POLYOROGENIC EVOLUTION OF THE WESTERN PAYS DE LĒON, FINISTERE, FRANCE

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PH.D.

1980

VOL.1: TEXT

ABSTRACT

A completely new lithological classification is made of the Lannilis Metamorphic Complex and the Plouguerneau Migmatites, which lie south and North respectively of the Porspoder Lineament in the north-west Pays de Léon. The sequence of metamorphic, magmatic and tectonic episodes is analysed and a correlation between the two complexes is suggested. The metasedimentary lithologies are thought to be derived from Brioverian semi-pelites, and the meta-igneous rocks from post-Brioverian intrusions. The later granitic rocks associated with the Plouguerneau Migmatites are described and classified in detail for the first time.

The structures which define the Porspoder Lineament itself are also described. This feature may have originally been an intra-continental fault of transform type.

Existing geochronological data and new K-Ar mineral dates are used to fit the geological evidence from the NW Pays de Léon to the absolute time scale. The importance of the Hercynian orogeny is emphasised; the main metamorphism and migmatisation are attributed to the Bretonic (Devono-Carboniferous) phase.

A study has also been made of the Le Conquet Metamorphic Complex in the SW Pays de Léon. An entirely new interpretation of the field relations and geochronology of the lithologies previously known as 'Gneiss de Brest', 'Gneiss de Lesneven', and 'Granodiorite des Renards' is presented. A single major intrusion, the Granodiorite de Brest, is recognised. It was emplaced into the already deformed and metamorphosed Briverian during the latter stages stages of the late-Precambrian/Cambrian Cadomian orogeny, probably at about 550 my. Other intrusions (Granodiorite de Pont-Cabioc'h and doleritic Filons de Kermorvan) were also emplced prior to the main regional metamorphism (the Bretonic phase of the Hercynian orogeny) which produced staurolite- and sillimanite-bearing assemblages in the associated (originally Brioverian) metasediments. This sequence of events, and later phases of folding and granite emplacement, are tentatively correlated with events in the NW Pays

de Leon and in the supracrustal terrain of central Finistère.

A special study has also been made of the Bretonic regional metamorphism of the whole of the western Pays de Léon. Observed assemblages suggest a geothermal gradient intermediate between the Barrovian and Abukuma types. Attention is drawn to the long and complex history (Lower Proterozoic or Pentevrian, Cadomian and Hercynian) represented by the rocks of the western Pays de Léon.

ACKNOWLEDGEMENTS

The work described in this thesis was carried out at the Department of Geology, University of Keele, under the supervision of Dr. R.A.Roach. The work was supported by an N.E.R.C. Postgraduate Research Grant which is gratefully acknowledged.

I should like to thank Dr. Roach for drawing my attention to the rocks of the western Pays de Léon, for many useful discussions, for critically reading the MS, and for permission to use photographic material.

I am grateful to Professor G.Kelling and other members and former members of the Keele Geology Department for their good-humoured encouragement, useful discussions, and technical assistance; particular thanks to the following: M.Aikin, D.M.Alderton, B.Besly, J.Cliff, J.S.Daly, M.M.Durance, D.W.Emley, P.A.Floyd, P.Greatbatch, J.Install, D.W.Kelsall, G.J.Lees, R.G.Park, J.Pepper, G.Rowbotham, M.W.Stead, and J.A.Winchester.

I am also grateful for useful discussions with the following: at the Université de Bretagne Occidentale in Brest with Professor J. Didier, M.Barrière, L.Chauris, J-R.Darboux and J.Rolet; at the Université de Rennes with Professor J.Cogné, M.S.N.Carpenter, S.K.Hamer, J-J.Peucat, Ph.Vidal and J-P.Brun; and elsewhere with C.J.D.Adams, A.J.Barber, B.Cabanis, Y.Corre, J.W.Gray, J.A.Miller, J.T.Renouf, L.Richards and B.Roberts.

I am indebted to J.G.Mitchell for collaboration on K-Ar dating, and to R.T.Taylor for permission to refer to his unpublished data.

I should also like to thank C.J.Guberman, M.J.Nichols, and K.O'Sullivan for assistance in typing and preparation of maps, and J.P Udal for financial assistance.

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CHAPTER 1 INTRODUCTION

A. LOCATION AND TOPOGRAPHY

This study is concerned with the western sector of the district whose traditional name is the Pays de Lēon. The Pays de Lēon forms the NW extremity of the mainland of France. It thus lies at the tip of the region known as Bretagne (Brittany) which extends into the Atlantic Ocean and separates the Golfe de Gascogne (Bay of Biscay) from La Manche (English Channel). The city of Brest is situated at the southern edge of the Pays de Lēon and the town of Morlaix near its SE corner.The western Pays de Lēon is surrounded on three sides by the sea (south, west and north). (Figs 1-1 and 1-2).

The south coast consists mainly of cliffs up to about 60 m high cut into the plateau which forms the interior. The line of cliffs has many small irregularities but the only major indentation is at the Anse de Bertheaume at the head of which the coast is low-lying and sandy. Elsewhere, the intertidal zone is narrow and rocky.

The west coast is also cliffed and resembles the south coast as far north as Pointe de Corsen, being also indented by sandy bays at Anse des Blancs Sablons and Porz-Illien (Fig 6-1).

North of Pointe de Corsen and as far as the vicinity of Portsall the west coast becomes lower-lying, more indented by small sandy and rocky inlets and fringed with reefs and rocks mostly submerged at high tide. The only major indentation is the estuarine ria of L'Aber-Ildut.

East of Portsall the north coast is much more irregular in plan, being fringed by a narrow coastal plain largely covered wwith blown sand, and indented by several rias (L'Aber-Benoît, L'Aber-Wrac'h). The actual coast of the mainland consists of low-lying sand dunes with numerous small rocky headlands. There is generally an extensive sandy inter-tidal zone from which project numerous small low-lying rocky islands and reefs; similar islands and reefs project above the shallow water beyond the low tide mark.

Inland the topography shows little relief being essentially a gently undulating plateau with its surface mostly between 50 m and 100 m above sea level. The plateau is terminated rather abruptly to the south and west by the coastal cliffs; on the north it descends by a series of steps to the low-lying coastal plain. The valleys of the rias mentioned above, and of numerous small rivers, are incised into the plateau, but for the most part it is rather featureless and covered with a blanket of superficial deposits, mostly loess. Natural rock exposures are rare inland, and there is little control of topography by the underlying lithology, so that most geological information is obtained from artificial exposures such as road cuttings, quarries and other excavations, often temporary. There is however commonly a narrow line of exposed rock at high tide mark along the various rias.

Coastal rock exposures are by contrast excellent. The variation in coastal morphology entails that on the south and west coasts the rock exposure is virtually continuous but confined to the line of the cliffs themselves, with only a narrow wave-cut platform, or none at all, while on the north coast, where most of the writer's field-work was carried out, rock exposures extend across a belt several km wide. Within this belt the numerous islands, reefs, headlands and stacks projecting through sub-tidal, intertidal or dune sands form a multitude of small patches of well exposed rock.

The Tertiary and Quaternary geology of the Pays de Léon has been described by Chauris (1966c, p 1-4; 1972c,p.1 7).

B. GEOLOGICAL SETTING

1. THE MASSIF ARMORICAIN

The Pays de Léon forms the north western extremity of the Massif Armoricain. The Massif Armoricain is the name given to the sub-Mesozoic basement in Bretagne (Brittany), Normandie (Normandy) and Vendée, including offshore islands such as the Channel Islands, Ouessant and Groix.

The eastern boundary of the Massif runs approximately southeast from Cherbourg (Fig 1-1) to Caen and then south to Angers (Fig 1-3). A convenient geological subdivision of the Massif is shown in the inset to Fig 1-3.

In this classification the northern part of the Massif can be regarded as consisting of two 'Domaines' : (i) the 'Domaine Mancellien'; this is a relatively simple terrain of folded late Precambrian supracrustal rocks (the Brioverian) intruded by extensive late Precambrian/Lower Palaeozoic granitoid rocks (the Mancellian Granites); (ii) the 'Domaine Domnonēen'; this is a more complex and varied zone than the Domaine Mancellien, comprising a variety of sedimentary, igneous and metamorphic rocks ranging in age from the Lower Proterozoic (parts of the Pentevrian: Fig 1-4) to the Upper Palaeozoic. The Pays de Lēon forms the western extremity of the Domaine Domnonēen.

The central part of the Massif (Domaine Centre-Armoricain; Fig 1-3) consists largely of folded late Precambrian and Palaeozoic supracrustal formations of low metamorphic grade which have been intruded by a number of large granitic plutons, mainly of Hercynian age.

The southern part of the Massif (Domaine Ligērien, Domaine de L'Anticlinal de Cornouaille and Zone Ouest Vendēen, like the Domaine Domnonēen, consists of a variety of sedimentary, metamorphic and igneous rock; migmatites are widespread. In this case however the effects of the Hercynian orogeny are more obvious and pronounced, particularly in the marked WNW ESE trend of lithological boundaries and other structures (Fig 1-3).

2. SUBMERGED BASEMENT AND OFFSHORE ISLANDS ADJACENT TO THE WESTERN PAYS DE LĒON

The Pays de Lēon is flanked to the north by a narrow (10 km) belt of submerged basement rocks generally similar to those found along the north coast of the mainland (Andreieff et al, 1973) 1973). These are overlain to the north below the waters of the English Channel by Upper Cretaceous and Tertiary sediments. To the west a group of islands including Ouessant and Molène extends for about 20 km from the coast of the Pays de Lēon westwards into the Atlantic. The geology of the island of Ouessant and its surroundings is similar in many respects to that of the north coast of the Pays de Léon (Chauris, 1966a; Andreieff et al, 1973). The rocks of the Molène archipelago resemble those of the SW Pays de Léon (Chauris, 1969a; Collin, 1922, 1924). Further west the submerged basement is again overlain by Mesozoic and Tertiary sediments (Chauris et al, 1972).

3. NEIGHBOURING HERCYNIAN MASSIFS

The Pays de Léon lies c 160 km south of Cornwall, England. The intervening English Channel is mostly less than 200 m deep and is floored by Mesozoic and Tertiary sediments which on geophysical evidence (summarised by Bishop et al 1969, p 339) overlie a basement which is thought to comprise Palaeozoic and metamorphic rocks.

The nearest sector of the Cornubian Massif to the NW Pays de Léon is the mafic-ultramafic complex of the Lizard Peninsula (Flett and Hill, 1912). Elsewhere in the Cornubian Massif, Upper Palaeozoic sedimentary rocks and intrusive granites predominate, and although stratigraphic and structural comparisons can be made between these li hologies and rocks of similar age and type in the central Hercynian belt of the Massif Armoricain (Renouf, 1974); the only counterparts in the Cornubian Massif of the higher grade regional metamorphic rocks of the Pays de Léon are relatively small areas of schists and gneisses which outcrop along the southern margin of the Massif between Start Point (Tilley, 1923) and the Lizard Peninsula. No detailed correlation or comparison between the latter and any rocks in the Massif Armoricain has been attempted.

The Iberian Massif is separated from the Massif Armoricain by the Golfe de Gascogne which is floored by oceanic crust (Ries, 1974, 1978). Although the two massifs may have been linked prior to the opening of the Golfe, and the present continental margins are at a high angle to the trend of structures in both massifs, the considerable extent of continental shelf overlain by Mesozoic and Tertiary sediments to the west of the Massif Armoricain has hindered any attempts which might have been made to trace individual features across the gap. Nonetheless close similarities in Palaeozoic stratigraphy and faunas in Armorica and Iberia have been recognised (summarised by Bishop et al, 1969, p 332 and Fig 7), and the two regions share a common late Hercynian geochronological pattern (Ries, 1979).

C. PREVIOUS GEOLOGICAL RESEARCH

1. DEVELOPMENT OF SOME KEY CONCEPTS IN THE GEOLOGY OF THE MASSIF ARMORICAIN

1.(a) The Brioverian

Bunel (1829-1833) recognised that in Calvados (North Normandy) a fossiliferous (Lower Palaeozoic) sequence overlay unconformably an older unfossiliferous slate-greywacke sequence.

The two divisions were recognised elsewhere in the Massif, by Dufrenoy (1838) and Dufrenoy and De Beaumont (1841). The lower division became known as the 'Schistes de St Lô' or 'Phyllades de St Lô' from the type area in Lower Normandy and in Western Brittany the 'Phyllades de Douarnenez' were correlated with the Phyllades de St Lô.

Opinions differed as to the age of these groups of rocks. At a meeting of the Geological Society of France in 1886 Barrois assigned them to the Cambrian, while Hé bert (1886) considered them to be Precambrian. Later Barrois (1888) described them as 'Infra-cambrien'.

Barrois (1895a) introduced the term 'Briovērien' to refer to the Phyllades de St Lô, and divided the formation into a number of lithostratigraphic units. Controversy concerning the age and status of various units assigned to the Brioverian continued. Barrois (1934a) considered that the Lower Brioverian rocks (by general convention labelled Xa) were Precambrian, while the Middle and Upper Brioverian (xb + xc respectively) were assigned to the Lower and Middle Cambrian.

Some clarification of the nomenclature was obviously needed by this stage, and Pruvost (1949) used the term 'Brioverian' to apply exclusively to what had been known previously as the 'Lower' Brioverian. Further elaboration of the Brioverian stratigraphy in the type area was presented by Graindor (1957) and extended to cover the whole of the Massif by Cogné (1962). The Precambrian age of the Brioverian in the type area was more firmly established by Chauris et al (1956) and Chauris (1956) who showed that granites intrusive into the Brioverian were overlain unconformably by Middle Cambrian sediments.

Radiometric dating of rocks and minerals mainly in the northeast sector of the Massif has provided some evidence for the timing and duration of Brioverian sedimentation. Dates ranging upwards from c 900 my (obtained mainly by Leutwein and co-workers) from rocks considered to form a pre-Brioverian ('Pentevrian') basement have been used by various workers as an older age limit for the Brioverian. Leutwein (1968) constructed a chronology for Brioverian sedimentation which, he suggested, lasted from c 750 my to c 560 my. Roach et al (1972) and Bishop et al (1975) suggested that the sedimentation occurred in the interval 900-750/650 my.

Relatively little attention was paid to the Brioverian from a sedimentological point of view until Graindor (1954) attributed pebbly mudstones developed locally at Granville to glacial activity. However Winterer (1964) argued that the most likely explanation for the Granville rocks was that they were produced by subaqueous turbidity currents; a similar origin has been suggested for the typical Brioverian interbanded shale/greywacke lithology elsewhere (Bishop et al, 1969; Darboux, 1974).

1.(b) The Cadomian orogeny

Bertrand (1921) introduced the concept of the 'Cadomien' orogeny to account for the folding, uplift and peneplanation of the Brioverian in the Massif Armoricain prior to the deposition of Cambrian sediments, corresponding to the

Huronian folding in North America. The term has passed into general use, although its exact sense has inevitably varied somewhat with the change in status given to the various divisions of the Brioverian (Graindor, 1957; Cogne, 1962). The work of Chauris et al (1956) and Chauris (1956) showed that the intrusion of the 'Mancellian' granites was an integral part of the Cadomian orogeny (see Figs 1-3, 1-4). Detailed accounts of the Cadomian orogeny in various sectors of the Massif have been given by Darboux, (1974), Brown (1974, 1978) Ryan and Roach (1977) Peucat (1973) etc.

The term Cadomian is now well established, and the concept of a Cadomian orogeny is useful in order to refer to the fairly well-defined episode of deformation, metamorphism and magmatism which occurred in the Massif Armoricain at around the boundary between the Proterozoic and the Palaeozoic.

1.(c) The Pentevrian

The presence of Pre-Brioverian basement which he termed 'Pentévrien' was argued by Cogné (1959) in the area to the east of St Brieuc; and the presence of comparable basement in the Channel Islands and Cap de la Hague (west of Cherbourg) by Graindor (1961) (Fig 1-4). The pre-Brioverian age of the original 'Pentévrien' in the type-area near St Brieuc has been disputed by Vidal et al (1974), but the presence of pre-Brioverian rocks, for which the term Pentévrien has been retained, in the islands of Guernsey and Alderney, at Cap de la Hague and possibly in the northern part of the Trégor peninsula is now generally accepted on both geological and geochronological grounds (Roach, 1977; Leutwein et al, 1973; Auvray and Vidal, 1973). The geochronological evidence is particularly strong in the case of the Icart Gneiss of Guernsey (Adams, 1967a; 1976; Calvez and Vidal, 1978).

At Palus Plage (north of St Quay) gneisses unconformably overlain by Brioverian metavolcanics have been assigned to the Pentevrian by Ryan and Roach (1977) and a similar relationship is seen at Cesson (near St Brieuc) (Barrois, 1895b; Roach, pers.comm.).

Suggestions have also been made as to the presence of pre-Brioverian or Pentevrian basement in other parts of the Massif Armoricain but for the most part these suggestions refer to areas where the superimposition of Hercynian and Cadomian structures makes interpretation difficult (Cogné and Shelley, 1966; Hanmer, 1977a), and where geochronological evidence is either lacking or gives no independent support to a Pentevrian date for the rocks in question.

2. SOME RECENT INTERPRETATIONS OF THE GEOLOGY OF THE MASSIF ARMORICAIN

A major study of the metamorphic and magmatic belt of southern Brittany was carried out by Cogné (1960). This has been followed by numerous detailed studies of particular sectors and aspects of the belt, notably by workers at the University of Rennes. Of special importance is the geochronological work of P. Vidal and J-J Peucat. It is now generally agreed that the south Armorican belt incorporates a basement of varied late Precambrian and Palaeozoic age which has been severely deformed, metamorphosed and intruded by granites during the Hercynian orogeny (see e.g. Vidal, 1972; Cogné, 1974; Hanmer, 1977a,b.).

