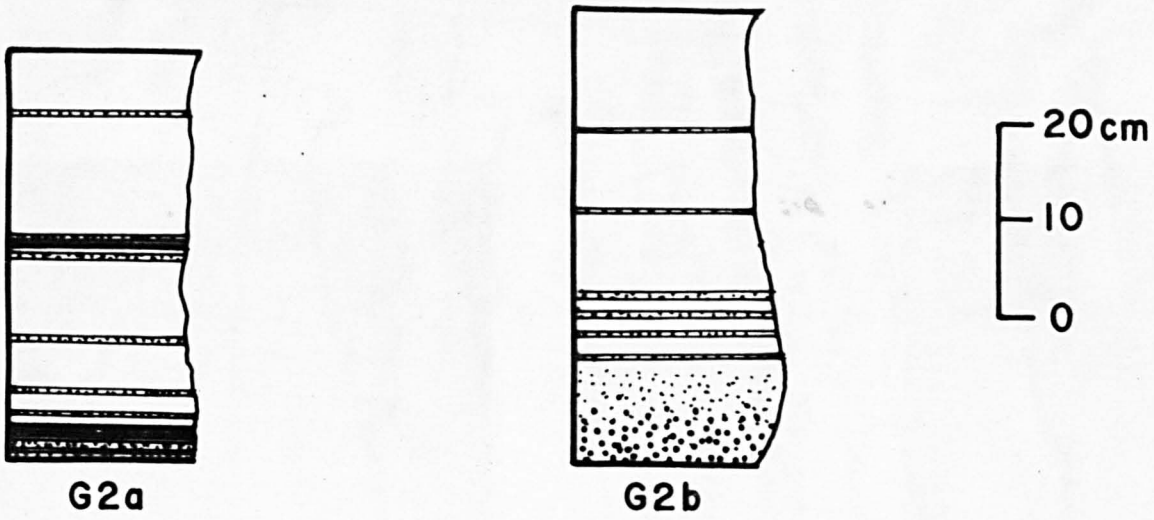


Plate 3.18. Finely laminated siltstones (lighter) and mudstones (darker) at the top of a graded unit in lithofacies G1b. A thicker siltstone band is boudinaged.



SKETCHES FROM NOTEBOOK ILLUSTRATING THE DIFFERENT TYPES OF BEDDING FOUND IN LITHOFACIES G_2.

KEY

sandstone

siltstone

mudstone

Figure 3.13. Sketches taken from notebook to illustrate the difference in the nature of the bedding in lithofacies G2a and G2b.

sometimes contain thin bands of siltstone and their bedding may be disrupted (Plate 3.17), they comprise 8% by volume of this lithofacies. Lithofacies G1b is made up of graded beds of sandstone which are 0.3-2.7m thick with a mean of 0.9m. These sandstones grade up into siltstones and laminated mudstones (Plate 3.18). In this lithofacies the finer sediments occupy a slightly larger proportion of each grade than they do in lithofacies G1a, comprising 20% of the thicker beds and up to 70% of the thinner beds. The bases of each graded unit are sharp but are otherwise featureless. These graded units are interbedded with laminated mudstones that have a mean thickness of 33cm which ranges from 10cm to 50cm. These mudstones comprise 14% by volume of this lithofacies.

Where these two lithofacies are seen to be in contact, lithofacies G1b is always seen to rest upon lithofacies G1a, which in turn is seen to rest upon lithofacies G2. This would suggest that these lithofacies are part of a cyclic sequence. In one instance a thin unit of lithofacies G1b is covered by lithofacies G2 (Figure 3.14, section 2).

(c) Lithofacies G2

This lithofacies is mainly comprised of laminated mudstones. It has been further subdivided into lithofacies G2a, G2b, and G2c on account of the amount and the distribution of the siltstone beds within these mudstones (Figure 3.13). Lithofacies G2a is largely composed laminated mudstones and is

Plate 3.19. Laminated mudstones and siltstones (lighter bands) of lithofacies G2a. Scale 30 cm.

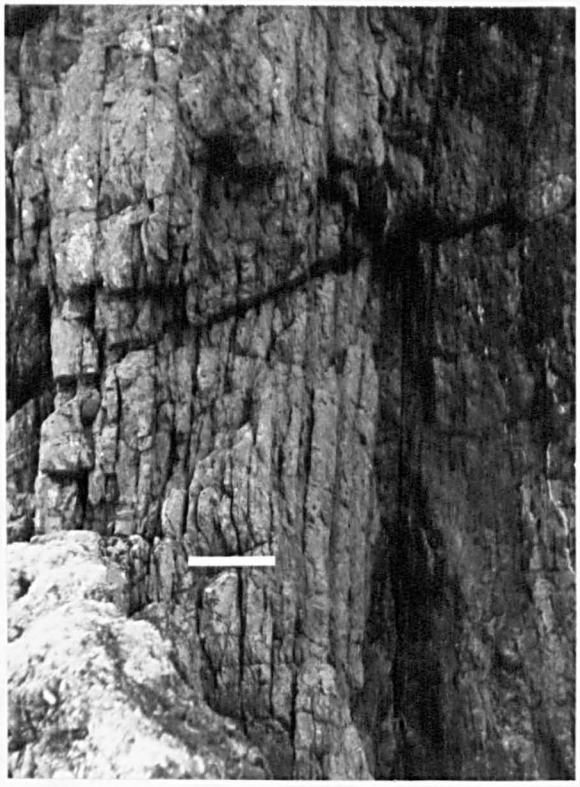


Plate 3.20. Interbedded laminated mudstones and siltstones (lighter bands) of lithofacies G2b. Scale 30 cm.

16.2-1.Om thick (Figure 3.13A). The individual laminae average about 5mm in thickness and are grouped in units that are from O.2-1.Om thick. These units contain thin beds of siltstone (Plate 3.19) that are rare at the top but increase in frequency towards the base of the unit which is entirely made up of finely banded siltstones. Many of these siltstones are seen to be underlain by up to 5cm. of sandstone. The thickness of these units decreases from the base to the top of this lithofacies. The beds at the base are anything from 100cm to 50cm in thickness, whereas this decreases to a thickness of 20cm at the top. The contact of this lithofacies with the overlying lithofacies G2b. is not always clearly defined and may be gradational over up to 1m of sediment.