In central Brittany Stille (1928) introduced the term 'Bretonic' to refer to an early Hercynian fold phase occurring at the boundary of the Devonian and the Carboniferous. An influential interpretation of the Palaeozoic basin of central and western Brittany was given by Pruvost (1949) who considered that this zone represented a trough (the 'Fosse Armoricaine') which received sediments throughout the Palaeozoic, being bounded to north and south by older massifs (called respectively 'Domnonéa' and 'Ligéria' (See fig 1-3.)).

Renouf (1974) has produced a comprehensive review of Palaeozoic stratigraphy and tectonics in the Armorican and Cornubian Massifs, particular attention being given to the Devonian and Carboniferous strata of central Brittany. Renouf emphasised the length and complexity of Variscan (Hercynian) tectonism in this area. He concluded however that there is inadequate evidence to support the recognition of such global tectonic features as subduction zones or island arcs in Brittany during the Hercynian orogeny.

In contrast attempts, such as that of Carpenter and Civetta (1976), to account for the presence of blueschists on the southern margin of the Massif Armoricain, have led to the publication of essentially global tectonic interpretations of the Hercynian development of the Massif, such as that of Chauris (1977). A widely favoured model has emerged of a northerly dipping subduction zone with high-pressure metamorphism approximately coinciding with the Ile de Groix blueschists, flanked to the north by a belt characterised by lower pressure metamorphism and granite production.

3. GEOLOGICAL STUDIES IN AREAS ADJACENT TO THE PAYS DE LÉON

A comprehensive geological map of north and west Finistere was produced by Barrois and published as the 1:80,000 sheets of Brest, Lannion and Morlaix (1902a, 1905a, 1909a). Barrois grouped the Quartzophyllades de L'Élorn, the Quartzophyllades de Morlaix and the Phyllades de Douarnenez within the Brioverian, and considered them to be overlain by the Lower Ordovician Grès Armoricain. According to this interpretation the Pays de Léon was an anticlinal zone relative to the Palaeozoic rocks of Central Finistère.

The Palaeozoic rocks of the Presqu'île de Crozon were mapped by Kerforne (1901), who also demonstrated the existence of a major NW-trending strike-slip fault affecting the rocks of the Crozon and the SW Pays de Léon.

Later workers (Pruvost et al, 1943; Delattre, 1952) argued that the Roche Maurice Quartzites, which had been correlated by Barrois with the Ordovician Grès Armoricain, were of Devonian/Carboniferous age; inverting Barrois' stratigraphy and structure they considered the Quartzophyllades (of L'Élorn and Morlaix) to be younger members of the Upper Palaeozoic sequence than those occurring in Central Finistère. According to this interpreation the crystalline rocks of the Pays de Léon were themselves of Devono-Carboniferous age.

J-T Renouf and J.D. Bradshaw (in Bradshaw et al, 1967; Bishop et al, 1969) once again inverting the stratigraphy and structure, recorrelated the Quartzophyllades de L'Ëlorn with the Phyllades de Douarnenez, which had universally been considered to be Brioverian, and recorrelated the Quartzites de la Roche Maurice with the Ordovician Grẽs Armoricain, thus re-erecting Barrois' original arrangement.

This interpretation was accepted and amplified by Chauris and Hallegouët (1973a), who also argued that the Quartzites de la Roche Maurice unconforma ly overlie the 'Gneiss de Brest' at the southern margin of the Pays de Lẽon.

The Quartzophyllades de Morlaix, considered by Barrois to be Brioverian and equivalent to the Quartzophyllades de L'Ëlorn were still considered by Cabanis (1972) to be Upper Palaeozoic, probably Dinantian, on the basis of micro-fauna.

The main phase of folding and cleavage-formation in the Brioverian of Central Finistẽre was considered by Bradshaw et al (1967) to be of pre-Ordovician (Cadomian) age, thus being distinct from the main phase of folding and cleavage formation in the overlying Palaeozoic.

Darboux et al (1975) recognised a sequence of three phases of folding in the Brioverian, assigning the major (2nd) phase to pre-Ordovician activity, thus agreeing on this point with Bradshaw et al.

Subsequently Darboux and Garreau (1976) recognised an early phase of recumbent folding in the Devonian of the Sizun (≠ Cap Sizun) area; the absence of this early phase from the Carboniferous of the Châteaulin Basin led them to re-emphasize the importance of the Bretonic (post-Devonian/pre-Carboniferous) fold phase. Cabanis (1975) assigned the major phase of deformation and cleavage formation in the rocks of the Morlaix area to a late (post-Dinantian) Hercynian phase.

4 PREVIOUS RESEARCH IN THE PAYS DE LĒON

After the publication of the 1:80,000 geological maps of Plouguerneau, Brest and Lannion (Barrois, 1893a,b, 1902a,b, 1905a,b), which defined some of the main lithological units in the Pays de Lēon, little attention was given to the area for some decades.

4(a) THE SW PAYS DE LĒON

In the SW Pays de Lēon, Barrois considered that the extensive 'Gneiss de Brest' lithology represented the result of granitisation (in situ transformation into granite) of material originally similar to the Brioverian Quartzophyllades de l'Ēlorn. This view was generally accepted (e.g. Berthois, 1954: Michot and Lavreau, 1965) until R. Taylor (in Bradshaw et al, 1967) pointed out evidence that the granodiorite was originally intrusive into the sediments. The latter interpretation has now gained general acceptance.

De Lapparent (1934) described the petrography of the well-known staurolite-garnet-mica schists of Le Conquet (Fig 1-2) and also recorded the presence of polyphase folding in this lithology. He also discussed the relationship between the Gneiss de Brest (Granodiorite de Brest) and the lithology now known as Granodiorite de Trēgana at Trez Hir. This granite is labelled Granite du Trez Hir by Chauris (1967). See Fig 1-6.

R. Taylor (in Bradshaw et al, 1967, Bishop et al, 1968 and in more detail in his thesis (1969)), described the structural, magmatic and metamorphic development of the SW Pays de Lēon between Brest and Le Conquet. He recognised two successive Cadomian episodes of intrusion of granodiorite magma (the 'Gneiss de Brest' and the Granodiorite (de la Pointe) des Renards)(Fig 6-2) and attributed the main metamorphic assemblages and fabrics to a Cadomian episode intervening in time between the emplacement of the two granodiorites. The Rb/Sr whole rock dating of the granodiorites by Adams (1967a, 1976, and in Bishop et al, 1969) enabled the age of this Cadomian episode to be bracketed between c. 670 and c. 550 m.y.

Chauris extended Taylor's interpretation to cover the islands of the Molēne archipelago (1969a) and the remainder of the mainland SW Pays de Lēon (1972c). This classification was used in the 3rd edition of the Brest 1:80,000 geological map (Chauris, 1972c; reproduced here as Fig 6-3).

U-Pb zircon dating was carried out by Deutsch and co-workers (Deutsch and Chauris 1965; Michot and Deutsch, 1970) on the Gneiss de Brest and other lithologies in the SW Pays de Lēon. The most concordant date obtained by them was c 460 m.y. for a sample of 'Gneiss de Brest' from Pont-Cabioc'h (Fig 6-1). The discrepancy between this date and the much older Rb-Sr whole-rock date obtained by Adams (1967) led Cabanis et al (1977) to make a new attempt to obtain a Rb-Sr whole-rock date for this lithology. They concluded that the samples collected by both Adams and themselves were heterogeneous and that the Rb-Sr whole-rock 'dates' did not indicate the date of emplacement. They suggested a possible correlation of the Gneiss de Brest with the Trondhjēm ite de Douarnenez (Barriēre, 1972) which occupies a structural position analogous to that of the 'Gneiss de Brest' on the opposite (southern) flank of the Palaeozoic synclinovian of West Finistēre, and has a well established Rb-Sr WR date (Barriēre et al, 1971) similar to the U-Pb zircon date of the 'Gneiss de Brest' mentioned above.

4(b) THE NW PAYS DE LĒON

This area is covered by the 1:80,000 Plouguerneau and Brest sheets (Barrois, 1893a; 1902a). Barrois used the term 'Gneiss de Quimperlē' to describe the Gneiss de Trēglonou together with similar lithologies further east in the area of Lanhouarneau and Plounevez-Lochrist (see Figs 1-2 and 1-6). Barrois (op.cit) also used the same term 'Gneiss de Quimperlē' for part of the granite outcropping north-east of Porspoder for which the term 'Granite de Landunvez' has been introduced by the present writer. Barrois used the term 'Gneiss de Quimperlē' where the 'Granite de Landunvez' shows structures now attributed to localised deformation associated with the Porspoder Lineament. It was presumably Barrois' intention to correlate or at any rate compare all these deformed granitic rocks with similar lithologies in south Brittany around Quimperlē.

Barrois also recognised and mapped the 'Diorite micacẽe de Lannilis' and included under this heading the lithology for which the present writer uses the term 'Diorite de Portsall', (shown as 'Amphibolites quartziques in Fig 1-7). He also defined and mapped the major granitic intrusions of the area: the 'Granite Porphyroide Rose de L'Aber-Ildut', the Granite de St Renan and the Granite de Kersaint (or Kersaint-Plabennec). He used the term 'granulite' (= muscovite-granite) to apply to the granites of Kernilis and Ploudalmẽzeau (see Figs 1-6, 1-7 and 1-9, for distribution of these granitic rocks).

De Lapparent (1934) followed the example of Barrois in using the deformed character of the granite (Granite de Landunvez) north east of Porspoder as evidence for its relatively greater age. He also observed the presence of garnets, which he considered to be of xenocrystic origin, in the less-deformed granites (also 'Granite de Landunvez' in the present writer's classification) near Portsall.

Shelley (1964, 1966, and in Cognẽ and Shelley, 1966) made a detailed study of the area round the L'Aber-Wrac'h and L'Aber-Benoît estuaries (Fig 1-8).

He drew attention to the ENE trending zone of localised deformation and mylonitisation which separates the metamorphic rocks of the Lannilis area from the migmatitic terrain to the north. This zone, for which Shelley used the term 'axe synclinal mylonitique' was also described around the same time by Chauris (1965a) who used the term 'zone faillẽe de Porspoder'. The structures associated with this feature are grouped by the present writer under the heading 'Porspoder Lineament'. Shelley pointed out the synformal nature of the mylonitic zone in the Lannilis sector, and calculated the sense and amount of displacement across it.

To the south of the 'Porspoder Lineament' Shelley described the increase in metamorphic grade between the mica schists of L'Aber-Wrac'h and the sillimanite-bearing 'mica-schistes migmatitiques' of L'Aber-Benoît (Figs 1-7, 1-8). He considered that the metamorphism which gave rise to this distribution was a Cadomian episode; but that the metasediments and 'amphibolite quartzique' (= Diorite de Lannilis) which underwent this metamorphism had also undergone an earlier ('Pentevrian') episode; the metasediments having been originally deposited on a volcanic basement terrain now represented by the Diorite de Lannilis.

To the north of the 'Porspoder Lineament' Shelley argued that the most widespread lithologies were originally similar to the lithologies south of the Porspoder Lineament in the Lannilis Sector, but had undergone 'granitisation' (in situ transformation into granite) in an early Hercynian (Bretonic) phase. Thus the 'migmatites' in the northern zone were granitised mica-schists, while the 'granite sombre' was granitised amphibolite quartzique (Diorite de Lannilis). Agmatitic and garnetiferous migmatites in the northern zone were correlated with a Cadomian shear belt in the south.

Shelley (in Cogné and Shelley, 1966) also made structural correlations across the 'Porspoder Lineament'. To the south he distinguished three phases of minor folds in the Mica-schistes de L'Aber-Wrac'h; these he described as Pentevrian, Cadomian and Variscan (Bretonic) respectively; he also mapped out major isoclinal folds affecting the 'Diorite de Lannilis' and the metasediments, attributing these folds for the most part to the Cadomian. To the north Shelley recognised both Pentevrian and Cadomian major folds affecting the 'migmatites' and 'granite sombre', and correlated individual major Cadomian folds and thrusts between the zones to the north and south of the 'Porspoder Lineament'.

Chauris (1966c, 1972c; see also Fig 1-9), provided brief descriptions of most of the metamorphic, migmatitic and granitic formations of the NW Pays de Léon. He considered that the Gneiss de Tréglonou and similar formations represented the oldest lithologies in the Pays de Léon, forming a basement, possibly of Pentevrian age, on which the Brioverian, now represented by the Mica-schistes de L'Aber-Wrac'h and other metasediments was deposited (1972). For the zone to the north of the 'Porspoder Lineament', Chauris used the terms 'Migmatites de Plouguerneau'(Fig 1-6) and 'gneiss granitisé et granite gneissique (Fig 1-7);(See also Fig 1-9). He recognised four main lithological divisions, which corresponded approximately to those of Shelley as shown in Table 1-1 below.

TABLE 1-1
NOMENCLATURE OF LITHOLOGICAL DIVISIONS IN THE NW PAYS DE LÉON

Cogné & Shelley (see Fig 1-8)	Chauris (1966) (see Fig 1-9)	Present work
Granite sombre	Granite à deux micas associé aux migmatites	Granite de Kern an Guen Adamellite de Ste Marguerite
Migmatites	Granite migmatitique	Granite de Landunvez
Agmatites et zones riches en gros grenats	Migmatites de Plouguerneau	Migmatites de Plouguerneau (in part)
Agmatites (in part)	Amphibolites quartziques de Lannilis	Migmatites de Plouguerneau (in part); Diorite de Portsall

The Diorite de Portsall does not outcrop within the area studied by Shelley. Chauris (1966c, p.7) seems to have accepted Shelley's interpretation of the structure and history of the area, but he points out that some minor bodies of the 'granite sombre' have the form of dykes or veins cutting the migmatitic granite.

Barrière et al (1973) discussed the significance of sillimanite nodules in the Gneiss de Tréglonou, and compared them with kyanite and andalusite nodules found in southern Brittany.

Cabanis (1976.) extending his interpretation of a Hercynian (post-Visēan) age for the metamorphism in the Morlaix area and the Eastern Pays de Lēon to include the metamorphic rocks of the Lesneven and Lannilis areas of the NW Pays de Lēon, considered that the metasedimentary and mafic lithologies in the Lannilis complex were probably derived from Upper Palaeozoic sediments and basic volcanics, and that these were laid down on a pre-Upper Palaeozoic basement represented by the Gneiss de Trēglonou and similar granitic gneisses.

Apart from the descriptions included in the 'notices explicatives' to the Plouguerneau and Brest sheets (Chauris, 1966c,1972c), publications on the later granitic formations of the NW Pays de Lēon include that of Chauris (1966b) on the setting contacts, facies, petrography and structure of the Complexe Granitique de L'Aber-Ildut; and on the tin/tungsten mineralisation of the Granite de St Renan (Chauris, 1964; Chauris and Moussu, 1972). Barriēre et al (1971a) have made a petrographic and mineralogical study of the Granite de L'Aber-Ildut near Porspoder; while Le Guen de Kerneizon (in preparation) has carried out a detailed petrological study of the Granite de Brignogan (= Granite de Kerlouan).

Geochronological investigations on the rocks of the NW Pays de Leon have been carried out by Deutsch and Chauris (1965); Adams (1967a); Leutwein et al (1969 a,b) and by workers at the Rennes laboratory (pers.comm). The detailed significance of these studies,whose main importance has been to emphasize the effects of the Hercynian orogeny in the history of the area, will be discussed in chapter 5.

D. PURPOSE AND ARRANGEMENT OF THE PRESENT STUDY

The central aim of the study is the elucidation of geological relationships and the evolution of the metamorphic, migmatitic and associated complexes of the NW Pays de Lēon; this includes the Complexe Mētamorphique de Lannilis and the Complexe Migmatitique de Plouguerneau, together with associated granitic intrusions. This aim was approached by means of lithological and structural mapping, combined with petrographic studies, of the rocks outcropping in the Plouguerneau and Lannilis districts.

In order to place the geology of this area in a wider context it was found desirable to carry out certain related studies. These include:

(i) an attempt to link the history of the predominantly high grade metamorphic and migmatitic rocks of the NW Pays de Léon with that of their lower-grade counterparts in neighbouring areas in the SW Pays de Léon and with that of the Brioverian/Palaeozoic sedimentary succession which outcrops in central Finistère.

(ii) an attempt to fit the geological evolution of the Western Pays de Léon to the absolute time scale by means of a critical assessment and interpretation of previously published geochronological data on the area, together with the presentation of some new data.

It was thought also to be desirable to describe and discuss the significance of the major metamorphic episode which is considered to have given the Pays de Léon as a whole its characteristic distribution of metamorphic and migmatitic rocks.

The present work is arranged as follows:

An introduction is given in Chapter 1.

Chapters 2 to 5 are concerned with the NW Pays de Léon.

Chapters 2 and 3 take the form of more or less parallel studies of the areas immediately south and north respectively of the Porspoder Lineament. In both chapters descriptions are given of the field relations and petrography of the chief lithological formations. Attention is directed towards an understanding of

(a) the field relations and origin of the various rock types

(b) the metamorphic, magmatic and structural evolution of the area.

In the case of chapter 2 more attention is devoted to the metamorphic rocks than to the associated granitic rocks which have been described in more detail by Chauris (1966b).

In chapter 3 brief reference is made to the Granite de Brignogan, but for a more detailed study of this lithology, the reader is referred to the work of Le Guen de Kerneizon (in preparation).

Chapter 4 consists of a description and interpretation of the Porspoder Lineament, a major zone of displacement and deformation which separates the areas dealt with in chapters 2 and 3.

Chapter 5 consists of an interpretation of new and previously published geochronological data concerning the NW Pays de Lēon.

Chapters 6 and 7 are concerned with the SW Pays de Lēon. Chapter 6 consists of a description, based on field observations and a limited petrographic study, of the field relations of the various lithological divisions in this area, together with a new interpretation of its geological evolution. Chapter 7 consists of a critical re-assessment of previously published geochronological data on the SW Pays de Lēon.

Chapters 8 and 9 are concerned with the Western Pays de Lēon as a whole. Chapter 8 deals with the climactic metamorphic and migmatitic episode for which the writer uses the term M2, and which may have occurred during the Bretonic phase of the Hercynian orogeny. Chapter 9 consists of a brief conclusion in which the geological evolution of the Western Pays de Lēon as a whole is summarised.

E. GEOLOGICAL MAPPING PROCEDURES

E.(a) AREAS MAPPED

Much of the fieldwork carried out by the author, has consisted of systematic lithological and structural mapping of all accessible exposures. This procedure was found to be particularly desirable in the area to the north of the Porspoder Lineament where the coastal exposures are numerous, extensive and complex and where the previously published maps (Barrois, 1893a, 1902a; Shelley 1964, 1966, and in Cognē and Shelley 1966; and Chauris 1966c, 1972c) were thought to be oversimplified and difficult to relate to the field evidence. Owing to the nature of the terrain, which is subject to great daily and seasonal variations in tidal range and in the case of the more offshore sectors to continuous wave action it was not possible to visit every islet and reef in the time available but a large proportion of the accessible exposures in and near the intertidal zone were examined.

In the case of the Lannilis Metamorphic Complex a similar procedure was followed but in this case the natural exposures are limited for the most part to a narrow strip at high water mark along L'Aber-Wrac'h and L'Aber-Benoit. Away from these estuaries it was found necessary to search for exposures, which are generally limited to a few quarries and road cuttings. Many road cuttings, even when quite deeply incised, only display superficial deposits of loess or of solid rock which is so severely weathered as to be indeterminable. However in contrast with the area to the north of the Porspoder Lineament the previous geological maps of the Lannilis Complex were found to be generally reliable as far as the field evidence could allow, and the present author's attention was concentrated on attempting to establish the relationships between the main metamorphic formations, and on producing a revised and locally more detailed geological map than those previously available.

In the case of that part of the SW Pays de Léon which is described in Chapter 6, the previously available geological maps are the 1:80,000 survey maps of Barrois (1902a) and Chauris (1972c) and the large scale maps included in Taylor's (1969) thesis.

As the exposures inland in the SW Pays de Léon are minimal the present writer's attention was concentrated almost entirely on the coastal section. It was found that Taylor's (1969) maps indicated the geological boundaries reliably and as accurately as is possible with the scales he used. (It should be noted however that the present writer's interpretation of the field relationships in the area differs in certain important respects from that of Taylor - see chapter 6 of the present work). The area mapped by Taylor did not extend further north on the west coast than the Pointe de Kermorvan (Fig 6-1) and the writer continued detailed geological mapping of the coast as far as the Pointe de Corsen, so as to include the whole of the mainland coastal sector of the Le Conquet Metamorphic Complex (Figs 6-6, 6-7).

E.(b) BASE MAPS AND SCALES UTILISED

E.(b)(i) Coastal Sectors

The marine charts published by the Service Hydrographique de la Marine were found to give the most accurate representation of coastal and intertidal morphology. Field observations were therefore recorded on copies or enlargements of these charts.

The west coast of the Pays de Lēon between Le Conquet and Porspoder and the north coast between Porspoder and l'Ile Vierge are covered by the 1:20,000 charts no. 5721 'De la Pointe de Kermorvan à L'Ile d'Iock' (1934) and no.5772.'Du Phare du Four à L'Ile Vierge' (1940). Observations were recorded on scale copies or approximately 1:5000 enlargements of these charts. For the sector of the north coast east of the Ile Vierge the best available representation was given by the 1:45,300 chart 'Des Roches de Porsal à Pontusval', published in 1842. In the latter sector observations were recorded on enlargements at various scales of this chart and on overlays to a series of air photos taken in 1944 by the R.A.F. and supplied by kind permission of the curator of the Department of Geography, University of Keele.

E.(b)(ii) Inland Sectors

Away from the coast and along the L'Aber-Wrac'h and L'Aber-Benoit estuaries use was made of the recently revised edition of the 1:25,000 topographic maps issued by I.G.N. Observations were recorded for the most part on scale copies of the following sheets: Plouguerneau 5-6, 7-8; Plabennec 1-2, 3-4; Plouarzel 3-4.

E.(c) GENERAL

All the geological observations in the NW Pays de Lēon were transcribed onto a single composite 1:25,000 outline map on which lithological boundaries were indicated and units shaded in.

In the case of the coastal sector of the SW Pays de Lēon the geological map was drawn up on a copy of the 1:20,000 chart.

The resulting geological maps are incorporated in Chapters 2, 3 and 6, the larger maps for chapter 3 being placed at the end of the volume.

CHAPTER 2

THE LANNILIS METAMORPHIC COMPLEX AND ASSOCIATED GRANITIC ROCKS

A. FIELD RELATIONS AND PETROGRAPHY

1. Metasedimentary types

(a) Mica-schistes de L'Aber-Wrac'h
- (i) Location
- (ii) Contacts
- (iii) Petrography
  - (I) Psammitic material
  - (II) Pelitic and semi-pelitic material
- (iv) Minor structures

(b) Gneiss a sillimanite de L'Aber-Benoît
- (i) Location
- (ii) Contacts
- (iii) Minor structures
- (iv) Petrography
  - (I) Psammitic material
  - (II) Pelitic material

2. Orthogneisses and metaigneous types

(a) Granitic gneisses : the Gneiss de Trēglonou and related types

(I) Gneiss de Trēglonou
- (i) Location
- (ii) Contacts
- (iii) Minor structures
- (iv) Petrography

(i) Outer porphyritic facies (Granite de L'Aber-Ildut)

(I) Pink-feldspar facies

(II) Marginal white-feldspar facies

(ii) Inner non-porphyritic facies (Granite de Ploudalmézeau)

(iii) Filons microgranitiques

4. Other occurrences in the Lannilis district of granites similar to those found in the Complexe Granitique de L'Aber-Ildut

(a) Porphyritic pink-feldspar biotite granite

(b) Granites resembling the Granite de Ploudalmézeau

5. Other post-M2 granites associated with the Complexe Métamorphique de Lannilis and the Porspoder Lineament

(a) Granite de Kervigorn

(b) Granite de Kerdalzou

(c) Granite des Anges

(d) Other post-M2 granites

E SUMMARY OF GEOLOGICAL HISTORY OF THE LANNILIS METAMORPHIC COMPLEX AND ASSOCIATED GRANITIC ROCKS

CHAPTER 2

THE LANNILIS METAMORPHIC COMPLEX AND ASSOCIATED GRANITIC ROCKS

Much of the inland portion of the NW Pays de Lēon is occupied by a series of medium and high grade regionally metamorphosed rocks. They are bounded to the north by the Porspoder Lineament and in other directions by various post-metamorphic granitic rocks. The best natural exposures are found along the shores of the drowned valleys (rias) known as L'Aber-Wrac'h and L'Aber-Benoît, which lie to the northeast and southwest respectively of the town of Lannilis (Fig 2-1). Elsewhere exposures are generally limited to road cuttings and a few quarries. Previous geological work on these rocks (which will be referred to as the Lannilis Metamorphic Complex) includes that of Barrois (1893 a and b, 1902 a and b); Shelley (1964, 1966, and in Cognē and Shelley,1966) and Chauris (1966c, 1972c).

A. FIELD RELATIONS AND PETROGRAPHY

1. METASEDIMENTARY TYPES

(a) Mica-schistes de L'Aber-Wrac'h

(a)(i) Location - The outcrop of the Mica-schistes de L'Aber-Wrac'h is intersected by the L'Aber-Wrac'h estuary between Moulin d'Enfer (7.625/53.990) and Pont de Paluden (7.610/53.985)(Fig 2-2). The formation is flanked to the south by the co-metamorphic Diorite de Lannilis (see section 2 (b) of this chapter) and to the north and north-west by the post-metamorphic granite of Kernilis (Figs 1-6, 1-7). East of Paluden the outcrop swings to a more south-easterly trend and is again intersected by L'Aber-Wrac'h east of Pont Crac'h Gue (7.575/53.970) also known as Pont du Diable (Fig 2-2).

(a)(ii) Contacts - Contacts between the Mica-schistes de L'Aber-Wrac'h and the Diorite de Lannilis are approximately parallel with the chief internal structures in both formations. The actual contact is rarely visible but can be approached within a few metres east of Loguivy (7.595/53.985)(Fig 2-1). Concordant bands of Diorite de Lannilis type are also exposed within the schist outcrop near Le Traon (7.610/53.990). The Granite de Kernilis displays discordant intrusive contacts with the schists on both banks of L'Aber-Wrac'h near Moulin d'Enfer (7.625/53.990) (Fig 2-2).

(a)(iii) Petrography - The formation consists predominantly of psammitic and pelitic material interbanded on a millimetric to decimetric scale.

I Psammitic material

Psammitic types in the Mica-schistes de L'Aber-Wrac'h have a granulitic, occasionally poikiloblastic, texture. Quartz and feldspar are generally in the grain size range 0.05 - 0.5 mm. Aggregates of garnet may be up to 1 mm or so in diameter. Micas are thinly distributed through most psammitic bands and muscovite may also occur in millimetric bands which cut across the main foliation. A rare calcareous example contains aggregates and poikiloblasts of pale pink garnet and colourless clinopyroxene in a ground mass of 0.1 - 0.3 mm quartz, andesine and garnet, with accessory sphene and white mica (Plates 2-1, 2-2). More commonly the mineralogy of psammitic types is garnet; biotite; muscovite; oligoclase and quartz (constituent minerals listed in reverse order of abundance).

II Pelitic and semi-pelitic material

These differ from the psammitic bands in possessing a more or less pronounced lepidoblastic schistosity due to the abundance and parallel arrangement of micas, which may form 30-70% or more of the rock.

Muscovite may also occur as relatively large flakes which have grown across the schistosity. Quartz remains abundant and most examples contain some oligoclase. The grain size of the quartzo-feldspathic minerals is in the range 0.05 - 0.2 mm. The mica flakes are commonly 0.2 - 0.4 mm across. A common feature is the presence of micaceous laminae 0.2 - 0.5 mm thick consisting of muscovite with minor biotite. These laminae may in some cases be traced round the hinges of syn-metamorphic folds and may represent clay laminae in the parent sediment.

(a)(iv) Minor structures - The schists possess a strong schistosity, probably of metamorphic origin. This commonly dips north or NNE at 40-50°. This schistosity is axial planar to isoclinal or tight minor folds (often decimetric in scale) which can be divided into two sets, one with axes trending E-W and the other with N-S axes. Shelley (1966) has argued that the E-W set refolds the N-S set. These early structures are refolded by an upright set of E-W or ENE trending chevron folds. These folds were described in some detail by Shelley (1966) and Cogné and Shelley (1966) and the present work does not attempt to improve on these earlier descriptions. However the significance of the structures in the schists will be discussed below in section B of this chapter.

(b) Gneiss à sillimanite de L'Aber-Benoît

(b)(i) Location - The main outcrop and only extensive exposures are found in a belt about 1 km wide which runs parallel to the central section of the L'Aber-Benoît estuary (Fig 2-3). At least one narrower belt occurs to the northeast of the main belt. The formation was described as 'Mica-schistes migmatitiques' by Cogné and Shelley (1966 p 40) and was included within a more extensive and probably heterogeneous grouping the 'Gneiss de Lesneven' by Chauris (1972c)(Figs 1-6, 1-9).

(b)(ii) Contacts - At its southern margin the Gneiss de L'Aber-Benoit is in contact with the Gneiss de Tréglonou (see section 2(a) of this chapter). The actual contact (repeated by a fault) is exposed at high tide mark north of Locmajan (7.685/53.950). Both here and elsewhere the contact appears to be approximately concordant with the main internal foliation in both formations. Similar concordance appears to be the case at the northern margin of the main belt of Gneiss de L'Aber-Benoît, and at the margins of the subsidiary belts where the Gneiss is in contact with the Diorite de Lannilis. North-west of Moulin du Quinou (Fig 2-1)(7.700/53.995) the outcrop of the Gneiss de L'Aber-Benoît appears to be interrupted by the post-metamorphic Granite de L'Aber-Ildut. East of Tréglonou (7.640/53.995) the various belts of Gneiss de L'Aber-Benoît swing from an E-W to a NW-SE strike and have not been followed away from the main valley of the L'Aber-Benoît. The main outcrop of the 'Gneiss de Lesneven' (Chauris 1972c) lies in this direction (Figs 1-6, 1-9) but the writer has not had an opportunity to observe the relationship between the Gneiss de L'Aber-Benoît and the Gneiss de Lesneven (s.l.). The relationship between the Amphibolites de L'Aber-Benoît and the Gneiss de L'Aber-Benoît will be discussed in section 2(c).

(b)(iii) Minor structures - The most prominent minor structures are planar and commonly more or less parallel to each other, typically dipping north or northeast at 30-50^o. At some localities an alternation of psammitic and micaceous bands can be observed. Elsewhere the more common type of banding is a rather fine (typically centimetric or millimetric) interbanding of micaceous and quartzofeldspathic material (Plates 2-3, 2-4) which gives the rocks the migmatitic character to which attention was drawn by Cogné and Shelley (1966). Generally parallel to the banding is a pronounced schistosity produced by the parallel arrangement of platy minerals, mostly biotite. Folds to which the schistosity is axial planar are much less commonly observed than in the Mica-schistes de L'Aber-Wrac'h, although Shelley (1966, fig 1) has drawn attention to west-plunging folds of this type at Meznaot (7.701/53.952) near the western extremity of the outcrop of the Gneiss. Early north-plunging folds have not been observed but post-metamorphic minor folds of chevron type are abundant, and frequently plunge at a moderate angle to the west or WNW, with steep axial planes.

(b)(iv) Petrography - Attention has already been drawn to the compositional banding in the Gneiss de L'Aber-Benoît. On the whole the formation is more heterogeneous than the Mica-schistes de L'Aber-Wrac'h, and the brief description which follows is not to be considered as a comprehensive or thorough description of the formation.

I Psammitic material

The psammites closely resemble those found in the mica-schistes de L'Aber-Wrac'h. They are fine grained with quartz, oligoclase and minor quantities of garnet and mica. They have a granulitic texture, and are generally only a few cm thick.

II Pelitic material

The pelitic portions of the Gneiss de L'Aber-Benoît are greatly in excess of the psammitic types. They commonly possess a gneissose or migmatitic banding on a millimetric to centimetric scale (Plate 2-4). The dark bands are rich in biotite, which may exceed 50% of the total. Muscovite is generally only present in subordinate quantity. Sillimanite (both prismatic and fibrolitic) is common and may form up to 30% of the dark bands (Plate 2-5). Quartz and plagioclase are also usually present. The light bands consist predominantly of oligoclase, microcline and quartz with some muscovite. In some cases these quartzofeldspathic bands thicken into swells or augen (Plate 2-4). In other cases leucocratic augen are largely composed of muscovite, which may be replacing some other mineral (feldspars or sillimanite).

2 ORTHOGNEISSES AND METAIGNEOUS TYPES

(a) Granitic gneisses : The Gneiss de Trēglonou & related types

I Gneiss de Trēglonou : I (i) Location

The main outcrop of granitic gneisses in the Lannilis District lies south of L'Aber-Benoit. Only the northern sector of the outcrop between Moulin du Quinou (7.70/53.95) and Trēglonou (7.63/53.95) has been examined in the present study. According to Chauris (1972c) the Gneiss de Trēglonou forms a periclinal dome and has a roughly circular outcrop about 4 km in diameter surrounded by 'Gneiss de Lesneven'(Fig 1-7). Away from the sector examined in the present study exposures are rare.

(a) I (ii) Contacts -
As mentioned above in section 1(b) the contact of the Gneiss de Trēglonou with the Gneiss de L'Aber-Benoît is essentially parallel with the internal structures in both formations. The Gneiss de Trēglonou structurally underlies the Gneiss de L'Aber-Benoit in the sector examined. The repetition of the contact north of Locmajan at 7.687/53.952 is thought to be due to late faulting. Rare concordant sheets of Gneiss de Trēglonou type up to lm thick occur within the Gneiss de L'Aber-Benoît on the south bank of the ria north west of Trouzilit (Fig 2-1).

(a) I (iii) Minor structures -
The rock is typically banded with biotite tending to be concentrated in discontinuous foliae less than 1 mm thick and a few mm apart (Plate 2-6). There is a well defined schistosity due to the parallel arrangement of biotite flakes. No folds to which this schistosity is axial planar have been observed. Post-metamorphic folds or flexures corresponding to those already mentioned in the Gneiss de L'Aber-Benoît are common but are generally much more open than in the latter formation; insufficient measurements have been made to define axes or axial planes with any precision .

(a) I (iv) Petrography -
In the sector examined the Gneiss de Trēglonou is relatively homogeneous in character, contrasting in this respect with the heterogeneous Gneiss de L'Aber-Benoît. The compositional banding has already been mentioned. The rock is a rather leucocratic gneiss of granitic composition. It is predominantly composed of microcline-perthite (50-60% of the rock) and quartz (25-30%). There is 5-10% of biotite, most of which is concentrated in the discrete bands already referred to, and a subordinate content of sodic plagioclase. Muscovite and garnet occur in accessory amounts. In the quarry at Locmajan much of the gneiss displays the partial metasomatic alteration of the original biotite gneiss to unfoliated biotite-free tourmaline granite (Plate 2-7); the garnets found in the gneiss are preserved apparently unaltered in the tourmaline granite. Biotite is also commonly altered to an intergrowth of chlorite and an opaque mineral.

Barrière et al (1973) described sillimanite nodules occurring as loose blocks within the main outcrop of the Gneiss de Trēglonou at Guelet ar C'hoat (7.65/53.91; Fig 2-1) but it seems possible to the present writer that these occurrences may represent metasedimentary enclaves and should perhaps be grouped with the Gneiss de L'Aber-Benoît rather than with the Gneiss de Trēglonou itself.