Lithofacies G2b is made up of composite graded units of thickness between 2cm and 10cm (Plate 3.20, Figure 3.13), . these graded units are made up of massively bedded or laminated mudstones (average thickness of laminae 1mm) which tend to grade into siltstones at the base. Unlike the siltstone of the previous lithofacies these siltstones are usually massively bedded, although there are also some finely banded siltstones at the base of some units. This lithofacies has a sharp contact with the overlying lithofacies G2c.

Lithofacies G2c is made up of a thick sequence of finely laminated mudstones (average thickness of laminae 1mm) (Plate 3.21), which are ovelain by massively bedded mudstones. The

Plate 3.21. Massive mudstones, lithofacies G2c. Scale 30 cm.

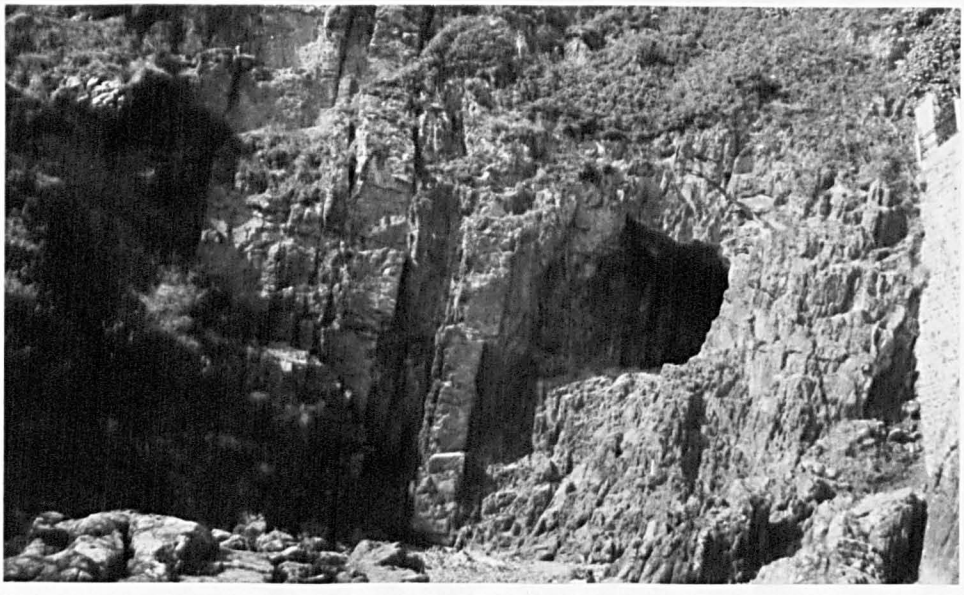
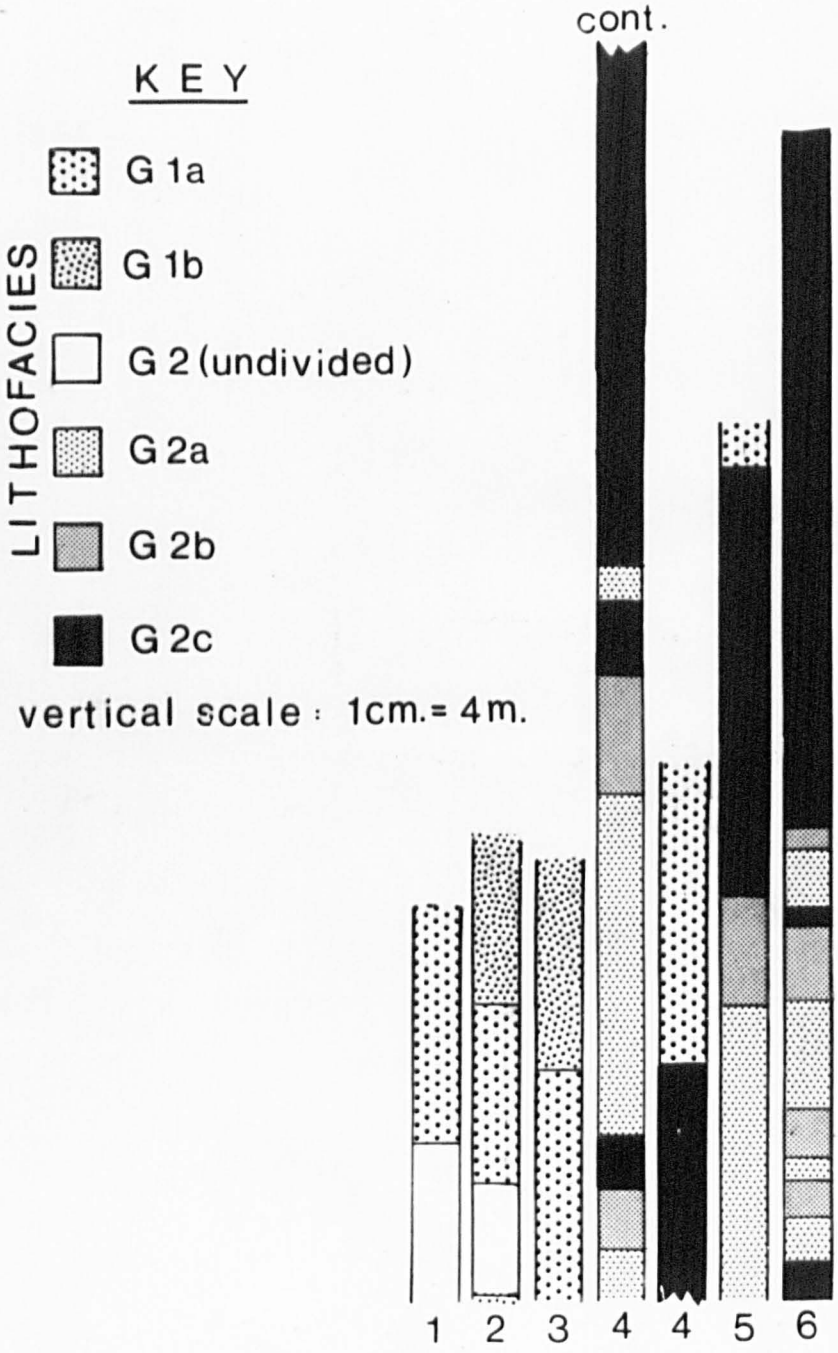


Plate 3.22. Contact between lithofacies G2c and G1 (on left), Section 1, Goudelin plage. Field of view is approximately 13m.



Measured Sections, Goudelin Plage.

Figure 3.14. Diagram to show the distribution of the lithofacies of G1a. G1b, G2a. G2b, G2c as recorded in the sections measured at Goudelin plage. The numbers in the sections correspond to those on the Goudelin plage section shown in figure 3.4.

lower finely laminated mudstones are rarely interbedded with silt laminae that show a rhythmic variation in their abundance over 1-2cm.

It has not always proved possible to carry out such a detailed subdivision of lithofacies G2 as has been outlined above since the quality of the exposure is not always good, and in some places it has only proved possible to record that the rock was principally comprised of mudstone. Where this has been the case the rock has been assigned to lithofacies G2.

As illustrated in Figure 3-14 these lithofacies are cyclically arranged with lithofacies G2a being overlain by G2b and this in turn being overlain by G2c and this is then covered again by G2a or G1 (Plate 3.22). It may be generally stated that lithofacies G2 is made up of composite units of mudstone with siltstone or sandstone at the base. The size of these graded units and the amount of coarser sediment decrease as the top of the lithofacies is approached. There are cyclic variations between sub-lithofacies of varying grain size within this lithofacies.

(d) Conclusions.

The following conclusions may be drawn from the above study of the Brioverian of the Moulin plage and Goudelin plage sections:

1. The sequence is comprised of a marked alternation of fine, medium and coarse grained clastic sediments.

2. The sandstones are greywackes. They are poorely sorted and contain angular fragments of quartz, felspar and lithic fragments, and a large proportion of matrix.

3. Within the succession various lithofacies may be identified. These are constant in composition throughout a great ghickness of the succession and they are repeated in a rhythmic fashion.

4. The bedding within this succession shows no lateral variation in thickness or in composition.

5. Thick beds of sandstone occur throughout the sequence and these are typified by graded bedding.

6. The bases of these sandstones may be planar or they may exhibit flute casts, flame structures and load casts.

7. The finer sediments show laminations, flame structures, rare current ripples, slumps and convolute laminations.

8. There is a general absence of cross stratification and ripple marks, especially in the coarser grained horizons.

9. The thickness of this sequence is considerable, the real thickness is not known but is at least 1km and is probably much greater.

The major differences observed between the Brioverian of the two areas are listed below:

1. There is proportionately much more fine grained sediment in the Brioverian of Goudelin plage.

2. The beds of sandstone are much thinner and show much more pronounced graded bedding in the Brioverian of Goudelin plage.

3. There are no calcareous nodules in the sandstones of Goudelin plage.

4. Load casts, flame structures and flute casts are visible at the base of the sandstones of Moulin plage but these structures are not seen in the Brioverian of Goudelin plage.

5. Slump structures and cross bedding are seen in the siltstones of Moulin plage, these are not seen in those of Goudelin plage.

6. The bedding of the finer grained sediments of Goudelin plage is much finer than that of Moulin plage.

7. The lithofacies in the Brioverian of the Moulin plage are repeated in a cyclic fashion to form a larger unit of sediment. This also appears to be the case for the Brioverian of Goudelin plage but here these cycles are a great deal thicker than those of Moulin plage.

The conclusions presented above indicate that these are probably geosynclinal sediments which were the result of deposition from turbidity currents and that they may be termed

"flysch" like (Dzulynski and Walton 1965). The total thickness of this sequence is not known but it must be greater than 1km as this thickness of sediment is found in the southern limb of the Moulin antiform. The main difference between the sediments of the Moulin plage section and the Goudelin plage section is that the Goudelin turbidites are of a more distal nature than the Moulin turbidites, however, the rocks of both sections show features that are typical of distal turbidites. If this variation is lateral it would indicate that the source of these sediments was to the north, possibly the Pentevrian mass around Plouha. However, as the exact position and attitude of the first phase of Cadomian folds in this region is not known, this variation may be a vertical one.