(a) II Other outcrops of granitic gneisses in and near the Lannilis district

(a) II (i) Les Anges and Enez Terc'h

Near Les Anges (7.682/53.996) and SE of Enez Terc'h (7.672/54.005) (Figs 2-1, 3-A) are limited exposures of rocks closely similar to the Gneiss de Trēglonou. At the former locality they are associated with another type of gneiss otherwise similar to the Gneiss de Trēglonou but with prominent quartzofeldspathic augen elongated parallel to the main foliation. These outcrops lie near the northern margin of the belt of post-metamorphic granites which coincide with the Porspoder Lineament in this sector, and are therefore separated from the main outcrop of the Lannilis Metamorphic complex by these granites.

(a) II (ii) Corn ar Gazel -

At Corn ar Gazel (7.737/53.976)(Figs 2-1, 3-A) there is a narrow band (50 m) of strongly foliated quartzofeldspathic biotite gneisses distinct from the Gneiss de Trēglonou on account of their more continuous and closely spaced banding, (Plate 2-8). These gneisses at Corn ar Gazel are associated with rocks comparable with the Gneiss de L'Aber-Benoît and the Amphibolites de L'Aber-Benoit, and may represent another fragment of the Lannilis Metamorphic Complex isolated on the north side of the Porspoder Lineament.

(a) II (iii) Plouider and Plounevez-Lochrist -

To the north and east of the town of Lesneven, (Fig 1-2) which lies 15 km east of Lannilis, there are extensive outcrops of gneisses closely resembling the Gneiss de Trēglonou together with augen gneisses similar to those found at Les Anges (Fig 1-7). These gneisses have been variously named after the villages of Plouider, Plounevez-Lochrist, Goulven, Treflez and Lanhouarneau, but are probably best considered as a single group. They are well exposed in a recently active quarry at Plouider, where they are accompanied by possibly metasedimentary gneisses and migmatites. Also in this quarry the non-augen type shows patchy metasomatic alteration of garnetiferous muscovite-biotite gneiss to garnetiferous tourmaline granite similar to that observed in the Gneiss de Trēglonou in the quarry at Locmajan (see above) (Plate 2-7).

(b) Metaigneous rocks of intermediate composition: the Diorite de Lannilis

(b) (i) Location -

Much of the ground which lies between the estuaries of L'Aber-Wrac'h and L'Aber-Benoît is covered by a blanket of Quaternary loess which obscures the underlying 'solid' formations. However the distribution of exposures along the two estuaries suggests that the loess is underlain for the most part by a distinctive formation, which was known to Barrois (1902 a and b) as 'Diorite Micacēe de Lannilis' to Cognē and Shelley (1966) as 'Amphibolites quartziques (Fig 1-8) and to Chauris (1967)as 'Amphibolites quartziques de L'Aber-Wrac'h (Fig 1-6). In the eastern part of L'Aber-Benoît belts of metasediment (Gneiss de L'Aber-Benoît) are interbanded with belts of Diorite de Lannilis, the latter being of the order of some hundreds of metres in thickness (Fig 2-3). Thinner bands of similar diorite are also found, e.g. on the north shore of L'Aber-Benoît south of Kerdraon (Fig 2-2) (7.68/ 53.96). The most continuous outcrop of Diorite de Lannilis is along both banks of L'Aber-Wrac'h between Kerouartz and Pont du Diable (Fig 2-2). The total thickness of the unit is probably of the order of 2 km, although this total may include repetition due to the possible presence of isoclinal folding on a major scale which has been suggested by Cognē and Shelley (1966) (Fig 1-8).

(b) (ii) Contacts -

It has already been recorded (section 1(a) and (b)) that the margins of the Diorite de Lannilis are apparently concordant with the foliation both of the Diorite itself and of the neighbouring metasediments. It has not been possible to obtain evidence as to whether this concordance is inherited from a primary pre-metamorphic concordance, or is due to syn-metamorphic deformation of an originally discordant relationship.

(b) (iii) Minor structures -

Locally the rock may appear massive. However more commonly observed is a weakly developed banding consisting of a fine almost microscopic alternation of bands with greater and lesser proportions of mafic minerals. In addition, particularly near the margins and in the thinner sheets the rock may have a strong planar and weaker linear schistosity ($S > L$ tectonite), which is generally parallel to the banding if present. The schistosity is caused by parallel arrangement of biotite and hornblende crystals. The lineation is generally sub-horizontal or gently-dipping, while the planar schistosity generally dips N or NE at 40 - 50°. Syn-metamorphic folds have not been observed except where early minor crosscutting leucocratic veins and pegmatites appear to have been deformed during the principal deformation and metamorphism of the host rock, resulting in ptygmatic folds or boudinage. Post-metamorphic folds and flexures are generally open, and of greater amplitude and wavelength than in the metasedimentary formations. As in the case of the Gneiss de Trēglonou the difficulty of measurement makes the attitude of axes and axial surfaces uncertain. Near the mouth of L'Aber-Benoît the Diorite de Lannilis is involved in the deformation associated with the development of the Porspoder Lineament (Chapter 4) and a new schistosity with SSE dip has locally been imposed on the previously north-dipping diorite (Figs 2-4, 4-2).

(b)(iv) Petrography -

The rock is transitional from leucocratic to mesotype and is easily distinguishable in the field on this account from other metaigneous rocks in the Lannilis Complex which are either distinctly leucocratic (e.g. Gneiss de Trēglonou) or melanocratic (e.g. Amphibolites de L'Aber-Benoît). Mafic minerals total 25-35%, with hornblende generally slightly in excess of biotite except in the more strongly foliated examples and near the margins where biotite is in excess. Biotite occurs as scattered brown flakes with greatest dimension generally in the range 0.2-1.0 mm, but becoming coarser where it is more abundant. Hornblende, which displays olive-green/yellow-green/yellow pleochroism and rather strong absorption (noticeably stronger than in the metabasic rocks from the same area such as the Amphibolites de L'Aber-Benoît) occurs as relatively coarse (0.5-3.0) poikiloblastic grains with extremely irregular 'ragged' margins, and containing rounded inclusions of quartz and feldspar (Plate 2-9). The most abundant mineral in the rock as a whole is plagioclase commonly An 40-45 but ranging from calcic oligoclase to sodic labradorite, which may form 45-55% of the rock. Quartz is an essential mineral, forming 15-20% of the total and occuring both as fine (< 0.2 mm) rounded inclusions in plagioclase and hornblende, and as coarser interstitial growths. Coarse (0.1 - 1.0 mm) sphene is commonly present in quantitites (2%) which almost make it an essential constituent. Apatite is a constant accessory, but opaque minerals are rare or absent. Microcline may locally occur as an interstitial mineral.

Where these have been examined the associated early leucocratic veins are composed of oligoclase in excess of microcline, with quartz. The petrography of the pegmatitic pods and boudins which occur within the Diorite along the L'Aber-Benoît near Pont de Trēglonou has not been described by earlier workers or studied by the present writer.

(b)(v) Other outcrops of Diorite de Lannilis type

The Diorite de Portsall, a dioritic metaigneous body of similar lithology to that of the Diorite de Lannilis but outcropping in the area to the north of the Porspoder Lineament will be considered in the following chapter (chapter 3) which deals with the Migmatites de Plouguerneau and associated rocks.

A number of small bodies of foliated dioritic rocks occur as enclaves in, or associated with, post-metamorphic granites near the northern margin of the Porspoder Lineament. These are intermittently exposed along the shores of the outer parts of the estuaries of L'Aber-Wrac'h and L'Aber-Benoît. These occurences are analogous to and sometimes (e.g. at Les Anges) (Figs 2-1, 3-A) associated with outcrops of Gneiss de Trēglonou type in the same sector. The most extensive of these bodies is at Bilou Bihan (7.66/54.00)(Fig 2-1, 3-A) where the mineralogy is closely similar to that of the Diorite de Lannilis but with a rather higher proportion of hornblende and biotite and a smaller proportion of quartz. Other examples, for instance at 7.332/53.978 (east of Corn ar Gazel) (Fig 4-2) are enriched in biotite but depleted in hornblende as compared with typical Diorite de Lannilis.

(c) Metabasic rocks

I Amphibolites de L'Aber-Benoît

(c) I(i) Location -

Along the south shore of L'Aber-Benoît between Grand Moulin (7.70/53.94) and Kerstephan (7.65/53.95)(Fig 2-3) the Gneiss à Sillimanite de L'Aber-Benoît contains numerous small bodies of amphibolite. These occurrences are concentrated in belts roughly parallel with the strike and between 50 and 250 m above the 'base' of the Gneiss (Figs 2-3, 2-4).

(c) I (ii) Form and contacts -
The amphibolites occur in two main forms : (a) as relatively thick (10 m) sheets concordant with the foliation of the enclosing Gneiss de L'Aber-Benoît; and (b) as smaller (0.5-1.5 m) pods whose internal foliation may be oblique to the foliation of the country rock; the latter may itself be 'deflected' round the margins of the boudins. In this case there may be segregations of quartzofeldspathic pegmatite at the point where the external foliation diverges.

(c) I (iii) Minor structures -
The less massive varieties possess a more or less marked linear and planar fabric due to parallel arrangement of hornblendes. Locally a fine banding is also present. No folds associated with these structures have been observed.

(c) I (iv) Petrography -
Most specimens are equigranular. However typical grain size varies from 0.2-0.4 mm in the more massive varieties to 1.0-2.0 mm in the more strongly foliated varieties. All specimens seen are predominantly composed of plagioclase and hornblende (Plate 2-10) which amount to 90% of the total. Plagioclase is about An 55-60 in the more massive varieties, decreasing to An 30 in strongly foliated types. Hornblende displays olive-green/yellow-green/yellow pleochroism with weaker absorption than in the Diorite de Lannilis and may show sieve texture with fine (< 0.05 mm) rounded blebs of quartz and feldspar. Quartz also occurs interstitially, making up about 5-8% of the rock. Sphene is abundant (c 2%) in the size range 0.02-0.4 mm, finer grains being rounded and ovoid, coarser grains having a more irregular outline. Opaque minerals (pyrrhotite and magnetite) form 2-3% of the rock as hollow masses and aggregates with inclusions of quartz. Some specimens have a few grains of biotite. There is minor chloritisation of mafic and opaque grains. A garnetiferous variety has been described by Cogné and Shelley (1966 p.5).

(c) II Other amphibolites -
At Corn ar Gazel a few pods of mafic amphibolite have a mode of occurrence similar to that of the pods of Amphibolites de L'Aber-Benoît. Here however they occur as enclaves in the probably orthogneissic banded and augen gneisses, rather than in material of metasedimentary type like the Gneiss de L'Aber-Benoît. Both massive and foliated varieties occur. The chief minerals are hornblende (c 55%) and plagioclase (calcic andesine).

(c) III Filon basique de L'Aber-Wrac'h -

On the north bank of L'Aber-Wrac'h at 7.623/53.994 a thin (< 0.2 m) schistose mafic sheet cuts obliquely across the banding of the Mica-schistes de L'Aber-Wrac'h. It appears to be a mafic dyke intruded into the metasediments prior to the main metamorphic deformation. It has not however been possible to prepare a microscope section of this dyke owing to its severely weathered nature.

(c) IV Pyribolite du Pont de Trēglonou -

At 7.638/53.952, within the outcrop of the Diorite de Lannilis, there is a small outcrop (mainly large loose blocks) of a coarse almost pegmatitic mafic rock. Its relations with the country rock are not clear. The chief constituents (Plate 2-11) are hornblende (showing yellow-green/yellow pleochroism and relatively weak absorption, both of which features distinguish it from the hornblende of the Diorite de Lannilis) together with pale green clinopyroxene and interstitial plagioclase (An 40-45). The two mafic minerals tend to be segregated into discrete portions of the rock. The only other abundant constituent is sphene, which is generally anhedral, occurring as 0.2-1.0 mm inclusions in hornblende and also as discrete grains up to 3mm across. Accessory opaque grains are present. The rock may represent a primary melanocratic segregation in the Diorite de Lannilis.

(c) V Gneiss à clinopyroxène de Brendaouez -

(i) Location and field relations

This very small outcrop lies some distance to the ENE of the main sector of the Lannilis Metamorphic Complex, being separated from it by areas occupied by post-metamorphic intrusive granites. The outcrop is in an area of poor exposure near the hamlet of Brendaouez (Figs 2-1,1-9). It appears to be in the form of an enclave a few tens of metres thick within a granite of the Kernilis type (see below). Metasedimentary gneisses comparable to the Gneiss de L'Aber-Benoit also occur in the vicinity (7.504/54.017) and it seems reasonable to classify the Brendauouez pyroxene gneisses provisionally as outlying members of the Lannilis Metamorphic Complex. The occurrence has been briefly described by Chauris (1966c).

(c) V (ii) Structure

The outcrop as a whole displays a coarse banded structure due to variation in mineral composition. Most specimens possess a crude foliation due to elongate concentrations of mafic and feldspathic components. The rocks are generally non-schistose.

(c) V (iii) Petrography

Mafic minerals form 40-60% of the rock. All examples examined contain plagioclase (An 35-50) and green to pale pink pleochroic clinopyroxene. Clinopyroxene may be the sole mafic mineral or may be accompanied by either hornblende or garnet (the latter pink in thin section)(Plate 2-12). Hornblende and pyroxene tend to occur as elongate aggregates. There may be subordinate quantities of quartz(less than 10%) which increases in abundance in the hornblendic varieties. Accessories include opaque minerals (ragged grains up to 0.5 mm), sphene, apatite and scapolite.

(d) Ultramafic Rock : Biotitite Du Carpont

At 7.685/53.953 in the uppermost of the quarries at Le Carpont or Locmajan (Fig 2-1) there is a single steeply-dipping dyke-like body c. 0.6 m thick which is discordant to the foliation in the Gneiss de Trēglonou. The rock is strongly schistose, the schistosity being oblique both to the margins of the body and to the schistosity in the host rock. The rock consists of about 80-90% of brown biotite, most of the remainder being quartz. No feldspar has been recognised.

The rock appears to have undergone a metamorphic episode comparable with that seen in the country rock (Gneiss de Trēglonou) but its origin or pre-metamorphic nature is obscure. Its discordant character suggests an origin as a dyke or intrusive sheet, but its present mineral composition indicates a chemistry unlike that of any common igneous rock, except perhaps some mica-lamprophyres. Perhaps a more likely possibility is that the biotitite may represent a (meta)sedimentary enclave incorporated in the granite precursor of the Gneiss de Trēglonou at the time of its emplacement. An argument in favour of this interpretation is that the biotitite is located close to the boundary of the Gneiss de Trēglonou and the Gneiss de L'Aber-Benoît.

(e) Pegmatites Associated with the Lannilis Metamorphic Rocks

Numerous quartzofeldspathic pegmatites are associated with the metamorphic rocks of the Lannilis district. Frequently they occur as large loose blocks whose relationship with the country rock is obscure, being particularly common on the banks of the upper reaches of L'Aber-Benoît. Smaller bodies of similar character occur as pods or boudinaged sheets, for instance in the Gneiss de L'Aber-Benoît east of Pont de Trēglonou (7.7633/53.951).

Pegmatites are also associated with pods of Amphibolites de L'Aber-Benoît at Locmajan (see above, section 2.c.(i).).

The petrography of the pegmatites has not been studied in detail. One example associated with a minor sheet of Diorite de Lannilis on the north bank of L'Aber-Benoît at 7.687/53.958 consists of about 50% andesine, 30% quartz and 15% alkali feldspar, with a little biotite.

Some at least of the pegmatites appear to have been emplaced in the metamorphic rocks of the Lannilis district prior to the culmination of the main metamorphic episode (M2) (see below). Shelley (1966) has, however, drawn attention to post-metamorphic pegmatites cutting the Mica-schistes de L'Aber-Wrac'h at Paluden.

B. METAMORPHIC AND STRUCTURAL HISTORY

1. INTRODUCTION

All the rocks so far described appear to have undergone a major orogenic episode which was largely responsible for the mineral assemblages and associated minor structures observed. Discussion of the physical conditions which may have prevailed during this episode is deferred until Chapter 8, where the effects and significance of the climactic metamorphism in the whole of the western Pays de Léon will be considered. However it is appropriate at this stage to summarise the metamorphic and structural evolution of the Lannilis Metamorphic Complex considered in isolation.

The successive metamorphic and tectonic episodes are listed in Table 2-1.

TABLE 2-1

METAMORPHIC AND STRUCTURAL EPISODES IN THE LANNILIS METAMORPHIC COMPLEX

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

2. THE D1/M1 EPISODE

The effects of the earliest orogenic episode demonstrable in the rocks of the Lannilis Metamorphic Complex are only apparent in the Mica-schistes de L'Aber-Wrac 'h, although other formations and lithologies may have been affected. The evidence for this episode, which was first pointed out by Shelley (1964, 1966), is to be found in the presence in the schists of two sets of isoclinal folds to which the metamorphic schistosity is axial planar. Since the trend and direction of plunge of these two sets is quite different (approximately N-S and E-W) it follows that the folding was polyphase.

The question arises as to which of the two sets of folds was the earlier. Fold interference patterns have proved difficult to find in the field. Perhaps the most cogent argument is that put forward by Shelley (1966) who points out that while syntectonic thickening of psammitic bands has taken place in the hinge zones of both sets of folds, the thickened hinges of the E-W set appear to be located in the already thinned limbs of the N-S set, while the converse (location of thickened N-S limbs in previously thinned zones) has not been observed. This argument indicates that the E-W set is the more recent. The original trend of the N-S set may have been approximately the same as it is at present, and this indeed seems to be the simplest solution; however since the N-S folds have been subjected to rotation on the limbs of the E-W folds, it is not possible to be certain about the original trend of the N-S set. The abbreviation 'D1' will be used to refer to the phase of deformation thought to be responsible for this early N-S set of folds.