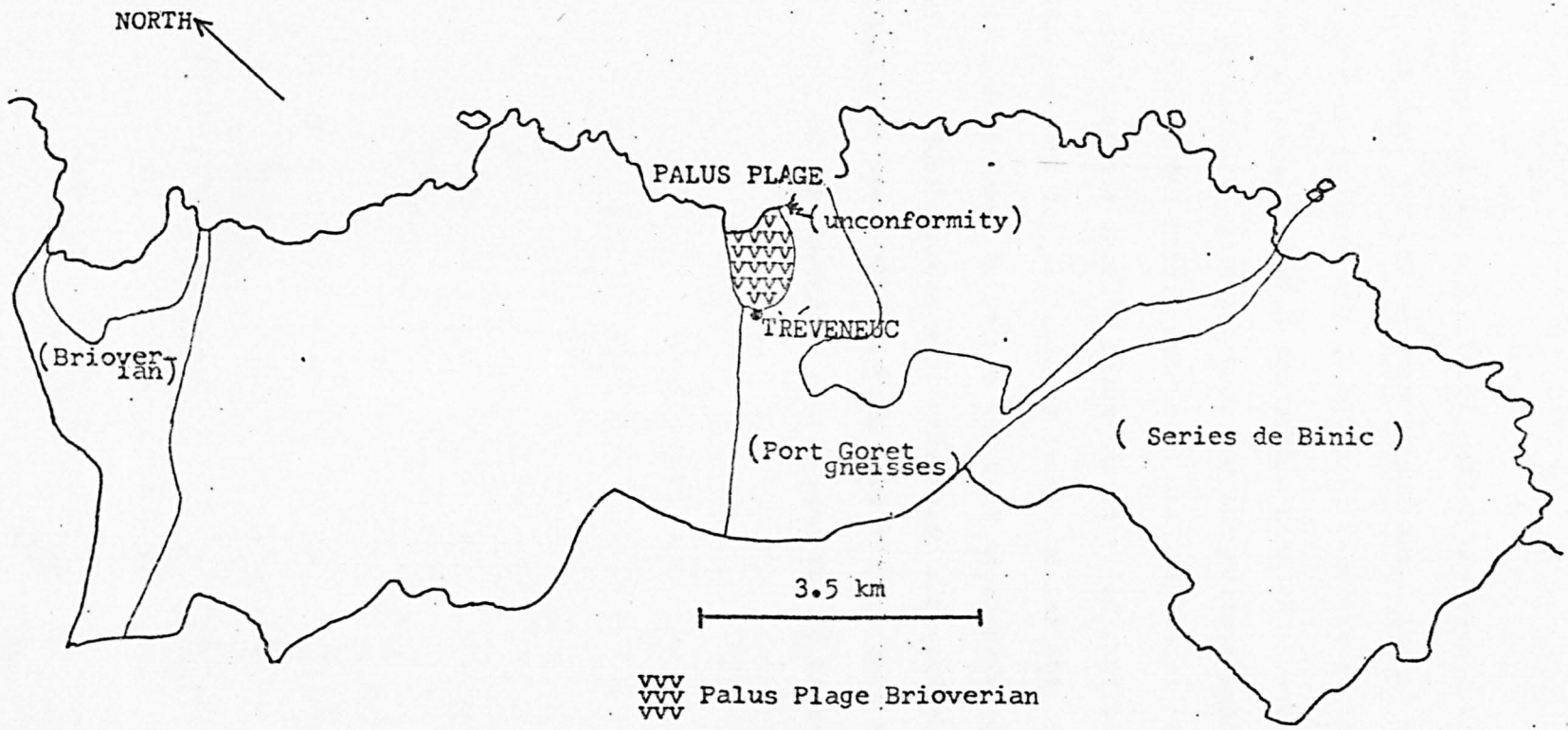

NORTH
PALUS PLAGE
(unconformity)
TRÉVENEUC
(Briovérian)
(Port Goret gneisses)
(Series de Binic)
3.5 km
Palus Plage Brioverian

Figure 3.15. Sketch geological map showing the outcrop of the Palus plage Brioverian (patterned) in the area mapped.

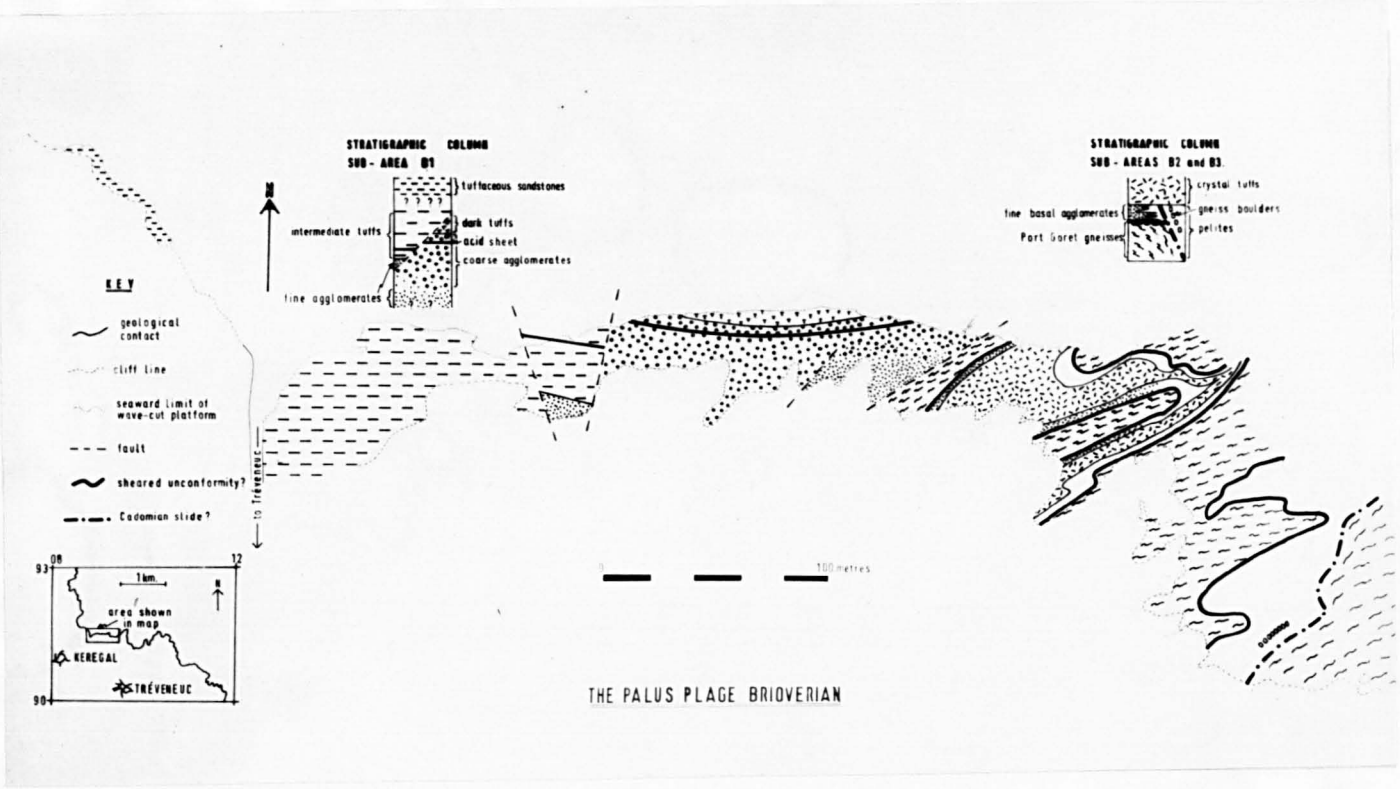

STRATIGRAPHIC COLUMN
SUB - AREA B1
tuffaceous sandstones
dark tuffs
acid sheet
coarse agglomerates
intermediate tuffs
fine agglomerates
STRATIGRAPHIC COLUMN
SUB - AREAS B2 and B3
crystal tuffs
gneiss boulders
pelites
fine basal agglomerates
Port Goret gneisses
KEY
geological contact
cliff line
seaward limit of wave-cut platform
fault
sheared unconformity?
Cadomian slide?
to Tréveneuc
93
08
12
90
1km.
area shown in map
KEREGAL
TRÉVENEUC
0
100 metres
THE PALUS PLAGE BRIOVERIAN

Figure 3.16. Geological map of the Palus plage Brioverian as it is exposed in the wavecut platform to the south of Palus plage.

C. The Palus Plage Metasediments and Metavolcanics

1. Introduction

The Palus plage metasediments and metavolcanics are well exposed in the wavecut platform on the northern side of the sandy bay immediately south of the Palus plage (Figure 3.15) where they are in contact with the Port Goret gneisses (Figure 3.16). The contact between these two sequences has undergone polyphase deformation during the Cadomian orogeny (Chapter IV), however, sedimentary evidence suggests that in places it may represent a Pentevrian/Brioverian unconformity. The metasediments are pelites and psammites, the metavolcanics were originally pyroclastics of an acidic/intermediate composition.

Acid volcanics also occur in the Brioverian between Morlaix and Tregastel, Côtes du Nord (Verdier 1968, Roach personal communication), on Jersey, Channel Islands (Mouraunt 1933) and at Saint Germain-le-Galliard, Manche (Graindor 1957). Graindor assigns the Rhyolites de Saint Germain-le-Galliard to the base of the Upper Brioverian as he believes that they were extruded onto a land surface formed as a result of uplift during the Constantian phase of the Cadomian orogeny.

2. Lithologies

The Palus plage metasediments and metavolcanics contain the following rock types: pelites; coarse and fine agglomerates; crystal tuffs; dark tuffs; intermediate tuffs; and tuffaceous sandstones. They will be considered in the order given .

(a) Pelites.

These lie at the base of the Palus plage Brioverian and

Plate 3.23. Interbedded meta-mudstones and meta-siltstones in the Pelites, Palus plage.

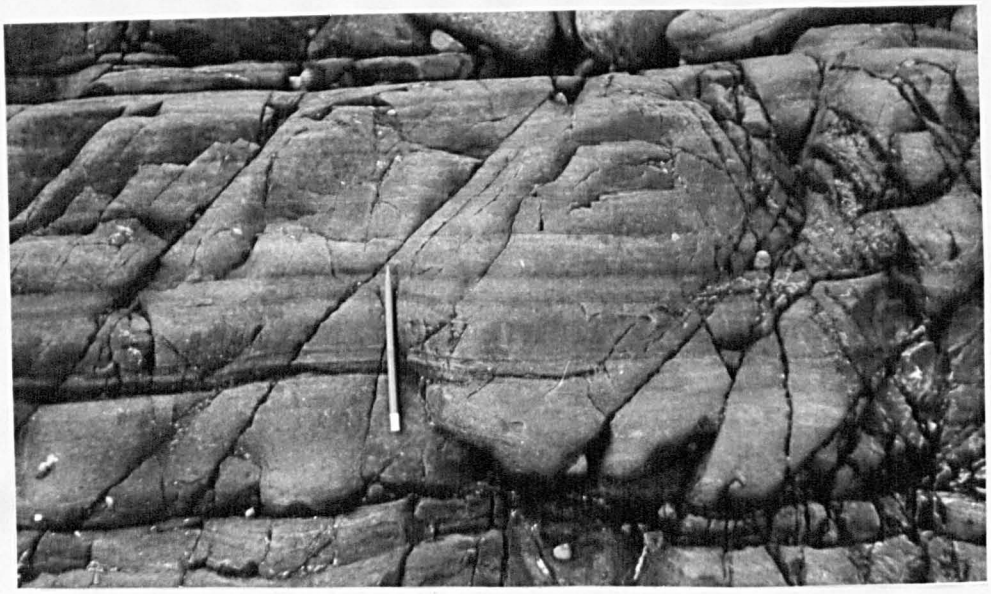


Plate 3.24. Graded beds in the Pelites. Grading (coarser sediments are lighter than the finer) indicates that the beds young in the direction of the pencil point, i.e. towards the west. Palus plage.

may rest unconformably upon the Port Goret gneisses in the eastern part of the Palus plage section (Figure 3.16). Original sedimentary banding is still evident (Plates 3.23 & 3.24) although they have been metamorphosed to a fine grained quartz+biotite+ plagioclase+magnetite schist. They were originally comprised of interbedded iron rich mudstones and siltstones. The siltstone bands are lighter in colour, from 5mm to 5cm thick and are graded. They are typically separated by 5-10cm of mudstone. Bands of siltstone are plentiful in the east of the outcrop but become rarer towards the west. 4m to the west of the eastern-most pelite/gneiss contact there is a conglomeratic horizon in which boulders of retrogressed gneiss, 20-40cm across, are set in a matrix of siltstone. This horizon is parallel to the sedimentary layering and is almost certainly a primary sedimentary horizon.

A study of the graded bedding found in the siltstones indicates that although there is some variation in the direction of younging the pelites young towards the east over most of their outcrop. The beds in fact dip to the west, indicating that they are overturned. This would suggest that the Port Goret gneisses occupying the Port Goret headland overlie the pelites. It is for this reason that it is felt that the eastern-most pelite gneiss contact is a tectonic and not a sedimentary contact, whereas the western contact of the main outcrop of the pelites with the gneisses may represent an original surface of unconformity that has now been inverted. It is not clear why the only boulder horizon

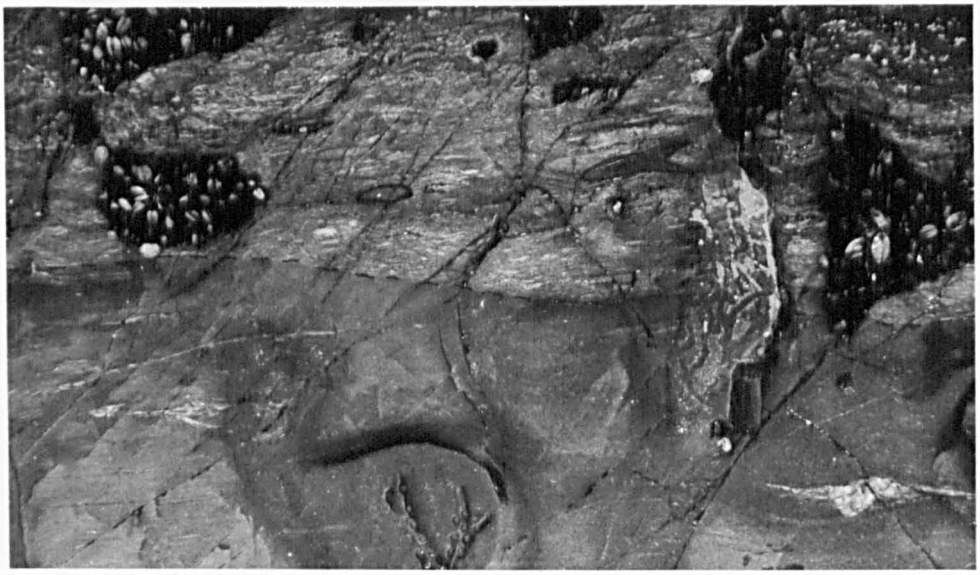


Plate 3.25. Contact between the basal Brioverian agglomerates and the Pentevrian basement (at bottom). This surface is thought to represent the original unconformity. Fragments of gneiss are outlined. Headland south of Palus plage. Field of view is approximately 1 m.