The D1 deformation in the lithology which is now represented by the Mica-schistes de L'Aber-Wrac'h may have been accompanied by metamorphic recrystallisation. However it is not possible at present to come to any definite conclusions concerning the metamorphic assemblages and conditions associated with D1. It may be argued however that since there seem to be few traces of relict high-grade assemblages in the assemblages formed during the M2 metamorphism, and primary structures such as compositional banding probably derived from bedding are quite well preserved in the schists, any metamorphism accompanying D1 is unlikely to have been of much higher grade than that accompanying D2. It may be noted however that the occurrence of higher An content in the plagioclase of the more massive varieties of the Amphibolites de L'Aber-Benoit than in the varieties with

TABLE 2-2

Effects of the D2/M2 episode in the Lannilis Metamorphic Complex

Rock Unit	Folds, etc.	Planar & Linear structures	Mineral assemblages *
Mica-schistes de L'Aber-Wrac'h	Abundant E-W trending Tight/ isoclinal.(Possibly includes folds in Plate 2-1)	Mica-schistosity	musc-bi-olig-qtz ga-olig-qtz ga-cpx-andes-qtz (Plates 2-1 & 2-2)
Gneiss de L'Aber-Benoît	E-W trending Tight/isoclinal (Few observed) Boudinage of peg-matites & quartzo feldspathic bands (Plate 2-4)	Quartzofeldspathic banding and lamina-tion of migmatitic character. (Plates 2-3 & 2-4) Biotite & sillimanite schisto-sity.	ga-plag-qtz. (musc)-(Ksp)-(sill)-bi-plag-qtz
Gneiss de Trēglonou	not seen	Biotite lamination and schistosity (Plate 2-6)	(musc)-(ga)-olig-bi-qtz-Ksp
Diorite de Lannilis	not seen	Poorly developed lam-ination. Biotite schistosity.Hornblende lineation.	sph-bi-hb-olig-qtz (Plate 2-9)
Amphibolites de L'Aber-Benoît	not seen	Weak lamination Hornblende schistos-ity/lineation	qtz-andes/labr-hb (Plate 2-10)
Granulites ā clinopyroxēne de Brendauouez	not seen	Interbanding of horn-blendic and hornblende-free portions	andes-cpx-qtz-hb-andes-cpx. ga-andes-cpx (Plate 2-12)
Pyribolite du Pont de Trēglonou	none	Coarse alternation of hornblendic and pyroxenic portions	plag-sph-hb-cpx. (Plate 2-11)

* Explanation of abbreviations is given in Table 2-3

strong D2/M2 fabrics may indicate higher grade conditions in a pre-M2 episode, which may possibly have been contemporaneous with the D1 folding in the Mica-schistes de L'Aber-Wrac'h. The term M1 will be used to refer to this inferred early metamorphic episode.

3. THE D2/M2 EPISODE

The main metamorphic episode, which affected all the lithologies in the Lannilis Metamorphic Complex described in section A of this chapter, was accompanied by the formation of synmetamorphic folds in the Mica-schistes de L'Aber-Wrac'h and theGGneiss de L'Aber-Benoît. The main axial planar schistosity in the metasediments is considered to be the result of metamorphic recrystallisation during this deformational episode. It is also argued that the various orthogneissic and meta-igneous rocks underwent deformation and had imposed on them their most prominent metamorphic foliation, schistosity and lineation during this same episode. For convenience this climactic metamorphic and tectonic episode the effects of which are observed in the Lannilis Metamorphic Complex will be referred to as the D2/M2 episode.

The effects of the D2/M2 episode are summarised in Table 2-2.

TABLE 2-3 EXPLANATION OF ABBREVIATIONS OF MINERAL NAMES IN TABLE 2-2

andes	andesine
bi	biotite
cpx	clinopyroxene
ga	garnet (usually assumed to be almandine-rich)
hb	hornblende
ksp	alkali-feldspar
labr	labradorite
musc	white mica (assumed to be muscovite)
olig	oligoclase
plag	plagioclase
qtz	quartz
sill	sillimanite or fibrolite
sph	sphene

All the assemblages listed in Table 2-2 can be broadly assigned to the amphibolite facies of Turner (1968, p 307), or the almandine-amphibolite facies of other authors. The assemblages observed in the metasediments signify a metamorphic gradient at the peak of metamorphism, with an increase in grade southwards from the muscovite-rich sillimanite-free pelites of L'Aber-Wrac'h to the structurally lower muscovite-poor sillimanite-bearing pelites of L'Aber-Benoît. This transition may have involved the reaction:

$$\underset{\text{Muscovite}}{KALSi_3O_{10}(OH)_2} + \underset{\text{Quartz}}{SiO_2} = \underset{\text{Alkali-feldspar}}{KALSi_3O_8} = + \underset{\text{Sillimanite}}{AL_2SiO_5} + H_2O$$

It is not possible to locate the sillimanite isograd precisely as the critical intervening zone between L'Aber-Wrac'h and L'Aber-Benoît is poorly exposed and largely occupied by the outcrop of the Diorite de Lannilis whose mineralogy is insensitive to the increase in metamorphic grade. An attempt has been made to ascertain the variation in An composition of plagioclase across the outcrop of the Diorite but this has proved inconclusive.

Other aspects of the M2 metamorphism, including its effects and significance in the western Pays de Léon as a whole, will be considered in Chapter 8.

It may be noted in passing that two examples have been found in the Lannilis Metamorphic Complex of rocks which present an opportunity for geothermometry using the partition co-efficient of Mg and Fe between co-existing garnet and clinopyroxene as described by Råheim and Green (1974). These examples are the mafic garnet-clinopyroxene granulite at Brendauouez and the garnet-clinopyroxene psammite near Le Traon (7.620 (7.620/53.993).

4. THE D3/M3 EPISODE

4. (a) Major Structures

An episode of folding subsequent to the D2/M2 episode is considered to have been largely responsible for the present disposition of the metamorphic rocks of the Lannilis district (Fig 2-4). Most of the area of L'Aber-Wrac'h and L'Aber-Benoît can be regarded as being situated on the northern limb of a major antiformal structure whose crest or culmination must lie somewhere to the south or south-west of Trēglonou. The half wave length of this structure is in excess of 5 km (measured between the Carrière de Trēglonou at 7.638/53.942 and the tidal inlet on the north bank of L'Aber-Wrac'h west of Le Traon (7.61/53.99)(Fig 2-1, Fig 2-4). The trough of a major synform (Fig 2-3 and SW of Plouguerneau on Fig 1-7) runs approximately E-W at the latter locality (Fig 2-2) and between the two localities the mean dip of the metamorphic foliation is constantly to the north or NNE. East of Trēglonou the direction of dip swings round to become NE, which may indicate the approach to an easterly-plunging fold nose in this direction. This interpretation is broadly similar to that of Chauris (1966c, 1972c).

4 (b) Minor Structures

The most prominent minor structures which postdate the D2/M2 episode are the chevron folds, and open flexures of variable orientation and scale particularly abundant in the more finely foliated rocks such as the pelitic schists and paragneisses. Other post-metamorphic (is post-M2) folds of somewhat greater amplitude occur in both the metasedimentary formations and in the more extensive metaigneous formations, notably the Gneiss de Trēglonou and, less commonly, the Diorite de Lannilis. While it is by no means certain that all these minor folds were exactly contemporaneous it is considered that it is justifiable to treat them together as 'D3' folds in the first instance. They have not however been studied in detail and there exists considerable scope for an analysis of these minor folds and their relationship to the major structures. It has been observed that in the case of the major synform at Coat Keririn (or Le Traon) (7.61/53.99) minor D3 M-folds plunge at about 25^{0} to the west.

4 (c) Metamorphism

The metamorphic assemblages inherited from the M2 metamorphism appear to have remained remarkably undisturbed during the severe D3 folding. It is possible that the common sericitisation of feldspars may have been associated with the D3 folding, as may be the minor and local chloritisation of biotite, and local growth of muscovite cutting across the M2 metamorphic schistosity. It should also be emphasised that the Lannilis Metamorphic Complex is almost surrounded by post-M2 granitic intrusions belonging to or associated with the L'Aber-Ildut Granite Complex.

Contact metamorphic effects of these granites are not obvious; this may be due in part to the stability of the medium and high grade regional metamorphic assemblages (inherited from M2) when subjected to the contact heating effects of the granites; but in addition it is possible that temperatures in the country rocks were still regionally elevated when the granite emplacement took place. If the latter was the case, this might also explain the lack of retrogression of the M2 assemblages during the D3 folding.

4 (d) Relationship between the D3 Folding and the L'Aber-Ildut Granite Complex

It may be further remarked that no unequivocal evidence has been found regarding the relative age of the D3 folding and the emplacement of the L'Aber-Ildut Granite Complex. Although no minor folds of D3 type have been observed in the granites it may be pointed out that the typically massive and homogeneous material of which the granites consist could hardly be expected to display small-scale folds of this type even if subjected to conditions which would produce them in more foliated material. It may also be remarked that the outcrop pattern of the Complexe Granitique de L'Aber-Ildut and the Granite de Kernilis as shown for example in Figure 1-7 shows that the distribution of the granites is related to the major structure of the area, notably in the absence of outcrops of post-metamorphic granites in the antiformal area occupied by the Gneiss de Tréglonou. Further work is required to elucidate the D3/Granite relationship.

5. THE D4 DEFORMATION

The deformation associated with movements along the Porspoder Lineament (indexed D4) will be discussed in Chapter 4. It is however appropriate at this point to mention certain aspects of this deformation in so far as it affects the rocks of the Lannilis Metamorphic Complex.

5 (a) L'Aber-Benoit Sector

Towards the mouth of the L'Aber-Benoît estuary near Stellac'h (Fig 2-1) (7.702/54.967) the D2/M2 schistosity of the northerly-dipping Diorite de Lannilis is cut by a later SSE-dipping fracture cleavage which increases rapidly in intensity northwards until at Morgan (7.72/53.97) (Fig 2-4) the early schistosity is locally obliterated by the new structure. Just further north at Kervigorn the Diorite abruptly gives way to an intrusive granite (Granite de Kervigorn (Figs 2-4, 4-2), which shows no sign of having undergone the earlier metamorphic and tectonic episodes which have been observed in the rocks of the Lannilis Metamorphic Complex, but which has been intensely affected by the same late cleavage producing movements as have affected the Diorite de Lannilis just to the south (Plates 4-1, 4-2). There seems to have been relatively little retrogressive metamorphism or recrystallisation associated with these movements. Biotite and hornblende both remain apparently stable in the deformed diorite, and chloritisation has not been obseerved in this sector.

5 (b) L'Aber-Wrac'h sector

Rather similar relationships can be observed on the banks of L'Aber-Wrac'h at Moulin d 'Enfer (7.625/53.990)(Fig 2-2; also near B on Fig 2-4) where however it is the Mica-schistes de L'Aber-Wrac'h which are in contact with the post-M2 granite occupying the Porspoder Lineament. The effects of the late deformation appear to be more marked in the granite, where they again appear as a southerly-dipping fracture-cleavage, than in the schists where there is only a minor amount of cataclasis superimposed on the D3 folds. In this sector the boundary between the schists and the intrusive granite seems to coincide approximately with the limit of the zone in which D4 fracture cleavage is developed.

It may be noted that Cognē and Shelley (1966, p 6-7) consider that the development of (D3) chevron folds in the schists and the D4 mylonitic structure in the granite at this locality are contemporaneous. However in the absence of firm evidence of contempora neity the writer prefers to consider the two phenomena independently.

C. PRIMARY NATURE AND PRE-M2 RELATIONSHIPS OF THE LANNILIS METAMORPHIC COMPLEX

1. INTRODUCTION

This section is concerned with the origin and development, prior to the climactic metamorphic episode M2, of the rock units which now comprise the Lannilis Metamorphic Complex. It has been found necessary to place this section later in the chapter than the section dealing with the metamorphic and structural history of the complex, as it is felt the early history of the complex could not be understood without first establishing the relative significance of the D1/M1 and D2/M2 episodes.

2. ORIGIN OF THE METASEDIMENTARY FORMATIONS

2(a) Introduction

For the purposes of this section the two main metasedimentary groups in the Lannilis Complex will be considered together, as although they are now at different metamorphic grades their compositional similarities are sufficient to suggest that they possess a common primary origin.

A number of different suggestions have been made concerning the original nature and age of the metasedimentary rocks of the Pays de Léon. These will be considered in sequence, starting with the most ancient origin suggested, and assessed in the light of stratigraphical and lithological evidence. The geochronological evidence bearing on the problem will be considered in Chapter 5.

2(b) The Pentevrian

Cogné and Shelley (1966) argued that the presence of an early (D1 in the present writer's classification) set of folds in the Mica-schistes de L'Aber-Wrac'h indicates that the schists were involved in an early phase of deformation in an orogenic episode distinct from and earlier than that which produced the (D2) structures and (M2) metamorphism. Cogné and Shelley assigned the (D2/M2) episode to the Late Precambrian Cadomian orogeny whose type area is in Lower Normandy (see Chapter 1) and which has been widely recognised elsewhere in the Massif Armoricain. The earlier (D1 in the present writer's classification) structures were assigned by Cogné and Shelley to the earlier pre-Brioverian possibly mid-Proterozoic Pentevrian orogeny, which was originally recognised in northeast Brittany by Cogné (1959), but whose status and extent have since been the subject of controversy and re-assessment (e.g. Vidal et al 1974). The only areas where there is general agreement on the presence of pre-Brioverian rocks are the islands of Guernsey and Sark, the Cap de la Hagne area and locally in the north of the Trégor peninsula. Outcrops of metamorphic and migmatitic rocks in various other sectors of the French mainland have been assigned to the Pentevrian (Brown, 1978; Hanmer 1977a; Ryan and Roach 1977; and see summary in Roach et al 1972). It is however, difficult to identify any features in the Mica-schistes de L'Aber-Wrac'h or other formations in the Lannilis Metamorphic Complex which are correlatable with features described in Pentevrian rocks elsewhere, and in view of the current lack of agreement over the nature and extent of the Pentevrian it would seem advisable not to go so far afield in searching for the parent material of the Lannilis metasediments.

2 (c) The Brioverian

Taylor (1969) and Bishop et al (1969) have discussed the original nature of the medium (staurolite) grade metasedimentary rocks of the SW Pays de Léon (i.e. the Mica-schistes du Conquet, Fig 1-6, etc), which like those of the Lannilis district consist predominantly of thinly interbanded psammitic and pelitic material. They are grouped under the same legend as the Mica-schistes de L'Aber-Wrac'h by Chauris (1972c) (see Fig 1-9). Bishop et al considered that the staurolite grade metasediments were the more highly metamorphosed equivalents of the low grade unfossiliferous laminated blue-grey shales and siltstones with sandy layers (Quartzophyllades de L'Élorn) which outcrop along the southern margin of the Pays de Léon. They considered the latter on stratigraphic grounds to be Brioverian, being unconformably overlain by fossiliferous Lower Ordovician (Fig 1-5). In view of the fairly well-established presence of Brioverian rocks at the southern margin of the Pays de Léon, it is at least reasonable in the first instance to consider that not only the medium-grade metasediments of the SW Pays de Léon but also the medium and high grade metasediments of L'Aber-Wrac'h and L'Aber-Benoit may originate from the metamorphism of Brioverian sediments similar to those seen in the Quartzophyllades de l'Élorn.

2 (d) The Palaeozoic

Cabanis (1975) in a study of the regional metamorphism in the Eastern Pays de Léon, considered the metasediments in the area to be the higher-grade equivalents of the low grade metasediments found further southeast in the Morlaix area and known in part as the Quartzophyllades de Morlaix (Fig 1-6) or Schistes Zebrés. These consist of finely interbanded quartzo-albitic and micaceous bands. Fossiliferous Devonian and Carboniferous rocks displaying similar deformational structures to those seen in the Schistes Zebrés have been recorded in the Morlaix area by Delattre (1952) and Cabanis et al (1974). Cabanis (1972, p 2129) has assigned the whole of the Schistes Zebrés to the Carboniferous. However Chauris (1971c, p 2045; see also Fig 1-6),followed Barrois' example in correlating the Quartzophyllades de Morlaix with the Quartzophyllades de l'Élorn, which are now generally accepted as Brioverian.

Unfortunately exposures are poor in the Morlaix region and the stratigraphic relations and status of the Schistes Zebrés or Quartzophyllades de Morlaix are still matters of controversy. The presence of Upper Palaeozoic rocks in the Morlaix area is indubitable. However it does not seem to have been definitely established that the Schistes Zebrēs are themselves of Upper Palaeozoic age.

It should also be emphasised that the metasedimentary rocks of the Pays de Lēon do not appear to include any metamorphic equivalents of the distinctive lithologies such as thick quartzitic and calcareous units which characterise the relatively well-exposed and well-understood Palaeozoic (Arenigian to Devonian) sedimentary succession overlying the Brioverian in the central part of West Finistēre immediately to the south of the Pays de Lēon (Figs 1-5, 7-1).

2 (e) Conclusion

It will be clear from the above discussion that the explanation of the origin of the metasedimentary rocks of the Lannilis Metamorphic Complex favoured by the present writer is that they seem likely to have been derived from material similar to the Quartzophyllades de l'Ēlorn. The latter are now generally accepted to be Brioverian.

This view is shared by Chauris (1966c p 8; 1972c p 25), and is consistent with the conclusions of Bishop et al (1969).

3 ORIGIN OF THE METAIGNEOUS FORMATIONS AND ORTHOGNEISSES

(a) Gneiss de Trēglonou and other granitic gneisses

As mentioned above Chauris (1966c, 1972c) has put forward the view, with which the present writer concurs, that the metasedimentary rocks of the Lannilis District are likely to have been derived from Brioverian parent rocks. Chauris (op.cit) further argued that the granitic orthogneisses such as the Gneiss de Trēglonou which underlie the metasediments are by virtue of this position to be assigned to a pre-Brioverian basement, i.e. the Pentevrian. Chauris considered that these granitic orthogneisses are the most ancient rocks outcropping in the Pays de Lēon. Cabanis (1976), who considered that the Lēon metasediments were derived from Upper Palaeozoic parent rocks, used similar arguements to those of Chauris to suggest that the Trēglonou and similar orthogneisses represent a pre-Upper Palaeozoic basement on which the sediments were unconformably deposited.