Plate 3.26. Weathered surface of the crystal tuffs showing relict plagioclase of primocrysts. Palus plage. Field of view is approximately 50 cm.

recorded within the pelites should be so far above their base.

In their western most occurrence the pelites thin to 2-4m and the siltstone bands become rich in grains of plagioclase (2-8mm) that are thought to be an original feature of the sediments as they show relict Carlsbad-Albite twinning, a law that is only developed in primary igneous plagioclases (Vance 1961). The appearance of these plagioclase primocrysts must represent the onset of volcanic activity in this area. This band passes laterally into a fine grained basal agglomerate (Figure 3.16) which contains fragments of volcanic rocks and rarely of gneiss which are set in a matrix similar to the overlying crystal tuffs. The nature of these agglomerates, which are in contact with the gneisses (Plate 3.25), indicates that this contact was originally an unconformity which has been subsequently modified by Cadomian deformation (Chapter IV).

(b) Crystal tuffs.

These immediately overlie the pelites and fine agglomerates (Figure 3.16). They are massively bedded and are monotonous in composition. The matrix was originally a fine grained tuff that has now been metamorphosed to a plagioclase+quartz+hornblende assemblage. A distinctive feature of these tuffs is the occurrence of plagioclase primocrysts, similar to those

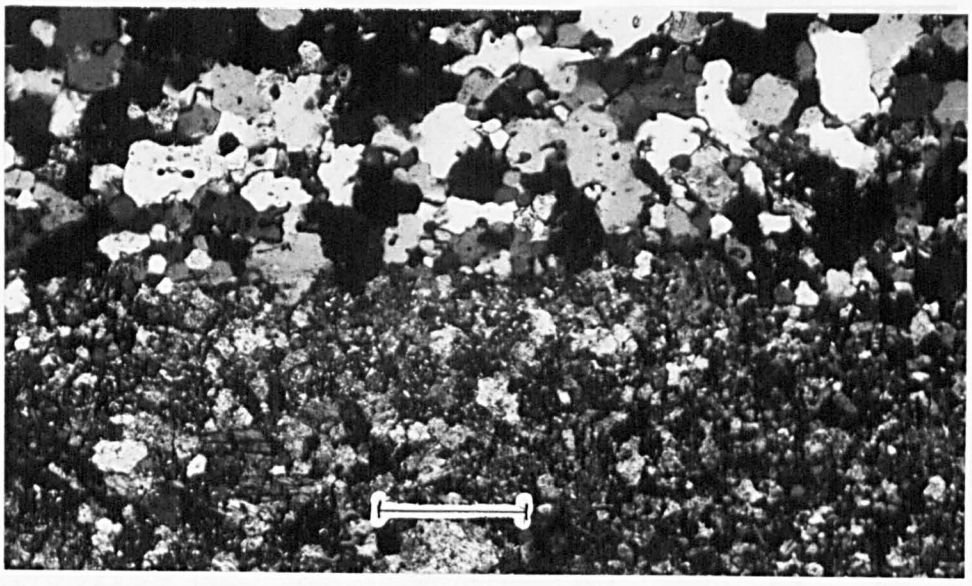


Plate 3.27. Photomicrograph (cn) of the contact between meta-rhyolite pebble (top) and the matrix of the agglomerates. Scale 0.19 mm.

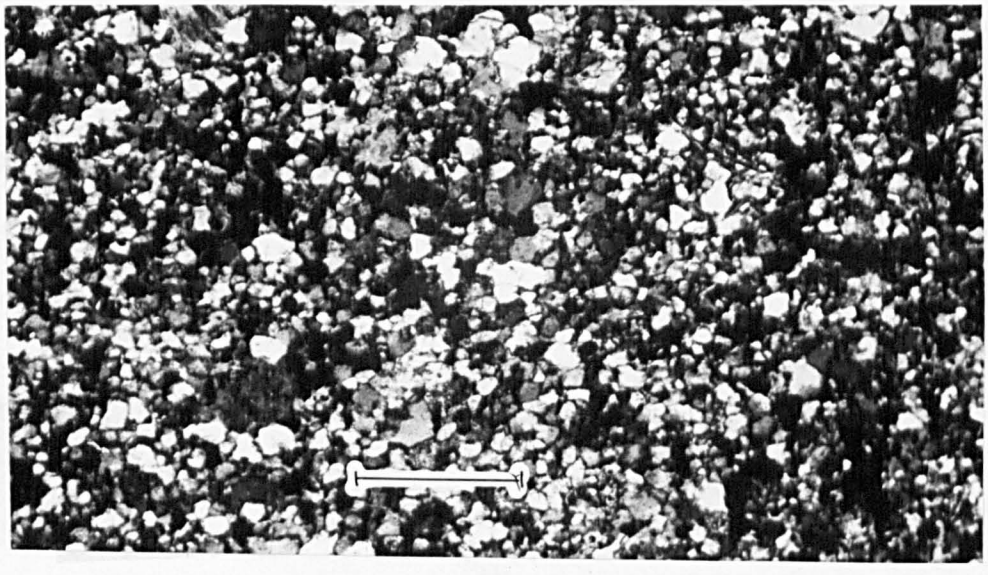


Plate 3.28. Photomicrograph (cn) of a meta-rhyolite pebble in the agglomerates. Scale 0.19 mm.

found in the pelites, which have been sericitised during a later metamorphic event (M_{4C} see page 4.22) and now stand out in relief in the weathered rock making it easily identified (Plate 3.26).

The pelites and the crystal tuffs outcrop only in the east of the Palus plage section and their stratigraphical relationships with the other rock types of this sequence are not known although the crystal tuffs and the fine grained basal agglomerate are most probably closely associated with the other volcanic rocks found in this sequence.