The occurrence of a band of mafic rocks (usually amphibolites) a short distance above the base of the metasediments at several localities was used by both Cabanis (op cit) and Chauris (op cit) to support their argument that the present base of the metasediments is a significant stratigraphic horizon. However features commonly associated with major unconformities such as overstepping relationships or basal conglomerates do not appear to have been observed or reported at the contacts between the Gneiss de L'Aber-Benoît (or 'Gneiss de Lesneven') and the Gneiss de Trēglonou (or Gneiss de Plounevez-Lochrist, etc). In the view of the present writer the fact that the granitic orthogneisses of Trēglonou and Plounevez-Lochrist structurally underlie the L'Aber-Benoît and Lesneven paragneisses does not necessarily imply that the orthogneisses are older, or that they constitute a basement.

Two other interpretations of the relations between the Gneiss de L'Aber-Benoît (and similar types) and the Gneiss de Trēglonou (and similar types) may be considered:

1. The metasediments and orthogneisses may have bean brought into juxtaposition by tectonic means such as faulting, thrusting or sliding. There seems however to be no evidence to support this interpretation.

2. The orthogneisses may have been intrusive into the metasediments and therefore younger than them.
   This interpretation is supported by the following arguments:
   (a) Occasional bands of Gneiss de Trēglonou type occur within the Gneiss de L'Aber-Benoît (see section A2(a)(I)(ii) of this chapter). These may represent minor intrusive sheets related to a nearby major intrusion.
   (b) The sequence of metamorphic and tectonic events is significantly simpler in the Gneiss de Trēglonou than in the metasediments. Neither early (D1/M1) nor synmetamorphic (D2/M2) folds have been observed in the orthogneiss.
   (c) The biotitite in the quarry north of Locmajan (section A.2.(d) of this chapter) is more easily interpreted as an enclave or xenolith of pre-existing host rock rather than as an intrusive sheet.

   This interpretation is further supported by the geochronological evidence (Vidal, pers.comm; see also chapter 5 of the present work); an Upper Palaeozoic

(Devonian) Rb-Sr whole rock isochron age has been obtained from samples of the Gneiss de Trēglonou and the Gneiss de Plounevez-Lochrist.

3 (b) Diorite de Lannilis

Shelley (1964) suggested that the Diorite de Lannilis may represent a volcanic basement originally of pyroclastic rocks, on which the sediments now represented by the Mica-schistes de L'Aber-Wrac'h and the Gneiss de L'Aber-Benoît were deposited. The diorite was thus of similar age to or older than the metasediments which Shelley (see above, section B.2) considered to have undergone a Pentevrian orogenic episode.

Chauris (1972c p 24) also suggested that the Diorite de Lannilis may have been derived from 'ancient volcanic tuffs'.

However Barrois' use of the term 'diorite' to describe the formation seems to indicate that he looked on it as possessing some characteristics of an intrusive igneous rock.

In the opinion of the present writer the discontinuous fine banding commonly observed in the Diorite de Lannilis which might be used to suggest a possible volcaniclastic or pyroclastic origin is more easily accounted for as being the result of severe syn-metamorphic deformation of a pre-existing unfoliated rock of intermediate igneous composition.

The question arises as to the original nature of the contacts between the Diorite de Lannilis and the metasediments. Similar possibilities to those considered in the case of the Gneiss de Trēglonou may again be considered:

1. The metasediments and diorite may have been brought into juxtaposition by tectonic means such as faulting, thrusting or sliding. There is however no evidence available to support this explanation.

2. The metasediments may have been unconformably deposited on a basement formed by the diorite. This is essentially the interpretation put forward by Shelley (1964) (see also Fig 1-8) but once again features characteristic of major unconformities such as overstepping relationships

and basal conglomerates have not been reported. Nonetheless this interpretation cannot be entirely ruled out.

3. The diorite may have been originally intrusive into the metasediments. This interpretation is supported by the following arguments:
(a) The diorite is typically rather coarse grained and homogeneous (even when relatively massive and apparently little deformed).
(b) Like the Gneiss de Trēglonou the diorite displays a structural history which is relatively simple compared with that observed in the associated metasediments.
(c) At one locality (7.812/53.966)(Fig 3-2) in the outcrop of the Diorite de Portsall (which is correlated with the Diorite de Lannilis), a band of migmatitic gneiss of metasedimentary type occurs as what appears to be an enclave within the diorite, consistent with an original intrusive relationship.

In view of the above arguments the present writer favours the view that the Diorite de Lannilis represents a plutonic or hypabyssal intrusion or group of intrusions into the metasedimentary rocks of the Lannilis district. A Rb-Sr whole-rock geochronological study of the Diorite is in progress in order to test the hypothesis of its post-Brioverian age.

3 (c) Metabasic rocks

The metabasic rocks comprise both amphibolites and clinopyroxene granulites. Both groups are equivalent in composition to mafic igneous rocks. They tend to occur as small pods or sheets distributed in elongate bands more or less concordant with the enclosing metasediments.

Two possible primary relationships between the metabasic rocks and the metasediments may be considered:

1. The metabasics may represent contemporaneous volcanic horizons within the metasedimentary group. This interpretation appears to be favoured by Chauris (1966c, 1972c), and is consistent with the known occurrence of occasional horizons of basic pillow lavas in the Brioverian of the Baie de Douarnenez (Darboux 1974).

2. The metabasics may represent minor intrusions into the metasedimentary group. This interpretation is consistent with the occurrence of metamorphosed basic dykes (Filons de Kermorvan) in the SW Pays de Lēon (Bishop et al 1969; see also chapter 6 of the present work).

There is not at present sufficient evidence to exclude either of these possibilities.

D. POST-M2 INTRUSIONS ASSOCIATED WITH THE LANNILIS METAMORPHIC COMPLEX

1. INTRODUCTION

This section is largely concerned with the relations between the Lannilis Metamorphic Complex and various associated post-metamorphic granites. The brief descriptions of the granites given here are not intended to supersede those given in the previous publications of Chauris (1966b, 1972c etc) and Barrière et al (1971a).

The outcrop of the Lannilis Metamorphic Complex is almost surrounded by outcrops of granitic rocks which generally lack the foliation, fabric and mineralogy which characterise the regionally metamorphosed rocks. Cross-cutting relationships indicating the intrusive nature of the granites can be obser ed at a few localities, for instance at Moulin d'Enfer (7.652/53.985) and Corn ar Gazel (7.737/53.951)(Figs 2-2 and 3-A).

2 COMPLEXE GRANITIQUE DE ST RENAN-KERSAINT

The Granites of St Renan and Kersaint (Fig 1-6), while not directly in contact with that sector of the Complexe Metamorphique de Lannilis, which has been described in this chapter, are none the less of considerable importance in the geology of the Western Pays de Lēon, occupying an extensive E-W belt which separates the metamorphic rocks of the central and northern parts of the Pays de Lēon from those of the southern and southwestern part. The St Renan-Kersaint Complex has been the object of several geochronological studies which will be considered in chapter 5.

The most detailed available description of the Complexe Granitique de St Renan-Kersaint is that of Chauris (1972c p 18-21) who recognised two main facies, the Granite de Kersaint and the Granite de St Renan, which he considered to be essentially contemporaneous. The Granite de Kersaint is porphyritic, with megacrysts of alkali feldspar (microcline or orthoclase) and with biotite in excess of muscovite. A major element chemical analysis given by Chauris (1972c p 29, no 10) indicates a rather potassic granitic composition. The Granite de St Renan is stated by Chauris to be more variable in character but is typically a non-porphyritic muscovite-biotite-microline granite. Tourmaline is commonly present in addition to or instead of biotite. Chauris and Moussu (1972) have described the widespread occurrence of greisenisation and tin-tungsten mineralisation in association with this facies.

The present writer has only had an opportunity to examine the Complexe Granitique de St Renan-Kersaint at a few localities. At the quarry of Langongar near St Renan typical Granite de St Renan predominates; the only rock type observed here is a tourmaline-free non-porphyritic muscovite biotite granite which shows no obvious signs of metasomatism, metamorphism or deformation. South of the Pointe de Corsen (Fig 1-2) the lithology is more variable, but the most common type, described by Chauris (op cit) as Granite de St Renan, is a non-porphyritic muscovite-tourmaline granite.

All available evidence seems to indicate that the Complexe Granitique de St Renan-Kersaint did not undergo any orogenic episode comparable with the D2 /M2 episode as seen in the Complexe Mētamorphique de Lannilis, and was intruded into the already metamorphosed rocks of the western Pays de Lēon at some time subsequent to that episode. The Granite de St Renan does, however, locally display evidence of profound metasomatic alteration (tourmalinisation and greisenisation).

3 COMPLEXE GRANITIQUE DE L'ABER-ILDUT

Including an inferred submarine extension westward to the northern part of the Molēne archipelago, the L'Aber-Ildut complex has an approximately oval outcrop about 35 km x 10 km in maximum dimensions (Fig 1-6, 1-7). Its northern margin is linear, terminating at the Porspoder Lineament. The most detailed descriptions are those of Chauris (1966b, 1972c p 15-18); and Barriēre et al (1971a). Only a small number of field observations in/this complex have been made by the present writer.

3 (a) Contacts

Exposed contacts between the L'Aber-Ildut complex and other lithologies are rather scarce. The complex is considered by Chauris (1966b, p 12) to be a later intrusion than the Granite de St Renan with which it is locally in contact on the coast south of Lampaul-Plouarzel (Fig 1-7) but the contact at this locality does not appear to show conclusive cross-cutting relationships. At Porspoder (Figs 1-7, 4-3) the contact with the Granite de Landunvez has been deformed by the D4 movements along the Porposder Lineament which have tended to obscure the primary relationship between the two units. It is possible that there has been a significant amount of displacement between the units at this locality.

Figures 1-6 and 1-7 show that the main outcrop of the Complexe Granitique de L'Aber-Ildut is in contact with rocks of the Lannilis Metamorphic Complex ('Gneiss et micaschistes de Lesneven') for about 7 km along its eastern margin. No exposures of the contact itself have been observed by the writer in this sector. Nonetheless comparison of the relatively undeformed and non-metamorphic character of the rocks of the L'Aber-Ildut complex near this eastern margin with the highly deformed and metamorphosed rocks of the neighbouring Gneiss de Trēglonou and Gneiss de L'Aber-Benoît, in addition to the evidence provided by the minor intrusive sheets of granite referred to in section 4 below, leaves little doubt that the L'Aber-Ildut Complex was intruded into the Lannilis Metamorphic Complex at some time subsequent to the D2/M2 orogenic episode.

3 (b) Petrography

The complex consists of two main facies and a number of minor facies. The minor facies include tourmaline-bearing varieties which occur along the southern margin of the complex, and various minor sheets of microgranite (Chauris, 1972c, p 17-18)(Fig 1-7).

The two major facies consist of an outer porphyritic facies and an inner aphyric facies, occupying about 80% and 15% respectively of the total area of outcrop.

3 (b) (i) Outer porphyritic facies (Granite de L'Aber-Ildut)

1. Pink-feldspar facies

This distinctive lithology is typically a massive coarse pink granite, with coarse euhedral alkali-feldspar (orthoclase or microcline) phenocrysts in a matrix of andesine/oligoclase, quartz and biotite (Plate 2-8). The alkali feldspars commonly display a preferred orientation. According to Barrière et al (1971a) the alkali-feldspars are generally orthoclase but as the northern margin, affected by the Porspoder Lineament (D4) movements, is approached they

become microcline of triclinicity increasing northwards. The writer has observed minor alteration of biotite to chlorite. The rock is characterised by the presence of rounded xenoliths darker and finer than the country rock, and consisting of the same minerals but with a larger modal content of biotite and plagioclase and minor alkali-feldspar. Chauris (1966b) has divided the xenoliths into two groups: I banded, K-rich,Ca-poor
II massive K-poor,Ca-rich
The xenoliths are inequidimensional and commonly show a preferred orientation parallelling that displayed by the feldspar phenocrysts in their vicinity.

2. Marginal white-feldspar facies
Along the eastern margin of the complex is found a narrow band of porphyritic granite resembling the pink-feldspar facies in many respects including the presence and type of xenoliths, but with phenocrysts somewhat finer and white in colour rather rather than pink. This facies can be seen in a quarry at Plouguin (Fig 1-7). A similar lithology also occurs at the boundary between the pink-feldspar facies and the Granite de Landunvez (= unit labelled $\zeta\gamma$ in Fig 1-7 (Chauris 1966b) at Porspoder and is correlated by Chauris (1972c p 16) with the white feldspar facies as seen at Plouguin. However it may be remarked that there is little evidence to distinguish the white feldspar granite at Porspoder from the neighbouring Granite de Landunvez.

3 (b) (ii) Inner non-porphyritic facies (Granite de Ploudalmézeau)
The central facies of the Complexe Granitique de L'Aber-Ildut is also known as the Granite de Ploudalmēzeau (Fig 1-7) and is well exposed in the quarries south of that town. It is a coarse flaggy leucocratic granite consisting of microcline perthite and sodic plagioclase in roughly equal proportions, with about 26% of quartz, 10-15% muscovite and 5% biotite. In the Ploudalmēzeau area the quartz displays mortar texture. Dykes and minor sheets of granite correlated by Chauris (1972c) with the Granite de Ploudalmēzeau cut the pink-feldspar facies at Porspoder.

3 (b) (iii) Filons microgranitiques
Chauris et al (1977) have described a set of NNE-SSW trending potassic microgranite dykes which intrude both main facies of the Complexe Granitique de L'Aber-Ildut between Ploudalmēzeau and Ploumoguer (Figs 1-7 and 1-9). The authors state that the microgranites do not appear

to be affected by the deformation associated with the Lineament Molène-Moncontour (see Chapter 4) although some of them appear to cross the Lineament. They may therefore postdate the D4 movements (see Chapter 4).

4 OTHER OCCURRENCES IN THE LANNILIS DISTRICT OF GRANITES SIMILAR TO THOSE FOUND IN THE COMPLEXE GRANITIQUE DE L'ABER-ILDUT

4 (a) Porphyritic pink-feldspar biotite granite

Granites which resemble the pink facies of the L'Aber-Ildut granite out crop in two other sectors of the Lannilis district. One of these occurrences is east of the town of Plouguerneau where a number of poorly exposed outcrops occur associated with the Granite de Kernilis (Figs 1-6, 1-9). Another is at the peninsula of Corn Ar Gazel (7.737/53.951) north of the Porspoder Lineament, where a steeply dipping sheet 15-20 m thick of pink L'Aber-Ildut type cuts obliquely across the gneisses described in section A.2.(a)(ii) of this chapter (Plate 2-8 ; Fig 3-a). This example contains accessory muscovite and displays some mortarisation of quartz.

4 (b) Granites resembling the Granite de Ploudalmézeau

The Lannilis Metamorphic Complex is bounded to the north and east by an aphyric leucocratic biotite-muscovite granite (Granite de Kernilis) (Fig 1-7), closely resembling the Granite de Ploudalmézeau and exposed in numerous quarries, for instance east of Tariec at 7.589/53.936 (at the head of L'Aber-Benoît on Fig 2-1). Similar granites also occupy much of the deformed zone associated with the Porspoder Lineament, commonly displaying a closely spaced parallel fracturation or fracture cleavage; this feature may be observed for example at the Quarry north of Kiloudern (Fig 2-1, 4-1; plate 4-5) at 7.564/54.016; and where the L'Aber-Wrac'h and L'Aber-Benoît estuaries intersect the Porspoder Lineament (Figs 2-2, 2-4, 4-2).

Minor sheets of Ploudalmézeau/Kernilis type intrude the Complexe Métamorphique de Lannilis at various localities, e.g. north of Locmajan (Fig 2-3) at 7.690/53.955 (Plate 2-3).

5 OTHER POST M2 GRANITES ASSOCIATED WITH THE LANNILIS METAMORPHIC COMPLEX AND THE PORSPODER LINEAMENT

5 (a) Granite de Kervigorn

The Ploudalmézeau type granite which occupies the Porspoder Lineament at the mouth of L'Aber-Benoît is associated with another granite (Granite de Kervigorn; fig 4-2) which is finer and darker than the

Ploudalmézeau type, with biotite equal to or in excess of muscovite. Both granites are affected by an ENE trending fracture cleavage, and outcrop in belts or bands which also trend approximately ENE. Where contacts are exposed the Granite de Kervigorn appears to be the later of the two, although the evidence is not conclusive. Granite similar to the Granite de Kervigorn also occurs at other points along the Porspoder Lineament, for instance on both banks of L'Aber-Wrac'h and as far east as the hamlet of Kerhournaouen (7.51/54.02)(Fig 2-1).

5 (b) Granite de Kerdalzou

Along the bank of L'Aber -Benoît near the hamlet of Kerdalzou (7.61/53.95) (Fig 2-1,2-3), a foliated leucocratic biotite granite occurs, mainly as large loose blocks. Its contacts with the country rock (Diorite de Lannilis) are not exposed, but the granite appears to be post-metamorphic. It is described as 'Granites de Lannilis' by Chauris (1972c) but the above term is preferred.

5 (c) Granite des Anges

On both sides of the outer sector of the L'Aber-Wrac'h estuary both in and extending to the north of the deformed (D4) zone of the Porspoder Lineament a porphyritic granite is associated with granite of Kernilis type and with various fragmentary outcrops of lithologies similar to those found in the Lannilis Metamorphic Complex (see above, section A.2) (and Fig 3-A). This granite is visible for instance at Cameleut (7.64/53.99)(Fig 2-1) and near the post office at the village of L'Aber-Wrac'h. Similar granites can be recognised further NE near 7.661/54.011 (Perros and Keridaouen)(Figs 2-1, 3-A). It is possible that these granites should be correlated with the Granites of Corréjou and/or Brignogan, which will be discussed in the following chapter.