(c) Agglomerates (of the western part of the Palus plage section)

The agglomerates are comprised of massively bedded pyroclastic rocks which contain boulders of volcanic rock of up to 50cm. across enclosed in a matrix similar to the crystal tuffs. The great majority of the volcanic fragments are a recrystallised acid igneous rock (Plates 3.27 & 28), of possible rhyolitic origin, which may or may not contain plagioclase phenocrysts. There are a few fragments that are granodioritic in composition which are made up of subhedral laths of plagioclase and a few small grains of quartz. Small fragments of meta-basalt are occasionally found. There is a marked increase in the size of these fragments in going from east to west. In the west of the section the largest fragments are up to 50cm in length but in the east they rarely exceed 5cm in length. It is difficult to estimate the original size of these

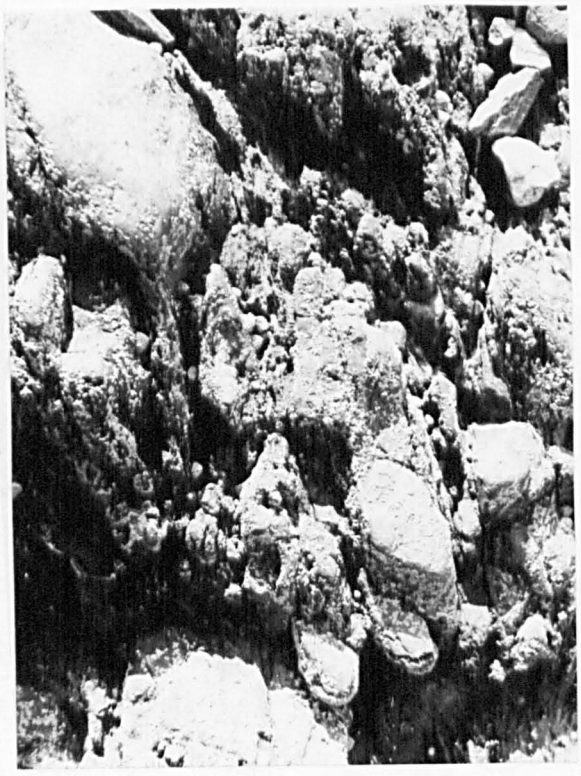


Plate 3.29. Deformed pebbles and boulders of metarhyolite and other igneous fragments in the agglomerates. Wavecut platform, 200 m east of track to Treveneuc, Palus plage. Field of view is approximately 1.5.m.

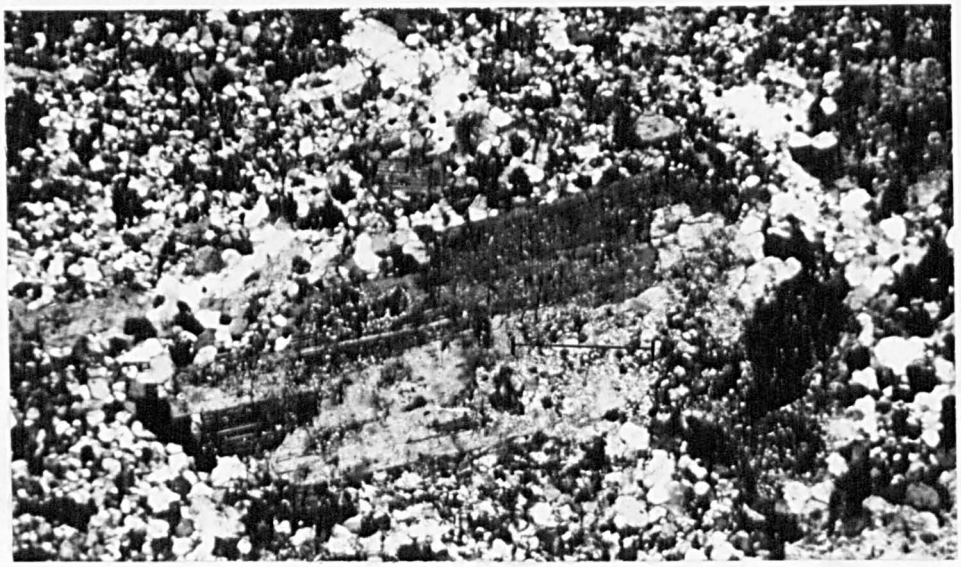


Plate 3.30. Photomicrograph (cn) of a relict igneous plagioclase primocryst, which exhibits Carlsbad Albite twinning, in the matrix of the agglomerates. Scale 0.69 mm.

fragments as they have undergone severe tectonic flattening (Plate 3.29) and their present form is statistically equivalent to an ellipsoid with axial ratios of X:Y:Z = 5:2:1.

These fragments are enclosed in a fine grained quartz+plagioclase+hornblende+biotite+chlorite matrix that contains many plagioclase primocrysts (Plate 3.30) (0.5-3mm) that show not only relict igneous twinning laws but also relict euhedral form that may be distinguished in spite of metamorphic overgrowths. Large grains of quartz occur, which have angular cores that are overgrown by metamorphic quartz, these are also thought to be an original feature of the agglomerates.

It should be noted that the pelites pass laterally westwards into a coarser agglomeratic rock type and that also the agglomerates described above coarsen to the west. This suggests that the site of volcanic activity lay to the west, i.e. towards Plouha.

(d) Dark tuffs

A band of dark coloured tuffs, structurally above the agglomerates, are poorly exposed along the seaward margin of the rocky foreshore in the centre of the Palus plage section (Figure 3.16). These are of unknown thickness. They are generally dark green in colour but are mottled with light green patches. They enclose fragments of volcanic material that do not exceed 10cm. in length. The matrix of these tuffs is a quartz+plagioclase mesh that contains rare plagioclase