5 (d) Other post-M2 granites

The present writer does not claim to have exhausted the list of post-metamorphic granitic intrusions associated with the Lannilis Metamorphic Complex. Chauris (1972c, 1:80,000 sheet) indicates a number of bodies of granite in the vicinity of Lannilis under the heading 'Granites de Lannilis'. He comments in the notice explicative that 'Granites of various facies, often pegmatitic and generally of limited extent, cut the mica-schists, gneisses and amphibolites in the vicinity of Lannilis'. Most of these granites are only visible in limited inland and temporary exposures. The Granite de Kerdalzou (see above, section (b)) is included by Chauris (op cit) in this group.

E. SUMMARY OF GEOLOGICAL HISTORY OF THE LANNILIS METAMORPHIC COMPLEX AND ASSOCIATED GRANITIC ROCKS

An outline of the sequence of geological events in the area covered in Chapter 2 is given in Table 2-4

TABLE 2-4 OUTLINE GEOLOGICAL HISTORY OF THE LANNILIS AREA

EPISODE	TECTONO-METAMORPHIC EVENTS	ROCK-FORMING EVENTS
	Late faulting	Quartz veins
		Filons microgranitiques
D4	Fracture cleavage and mylonitisation associated with movements along Porspoder Lineament	
D3	Orogenic episode. Chevron folds and open flexures. Minor retrogressive metamorphism.	Granite de Ploudalmēzeau Granite de L'Aber-Ildut
		Complexe granitique de St Renan-Kersaint
D2/M2	Orogenic episode. E-W tight/isoclinal folds and associated medium and high grade metamorphism	Penecontemporaneous pegmatites
D1/M1	Orogenic episode. Folds, axes now trending N-S. Probable associated metamorphism, grade uncertain	Pre-D2, post-D1. { Emplacement of parent rocks (plutonic/hypabyssal) of Gneiss de Trēglonou and Diorite de Lannilis. Possible basic minor intrusions
		Deposition of (possibly Brioverian) greywacke-shale sedimentary sequence possibly by submarine turbidity currents. Possibly contemporaneous basic volcanics and/or penecontemporaneous basic minor intrusions.

CHAPTER 3

THE PLOUGUERNEAU MIGMATITE COMPLEX AND ASSOCIATED GRANITIC ROCKS

G. STRUCTURAL AND MAGMATIC EVOLUTION OF THE PLOUGUERNEAU - LANDUNVEZ MIGMATITIC AND GRANITIC COMPLEX

1. Introduction
2. Pre-M2 episodes
   (a) Pre-M2 lithologies
   (b) Pre-M2 structures
3. The M2 episode
   (a) Metamorphic fabrics and associated structures
   (b) Migmatisation
4. Post-M2 phenomena
   (a) Granite de Landunvez
   (b) Adamellite de Ste Marguerite and associated structures
   (c) Later granites of Kern an Guen, Beg ar Spitz, Corrējou, Brignogan
   (d) Pegmatites
   (e) Deformation (D4) associated with the Porspoder Lineament
   (f) Faulting subsequent to the Porspoder Lineament deformation

CHAPTER 3

THE PLOUGUERNEAU MIGMATITE COMPLEX AND ASSOCIATED GRANITIC ROCKS

A. INTRODUCTION

The area described in this chapter lies at the NW extremity of the Pays de Lēon and forms an elongate strip between the north coast and the Porspoder Lineament. The eastern and western extremities are at the villages of Guissēny (7.89/53.90) and Porspoder (7.49/54.03) respectively (Fig 3-1). The area is separated from the main outcrop of the Lannilis Metamorphic Complex and its associated granites by the Porspoder Lineament, although as indicated in Chapter 2 small outcrops of rocks similar to those of the Lannilis Complex also occur to the north of the Porspoder Lineament. The topography of the area has been briefly described in Chapter 1, and a summary of previous geological work in the NW Pays de Lēon is also included in that chapter. A geological map of this area (except for its eastern margin - see figure 3-4) is presented as figure 3-A (rear end pocket).

The arrangement of the chapter is as follows: the first four sections deal with the main lithological groups recognised in the area in chronological order of their formation or emplacement, while the fifth section is concerned with the structure of the area.

B. DIORITE DE PORTSALL

1. Location and contacts

The Diorite de Portsall has a well-defined ENE-WSW trending outcrop of about 3 km x 1 km to the north of the village of Portsall (Fig 3-2). To the west the diorite is covered by the sea. On the other three sides it is flanked by later intrusive granitic rocks. On the north and south the diorite is intruded by the Granite de Landunvez, which appears to dip beneath the diorite at the southern margin, e.g. at Pointe de Penvir (7.825/53.910) and to overlie it at the northern margin, e.g. at Ile Carne (7.808/53.922) (Fig 3-2). A sheet of Granite de Landunvez also occurs within the outcrop of the diorite on the west side of Grēve de Trēompan (Fig 3-2). The eastern margin of the outcrop of the Diorite de Portsall is formed by the steep N-S crosscutting margin of an extensive body of Adamellite de Ste Marguerite (see section E) on the reefs SE of Carrec

Cros or Fourn Cros at 7.793/53.977 (Fig 3-2).

2. Petrography

In the field the Diorite de Portsall is easily recognisable for its similarity to the Diorite de Lannilis (Chapter 2). There are however certain obvious differences including the abundance of (centimetric to decimetric) leucocratic veins and migmatitic patches (Plate 3-24); these are generally of relatively minor volume compared with that of the country rock (Plate 3-1). Agmatites are however, locally developed (Plate 3-2) as are more severely migmatised portions (Plate 3-3). Other obvious differences are the presence of inclusions of more mafic character (Plate 3-3) and the greater variability in grain size and intensity of foliation and lineation than is seen in the Diorite de Lannilis. Thin section studies also indicate a greater variability in the relative proportions of hornblende and biotite in the Diorite de Portsall.

There is commonly a gently dipping or flat-lying planar fabric due to orientation of biotite, sometimes accompanied by a weak banding (Plate 3-1). There may also be a sub-horizontal lineation due to orientation of hornblendes. In some cases however the rock is essentially massive lacking any obvious fabric.

The rock is coarse-grained but non-megacrystic (Plate 3-4). The colour index varies between 25 and 40, the median value being about 30. Hornblende and biotite are commonly present in approximately equal proportions, but the relative proportion can vary widely from hornblende being in excess of biotite by 2:1, to cases where hornblende is absent, as near the margins at Carrec Cros (7.796/53.977) (Fig 3-2). The habit of the hornblendes is similar to that seen in the Diorite de Lannilis, occuring as coarse crystals up to 2 mm in length and with extremely irregular outline, enclosing rounded blebs of quartz and plagioclase. The biotite is finer than the hornblende, being mostly in the range 0.2-1.0 mm. It is usually brown in colour, but occasionally green, and is often slightly altered to an intergrowth of chlorite and opaque mineral. The bulk of the rock consists of a xenomorphic granular intergrowth of quartz (10-15%) and plagioclase (40-50%). The plagioclase is generally andesine (c.An 35) while the quartz is sometimes fragmented to a fine-grained mosaic (mortar texture). Quartz also occurs as rounded blebs in plagioclase or hornblende, and mortar texture is not seen in this type of quartz. Sphene is a constant accessory and may be coarse and abundant enough in some of the more hornblendic examples to be easily visible in hand specimen, approaching the status of an essential mineral. Apatite, much finer than the sphene, is always present, but opaque minerals are scarce or absent, except as an alteration product of biotite.

The leucocratic quartzofeldspathic veins may be discordant or concordant to the structures within the diorite. They are heterogeneous, some being apparently offshoots of the neighbouring Granite de Landunvez, while others cannot easily be related to any external unit and give a migmatitic character to the diorite. An example of the latter are the leucodiorite veins at Pointe de Penvir (7.824/53.960) (Fig 3-2). These consist of euhedral or subhedral 2-3 mm hornblendes (20-25%) in a coarse matrix of plagioclase (c.An 30) (55%) and quartz, with accesory coarse hematite (Plate 3-23).

3. Correlation

The Diorite de Portsall and the Diorite de Lannilis outcrop on opposite sides of the Porspoder Lineament; their nearest approach is c. 5 km, most of the intervening ground being occupied by the later intrusive Adamellite de Ste Marguerite, or covered by superficial deposits. However the high degree of mineralogical, textural and structural similarity between the two diorites enables one to be fairly confident in following the example of Barrois (1902a,b), and Chauris (1972c) in correlating them. It should however be emphasised that the present geological setting of the two diorites is quite different. The Diorite de Lannilis is flanked by the co-metamorphic metasedimentary schists and gneisses of L'Aber-Wrac'h and L'Aber-Benoît, while the Diorite de Portsall is flanked by post-metamorphic intrusions.

C. MIGMATITES DE PLOUGUERNEAU

1. Introduction

The Migmatites de Plouguerneau occupy most of the coastal outcrop between Guissény and St Michel (7.62;5404) in the eastern sector of the area north of the Porspoder Lineament, and in the central sector occupy most of another large sector to the north and west of Lilia (7.66;54.02). Elsewhere they occur as enclaves of various sizes in the Granite de Landunvez (Figs 3-2, 3-6, 3-A). Three main categories are recognised within the Migmatites de Plouguerneau:

(a) Metasedimentary migmatites and related types

(b) 'orthomigmatites'

(c) Leucogneisses and aplogranites

Representatives of all three categories occur throughout the area; other migmatitic rocks not easily accommodated by the above classification are also common, particularly in the Guissény area (Fig 3-4).

2. Metasedimentary migmatites and related types

(a) Distribution and extent

Migmatites which retain evidence of derivation from metasedimentary material are widespread in the Plouguerneau Complex, although they are subordinate in volume to migmatites whose palaeosome appears to have been derived from pre-existing igneous rocks ('orthomigmatites')*. Towards the eastern extremity of the Plouguerneau Complex it becomes increasingly difficult to differentiate between different types of migmatites in so far as their parent rocks are concerned. Certain of the migmatites out cropping between Grève de Corréjou (7.61/53.03) and Guissény (Fig 3-4) resemble the more easily identifiable metasedimentary types further west (Fig 3-A) in some respects and are therefore grouped with them in this account.

The metasedimentary migmatites occur in the following ways:

(i) As broad bands in which the most abundant type of migmatite is metasedimentary, but intimately associated with large quantities of concordant banded leucogranites which appear to have been

* By analogy with the common use of the term 'orthogneiss' to indicate a metamorphic rock which appears to be derived from the deformation and metamorphism of an igneous rock, the term 'orthomigmatite' is suggested to indicate a migmatite which appears to be derived from the migmatisation of an igneous rock.

emplaced during the migmatisation episode. The most important band of this type outcrops near Mogueran (7.60/54.02) and including the associated leucogneisses is about 1.5 km thick. Other narrower bands of similar character occur further east, e.g. at Enez Croaz-Hent (7.54/54.04) (Fig 3-4).

(ii) As relatively thin (tens of metres) discontinuous bands or lenses concordantly interbanded with 'orthomigmatites'. Examples of this type are common in a belt about 1 km wide and 4 km long extending from Ile Venan (7.66/54.03) to Ile Cézon (7.69/54.00) (Fig 3-A).

(iii) As discrete pods and lenses, intimately associated with aplogranites, occuring as enclaves in the Granite de Landunvez. There are numerous occurences of this type, many of which, e.g. at Ile Carne (7.810/53.972) are a few metres or tens of metres thick and a few tens or hundreds of metres long (Fig 3-2). Similar material can be recognised as enclaves in the Granite de Landunvez at all scales down to the microscopic, e.g. at Pointe de Landunvez (7.877/53.937) (Labelled 'sillimanite gneisses' on Fig 3-2).

(b) Contacts

Three main different types of contact have been recognised:

(i) Contacts with other members of the migmatitic assemblage

The contacts are often ill-defined owing to the fact that the various different types of migmatite generally pass laterally into one another by way of aplogranitic or leucogneissic material indistinguishable from the leucosome within the respective types. In some cases migmatites of different kinds are intimately intermingled, as for example the mafic agmatite which is associated with the Mogueran metasedimentary migmatite band at several points on the coast north of Creac'h an Avel (7.59/54.02) (Fig 3-1, 3-A). A better defined margin is however seen in the case of a metasedimentary screen in the Diorite de Portsall at Kerros (7.812/53.967). In general the contacts between different types of migmatites appear to be concordant with the internal structures, when the latter can be ascertained.

(ii) Contacts with the Granite de Landunvez

The Granite de Landunvez is easily distinguishable from the aplogranitic and leucogneissic material which is an essential component of the migmatitic assemblage, so it is generally possible to make a precise demarcation between the metasedimentary migmatites with their associated aplogranites and adjacent Granite de Landunvez. In general the contacts seem to be approximately concordant with the internal structures in both the migmatites (lithological banding and mica-schistosity) and the granite (preferred orientation of alkali-feldspar megacrysts). The Granite de Landunvez has not been observed to cut discordantly across internal structures in this or any other group of migmatites.

(iii) Contacts with the Adamellite de Ste Marguerite and other late granitic intrusions

The late intrusive granites are typically sharply discordant although locally they are intruded parallel with the internal structures of the migmatites.

(c) Lithological types

(i) Palaeosome

(I) Psammitic and calcareous types

Small (centimetric* or decimetric*) blocks of psammite are widespread although not abundant in the metasedimentary migmatites. They have not however been observed east of Grève du Zorn (7.57/54.02). More rarely thin (centimetric) continuous bands of psammite are seen, as east of Trēmazan at 7.838/53.949 (within the 'sillimanite gneiss' on Fig 3-2). The blocks tend to be isolated and surrounded by aplogranite neosome. Volumetrically the total amount of psammitic material in the complex is insignificant, but its importance lies in the fact that it is clearly

* 'centimetric' : used in the sense 'of the order of 1-10 cm'
'decimetric' : used in the sense 'of the order of 10 cm - 1 m'

identifiable as of sedimentary origin.

The psammites in some cases display a compositional lamination which may be derived from sedimentary bedding. Folded lamination of this type can be observed at Ile Carne (7.810/53.973) and resembles similar structures in the psammitic portions of the Mica-schistes de L'Aber-Wrac'h.

A typical psammite at the fishing harbour of Portsall is rather fine-grained, quartz and feldspar being c. 0.2-0.4 mm. The rock consists of a granulitic intergrowth of quartz (70%) and oligoclase (< 20%) with minor amounts of biotite (10%; defining a weak schistosity, and mostly altered to chlorite and opáque ore), garnet and muscovite (in order of abundance). A less typical example (Plate 3-5) from Trolouc'h (7.608/53.936) (Fig 3-A) is also fine-grained, but appears to be of more calcareous composition. It consists of quartz (45%) plagioclase (An 45-50) 40%, with about 5% each of garnet (pink grains of 0.1-0.3 mm) and irregular or interstitial hornblende. There are accessory quantities of chloritised biotite, sphene (giving rise to pleochroic haloes in hornblende) opaque mineral (associated with hornblende), translucent hematite (associated with the opaque mineral) and muscovite. The rock resembles to some extent the clinopyroxene-garnet psammite described in Chapter 2 from the Mica-schistes de L'Aber-Wrac'h, but is more hydrated, containing amphibole rather than pyroxene, and a somewhat larger content of micas.

A rare example of a block of calc-silicate paleosome has been observed at Creac'h An Avel (7.580/54.028) (Fig 3A). The rock consists of a coarse (1-2 mm) xenomorphic granular association of almost colourless tremolite/actinolite (30%), labradorite (c. An 58; 55%) quartz (12%) and opaques.

(II) Pelitic types

Recognisable pelitic paleosome material is rare in the Migmatites de Plouguerneau, most pelitic rocks having been differentiated into discrete melanosome and leucosome portions. However an example from near Trémazan (7.833/53.949) is relatively undifferentiated, consisting of augen of microcline string-perthite in a matrix consisting predominantly of biotite and fibrolite, with minor quartz and feldspar and rare muscovite. The schistosity, defined by parallel arrangement of biotite and fibrolite, diverges round the augen, within which the perthitic lamination is bent.

In the area of Enez Croaz-Hent (Fig 3-4) more common finely banded biotite-rich gneisses (Plate 3-8) lack sillimanite but in some respects resemble the pelitic types and can possibly be grouped with them.

(ii) Neosome

Most pelitic material appears to have been differentiated into melanosome (or restite) and leucosome (or mobilisate) portions (Plates 3-6, 3-7, 3-9).

(I) Melanosome

The essential component of all melanosomes is biotite, usually in thin bands or laminae, but occasionally massive. The most distinctive pelitic melanosome assemblage is biotite and fibrolite $\pm$ garnet (Plates 3-9, 3-10). All three often occur together for example south of the fishing harbour NW of Lilia at 7.668/54.025 (Fig 3-A) and at Ile Carne (7.810/53.973) (Fig 3-A). More commonly biotite and fibrolite occur without garnet, e.g. at Beg Hamon (7.725/54.002) (Fig 3-1). Minor quantities of quartz, oligoclase and microcline commonly occur within the melanosome bands. A rare but important assemblage undersaturated with respect to silica has been discovered insitu at Ar Penvidiqiou (7.676/54.027) (Fig 3-A) after the occurence of corundum-bearing beach pebbles in the area had been pointed out to the writer by M. Barrière. This occurence is in the form of a pod (c 1.5 m x 1.0 m) consisting of biotite (70%), fibrolite (10%) pale lilac corundum (15%) and microcline perthite (5%) (Plate 3-11). The rock appears to be derived from a highly aluminous sedimentary parent.

(II) Leucosome

The leucosome or mobilisate portion of the pelitic migmatites consists typically of a coarse-grained sometimes sub-pegmatitic intergrowth of microcline-perthite, quartz, oligoclase and chlorite pseudomorphs after biotite (in order of abundance). Quartz and feldspars are commonly in the range 1-3 mm (quartz grains often display mortar texture however). Perthite may exceed 55% of the total, and myrmekitic intergrowths are common.

The leucosomes may merge laterally into more extensive belts of aplogranite and leucogneiss, and are not generally distinguishable petrographically from the latter.