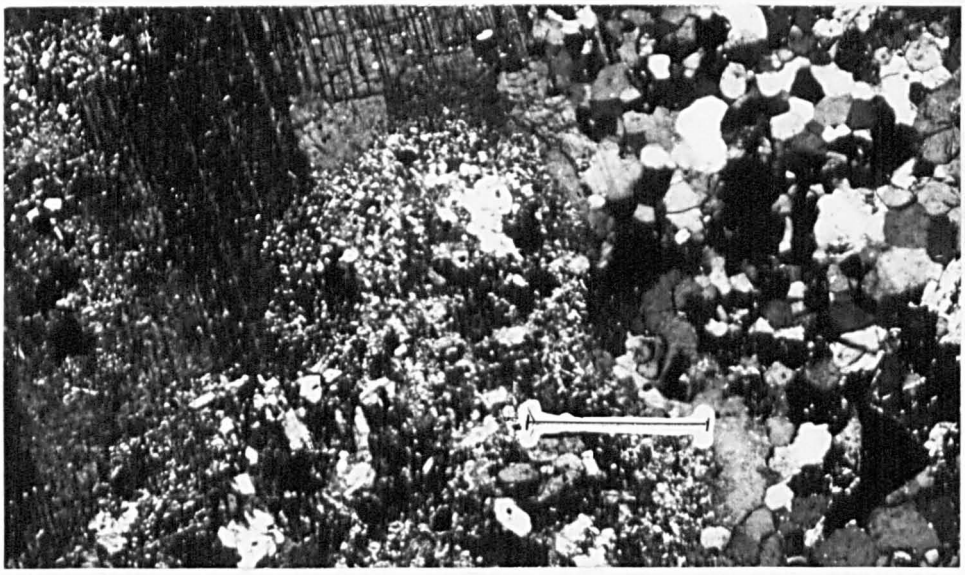


Plate 3.31. Photomicrograph (cn) of relict plagioclase primocryst in the matrix of the intermediate tuffs. Scale 0.69 mm.

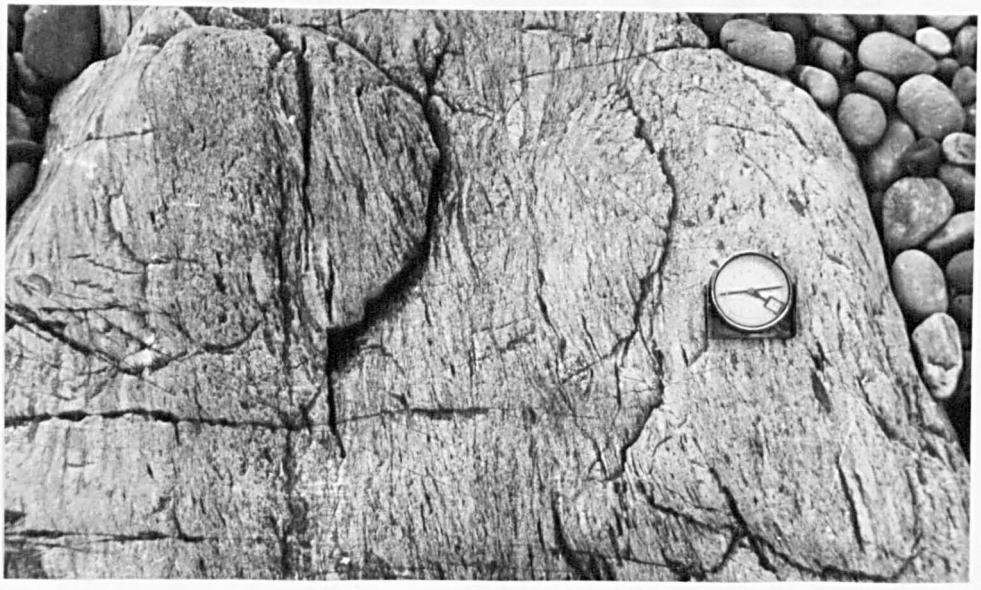


Plate 3.32. Rhyolitic tuff band in tuffaceous sandstones, Palus plage 30 m. west of track to Treveneuc.

primocrysts and is generally pelitic in composition. The gragments that are found in these tuffs are similar to those found in the agglomerates and are probably of a rhyolitic nature.

The variation in the colour of these sediments is due to two factors. The first being the rapid variation in the composition of the sediments, the pelitic tuffs being interbedded with coarser tuffs that are very similar in nature to the crystal tuffs. The actual relationship between these two rock types is not clear, but generally it may be said that the coarser tuffs exist as irregular lenses within the dark tuffs. The second factor that causes variation in the colour of these tuffs is the retrogression and epidotisation of the dark tuff to produce a rock that is a light green in colour. These retrogressed patches are irregular in size and occurrence.

(e) Intermediate tuffs.

These meta-tuffs occupy the wave cut platform immediately to the west of the track that leads to Tréveneuc (Figure 3.16). Since they are faulted against the dark tuffs and the agglomerates their stratigraphical relationship to these beds is not known. They are comprised of light coloured tuffs that have been metamorphosed to a quartz+ plagioclase+hornblende assemblage (Plate 3.31). These are inter-bedded with lenses of crystal tuffs and fine agglomerate. These agglomerates have a matrix of intermediate tuff and contain

pebbles that may represent fragments of the basement gneiss although the majority are similar to the rhyolitic pebbles found elsewhere.

Recognition of the original nature of these tuffs has been made more difficult as the result of a static phase of metamorphism (M_{3C} see page 4.20) that has resulted in the growth of large poikilitic porphyroblasts of plagioclase and hornblende up to 5cm in length. These are particularily common in the pressure shadows of the occasional large boulders that occur in these tuffs.

(f) Tuffaceous sandstones

These outcrop in the extreme west of the Palus plage section (Figure 3.16) and are comprised of interbedded tuffs and fine grained sandstones. The tuffs are very similar to the previously described intermediate tuffs while the sandstones have a large percentage of matrix enclosing clasts of plagioclase, quartz and rock fragments and are felspathic greywackes. A band of poorly exposed, hard, white, fine grained rock that contains many extremely flattened micaceous inclusions is interbedded with the sandstones. This may represent a rock that was originally a rhyolite or even an ignimbrite (Plate 3.32). The stratigraphical relationships of the tuffaceous sandstones with the other rock types is not know.

3. Conclusions.

The coastal section along the east side of Palus plage is composed of a sequence of Brioverian volcanic rocks with minor sediments, which rests unconformably upon the Pentevrian basement. Boulders of gneiss, similar in composition to the Port Goret gneisses, occur within the boulder horizons and the agglomerates near the base of the sequence. The nature of the pyroclastics indicate that there was a volcanic centre not far to the west. The relationship between the Palus plage meta-volcanics and meta-sediments and the Binic-Bréhec Series is not known.

The nature of the Palus plage sediments, bedded pyroclastics of acid affinities immediately overlying fine grained pelitic sediments containing horizons of basal conglomerate, indicates that they were formed as a result of volcanic activity in a sub-aeriel to shallow water environment. This setting strongly contrasts with the thick sequence of basic pillow lavas and intrusive sheets which are developed at the base of the Brioverian further south between Cesson and Erquy (Cogné 1961, Brown and Roach 1972).