3. 'Orthomigmatites'

(i) Introduction

The majority of the migmatitic rocks in the Migmatites de Plouguerneau have paleosomes whose structure and mineral composition suggest that they may be derived from metamorphosed igneous rocks. They may be schistose or banded, but the banding is generally on rather a fine scale and the palaeosomes as a whole present a homogeneous or even massive aspect. The mineral composition of the paleosomes approximates to that of a mafic, quartz-dioritic or granodioritic rock.

Varying degrees of severity of migmatisation are reflected in variation in the relative proportions and interrelationship of the paleosome and neosome components and in variations in mineral composition of the paleosomes. The latter variation is superimposed on original compositional variation in the parent rocks, thus making it difficult to be certain in many cases what the original composition of the parent was.

Nonetheless it is felt that the migmatites of this type in the Plouguerneau Complex are distinctive enough to warrant introduction of the term 'orthomigmatites'.

(ii) Relations between palaeosome and neosome

Orthomigmatites in the Plouguerneau Complex range from examples with relatively minor development of heterogeneous leucocratic veins seen in much of the Diorite de Portsall (Fig 3-1) (compare Fig 3-13) at one extreme, to examples where dispersed remnants of amphibolitic or granodioritic material occur in a much greater volume of leucogranite as seen at Le Zorn (7.568/54.028) (see also Fig 3-17). These are extreme examples and most commonly the orthomigmatites are in the form of net-vein complexes, (Plate 3-14) and agmatites (Plates 3-15 to 3-17) with anything from 10 to 90% of leucosome penetrating or enveloping the palaesome. In the less migmatised types bands of paleosome, commonly foliated biotite granodiorite, maintain their pre-migmatitic orientation and identity for some tens of metres or as far as they can be followed, although flanked and penetrated by leucogranite (Plate 3-13). Examples of this type can be seen at Ile Venan (7.637/54.035). In the most abundant type of orthomigmatite the paleosome has been penetrated and disrupted to such a degree that it has been split up into numerous discrete blocks, commonly c. 0.5-1.0 m in greatest dimension (Plate 3-16). Each is surrounded by leucosome, which commonly forms 30-70% of the total volume. At this stage the blocks lose their angular and rectilinear form and become rounded. They may also undergo rotation (Plate 3-15), so that the internal foliation in an individual block may be rotated and become discordant with that of its neighbours. The leucosome in this type may be banded (Plate 3-16, 3-18) with some bands displaying higher concentrations of biotite. This leucosome banding tends to follow the margins of neighbouring blocks rather than remain parallel to the margins of the particular belt of agmatite itself, suggesting mobile behaviour of the leucosome.

Agmatites of these types are both widespread and abundant; they can be observed, for instance, at Porz Grae (7.649/54.038) (Plate 3-26) and at Penn Enez (7.604/54.034)(Fig 3-A).

The shape of individual blocks in the agmatites is also variable, being approximately equidimensional in some cases, (Plate 3-15), while in other cases the agmatite may consist of oblate slabs (Plate 3-17), which display a preferred orientation parallel to the margins of the agmatite belt. The observation of folded foliation within some oblate blocks of this type at St Michel (7.616/54.038) may indicate that the oblate form may be due to a deformational flattening pene-contemporaneous with the migmatisation.

More severe migmatisation with progressive anatexis of palaeosome blocks appears to have taken place in some localities (Plates 3-17, 3-18, 3-19).

(iii) Composition of orthomigmatite palaeosomes

It may be assumed that the present mineral and chemical composition of the orthomigmatite palaeosome has undergone metamorphic and possibly metasomatic alteration during the migmatisation; none the less it remains possible to use the present mineral composition to propose a classification of the palaeosomes which is related to their supposed pre-migmatitic character.

(I) Mafic types

These are relatively uncommon and sometimes consist merely of isolated pods associated with other types of migmatites or occasionally as rare enclaves in the Granite de Landunvez (e.g. east of Pointe Scoune, north of Portsall, 7.815/53.968) (Fig 3-A), where a fine-grained mafic pod with a biotite content > 45% can be observed. Groups of mafic pods are found closely associated with the metasedimentary migmatites, as at Ile Carne (7.809/53.973) or with migmatites whose palaeosome is of intermediate composition as at Enez Terc'h (7.679/54.011) (Figs 3-1, 3-A). Mafic lenses in leucogranitic occur at Creac'h an Avel (7.593/54.025) (Plate 3-12). Internally the mafic portions vary from massive to schistose. They are usually finer-grained than the intermediate palaeosome agmatites, most grains being <0.5 mm, although poikiloblasts or aggregates of hornblende may be in the range 0.5 - 2.0 mm. Hornblende (25-55%) is generally the most abundant mafic mineral, in excess of or to be exclusion of biotite or chlorite (0-30%). Plagioclase (An 40-60) is the only feldspar, while quartz is invariably present both as fine rounded blebs in hornblende and plagioclase, and as coarse but partially mortarised interstitial grains. Chlorite is often present as an alteration product of biotite, completely pseudomorphing it in an example from Creac'h An Avel (7.593/54.025). Replacement of hornblende by chlorite has only occurred to a limited extent. Apatite and opaques have been observed in all examples examined, but sphene and zircon are not prominent. No trace of pyroxene, garnet or epidote has been found.

(II) Ultramafic types

Lenticular masses some tens of cm long essentially composed of hornblende have been reported by Chauris (1966c) as enclaves in 'migmatites granitiques' (probably = Granite de Landunvez) at Ile Trevors or Trevoc'h (7.75/5.398) (Fig 3-1). Pods of this type are, however, rare in the Migmatites de Plouguerneau.

(III) Orthomigmatite palaeosomes of intermediate composition.

(a) Coarse grained types

The most abundant type of orthomigmatite consists of an agmatite with coarse-grained blocks approximating to quartz-diorite or granodiorite in composition. In thin section the palaeosome blocks may appear massive or with a foliation of variable intensity.. The foliation consists of a fine interbanding of portions with varying contents of biotite. The biotites display preferred orientation producing a noticeable schistosity. The essential mineral constituents are plagioclase (55-60%) (An 30-40), biotite (20-35%) and quartz (10-20%)

(Plate 3-20). Hornblende has not been observed in this type. Plagioclase may be fresh or sericitised; biotite, with prominent pleochroic haloes, is locally chloritised, while quartz is locally mortarised. Alkali feldspar and muscovite are rare. The most prominent and constant accessory is apatite, and zircon is usually observed. Sphene and opaques have only been observed in a minority of samples and in small amounts.

Agmatites of this type are particularly abundant and well-displayed in a broad belt extending NNE from Petites Iles Wrac'h (7.68/54.015) (Fig 3-1).

(b) Fine grained types

Qualitative assessment indicates that there is a bimodal distribution of grain size in the intermediate palaeosomes The fine-grained types are of similar mineral composition to that of the coarse-grained types. The agmatitic blocks are smaller, mostly < 50 cm in length, and the grain size is generally < 0.7 mm. The blocks superficially appear darker than those of the coarse-grained types, but the modal colour index is only slightly greater (25-30) in the examples seen.

Quartz and plagioclase are in similar proportions to those seen in the coarse-grained types. Apatite and opaques are always present, but sphene has not been observed. An example of this type occurs at Penn Enez (7.604/54.034)(Fig 3-1, 3-A) and are abundant round Enez Croaz-Hent (7.53/54.04) (Fig 3-4) where some examples may be transitional to the mafic types described in the previous section.

(IV) Other migmatised granodiorites

This is a rather ill-defined group, and it is not always clear that the palaeosome in this type has a similar pre-migmatitic metamorphic history to that which appears to have affected the palaeosomes of the majority of the orthomigmatites. They are also distinguished, in the examples seen, from the other groups by the presence of minor or essential alkali-feldspar, in addition to the predominant plagioclase (An 28-35) (35-45%) biotite (15-30%) and quartz (15-25%). Examples occur at the south end of Ile Tariec (7.730/53.998), where agmatites of this type are found, and west of Le Vougo at 7.562/54.030 (Fig 3-4). It is possible that the deformed and slightly migmatised granodiorite which has an extensive outcrop (mainly inland) round Kersaint-en-Landunvez (7.83/53.94) belongs in this category, although it has been marked as Adamellite de Ste Marguerite on Fig 3A.

(iv) Leucosomes of the orthomigmatites

It has not in general proved practicable to classify the orthomigmatite leucosomes in relation to the corresponding palaeosomes described in the last sub-section, and so they are considered together here*.

They are of characteristically coarse and variable grain size, and although macroscopically banded any foliation is usually on too coarse a scale to be visible in thin section. Preferred orientation of biotite may sometimes be observed. Textures are generally xenomorphic granular. A typical example is shown in Plate 3-21.

The colour index is in the range 5-15, generally < 10. The chief coloured mineral is biotite, often pseudomorphed by a chlorite/opaque intergrowth, the chlorite showing inky-blue interference colours. A few percent of red garnet is a frequent component, and may be very coarse (up to 2 cm at Castel Ac'h, 7.667/54.028). The most abundant mineral in every example that has been examined

* Some leucocratic veins in the Diorite de Portsall (Plate 3-23), as indicated above (Section A.2 of this chapter) appear to have a mineral composition similar to the composition of the host rock, and can be regarded as of migmatitic character.

is string perthite, (35-65%) generally showing microcline twinning. Quartz (often mortarised) is in the range 10-30%. Sodic oligoclase is often present in amounts up to 25%. Myrmekite is a common feature. (Part of the variability in the modal contents is probably only apparent, being a result of the coarseness of grain size).

Accessory minerals include muscovite in most examples. Apatite, sphene and zircon have also been observed, the latter two mainly as inclusions in biotite.

4. Unclassified migmatites and other lithologies associated with the Migmatites de Plouguerneau

A minority of lithologies whose outcrops are associated with the Migmatites de Plouguerneau cannot be easily incorporated into the above classification.

(a) Mēlange of Enez-Croaz-Hent

In the northern part of the former island (now linked to the mainland by an artificial wall) of Enez Croaz-Hent near Le Curnic (7.53/53.04 (Fig 3-4) a belt several hundred metres wide consists of a mixture of migmatites of the following three types:

(i) Agmatites with coarse granodioritic palaeosomes
(ii) Agmatites with darker, fine-grained quartz-dioritic palaeosomes
(iii) Migmatites of possibly metasedimentary type, but lacking sillimanite and garnet in the melanosomes.

(b) Migmatites of Grève de Lilia

Particularly well developed in pinnacles (eg at 7.672/54.032) rising out at the intertidal sands north of the Lilia fishing harbour are coarsely and irregularly banded migmatites and gneisses (Fig 3-A) which although apparently the product of the same migmatitic episode as the neighbouring agmatites of Enez-ar Vir (7.666/54.030) (Fig 3-1) lack distinctive palaeosomes and cannot easily be classified with them.

5. Aplogranites and leucogneisses in the Migmatites de Plouguerneau

Intimately associated with the Migmatites de Plouguerneau are outcrops of leucocratic granitic composition which are commonly extensive enough to have been mapped at the 1:25,000 scale. In the eastern part of the area, notably between Corrējou and Grève de Zorn and near Le Curnic coarsely banded or gneissic varieties are more common, while further west the granites are typically massive.

(i) Massive aplogranite type

Constantly associated with the metasedimentary migmatites in the area between Ile Venan (7.66/54.03) and Pointe de Landunvez (7.868/53.941), (see Fig 3-A) also occuring as separate enclaves within the Granite de Landunvez as at Trelam (7.735/54.005) (north of Ile Tariec; Fig 3-A) are bands or masses of aplitic granite a few metres or tens of metres in thickness. They are generally massive, unbanded, and coarse-grained (1-3 mm). The colour index is low (0.5-5). In many examples garnet is the chief mafic mineral, with minor chloritised biotite. Garnet may occur to the exclusion of biotite, as at 7.806/53.968 (marshland opposite Ile Carne Fig 3-2) or biotite to the exclusion of garnet. The biotite may be either thinly distributed in flakes throughout the rock, or concentrated in schlieren. (Both can be seen at the Blockhaus of Greve de Trēompan (7.801/53.968) (Fig 3-2). Muscovite is rarely seen, and aggregates of sillimanite rods have been observed in a sample from east of Trēmazan at 7.837/53.950 (Fig 3-2). The most abundant mineral is always string perthite (40-60%) which may display microcline twinning, followed by quartz (20-35%) which occurs both as coarse xenomorphic grains, or as fine blebs in feldspars, and oligoclase (15-25%). Myrmekite is commonly present. Apatite is occasionally observed as an accessory and biotites commonly contain pleochroic haloes probably caused by sphene or zircon.

The close petrographic similarity between these more extensive bodies of aplogranite and the leucosomes of both the metasedimentary and orthomigmatitic types of migmatites is emphasised. The aplogranites appear to represent more homogeneous and extensive developments of the material which forms the leucosomes.

(ii) 'Pseudogarnet' aplogranites and leucogneisses

A distinctive lithology in the area between Penn Enez (7.606/54.0?5) and Guissény (Fig 3-A) consists of bands of aplogranite a few metres or tens of metres in thickness of massive or faintly banded aplogranites interbanded with migmatites of predominantly metasedimentary type (Plate 3-22) These aplogranites are characterised by the presence of equidimensional aggregates 1-2 cm in diameter, composed of biotite and/or chlorite. It is thought that the aggregates may be pseudomorphous after garnets, and that these aplogranites are thus equivalent to the garnetiferous aplogranites found further west.

(iii) Leucogranites of Grève du Zorn

The leucogranite found just east of le Zorn (Fig 3-4) is unlike other leucogranites in the Migmatites de Plouguerneau, being noticeably more homogeneous and granitoid than many of the aplogranites and leucogneisses. It is a weakly foliated medium to coarse-grained homogeneous biotite granite with about 5% biotite (chloritised) 50-60% perthite, 25 - 30% quartz and some oligoclase.

(iv) Gneiss rubanés de Dibennou

Leucocratic gneisses with a prominent even continuous banding are common in the area of Le Curnic, notably in the promontories of Dibennou (7.523/54.046) and Beg ar Skeiz (7.528/54.047) where they are concordantly interbanded with the sillimanite-free pelitic type of metasedimentary migmatites (Fig 3-4). These banded gneisses may have been produced during the main migmatitic episode. The origin of the banding is uncertain.

(v) Gneiss de L'Ile d'Ioc'h

In the western part of Ile de'loch north of Porspoder, (Fig 3-A) a group of granitic gneisses appear to occur as large enclaves in the Granite de Landunvez. It has not been established whether these gneisses belong to the migmatites de Plouguerneau, or represent some pre-Granite de Landunvez granitic orthogneiss, comparable with the Gneiss de Tréglonou.

6. Origin of the Migmatites de Plouguerneau

The rock material now observable in the Migmatites de Plouguerneau can be conveniently divided into two categories:

(a) Material which retains or directly reflects characteristics of the pre-migmatitic rocks; this includes material described above as 'palaeosome' and 'melanosome'.

(b) Material which was newly created or introduced during the migmatization; this includes material described above as 'leucosome' and also the aplogranites and leucogneisses.

(a) Indications of pre-migmatitic nature

The evidence of the palaeosome and melanosomes of the 'metasedimentary' migmatites suggests that the latter were derived from a series of metasedimentary rocks which included a large proportion of aluminous or pelitic material, together with plentiful psammites and rather rarer impure calcareous rocks. The pelitic and psammitic types were probably intimately associated.

The distribution of the various types of 'orthomigmatitic' palaeosomes, including the Diorite de Portsall, suggests that the precursors of the 'metasedimentary' migmatites were brought into association with a number of different lithological types of probably igneous origin at some time prior to the migmatization. Among these supposedly metaigneous rocks a greater proportion consisted of broadly intermediate composition, such as diorites, quartz diorites and granodiorites, than of more mafic types, but both intermediate and mafic types were widespread. The severe metamorphic and possibly metasomatic changes which have accompanied the migmatisation may have obscured the original composition so as to render it uncertain; but the relatively unaltered condition of the Diorite de Portsall enables one to be fairly confident in correlating it with the Diorite de Lannilis in the Complexe Métamorphique de Lannilis; and it is possible that much of the abundant and widespread rock of tonalitic composition occuring as palaeosome in the orthomigmatites is also derived from parent material similar to the Diorite de Lannilis. However the mafic mineral content in the orthomigmatite palaeosomes is commonly rather lower (20-35%) than that in either the Diorite de Portsall (25-40%) or the Diorite de Lannilis (25-35%) so that either there were original differences in composition, or there has been significant metasomatic alteration of the orthomigmatite palaeosomes. It is also possible that other plagioclase-rich igneous lithologies, not now represented in the Complexe Metamorphique de Lannilis, may have been the precursors of some of the 'intermediate' orthomigmatite palaeosomes.

The mafic palaeosomes in the Migmatites de Plouguerneau have fairly close counterparts in the sporadic minor occurences of mafic rocks in the Lannilis Complex, such as the Amphibolites de L'Aber-Benoît. It is also possible that some of the mafic palaeosomes have undergone metasomatic alteration, particularly where they contain biotite rather than hornblende. No undoubted counterparts of the alkali-granitic Gneiss de Trẽglonou have been found in the Migmatites de Plouguerneau, although, as indicated in Chapter 2, there are minor outcrops of this type just to the north of the 'Porspoder'Lineament, and possibly pre-migmatitic gneisses occur elsewhere; e.g. at Ile d'Ioch (Fig 3-A). It is possible that alkali-granitic gneisses of the Trẽglonou type were not represented in the area now occupied by the Migmatites de Plouguerneau; another, perhaps more likely possibility is that material of such composition could have been present but would have been liable to undergo more extensive or even complete melting at temperatures at which the other lithologies were only undergoing partial melting, or resisted melting altogether. In support of this suggestion it may be noted that the Gneiss de Treglonou is both fairly homogeneous and of a mineral composition and chemical composition unlikely to be far removed from that of the cotectic minimum for granite (Major element analyses of samples of Gneiss de Trẽglonou are given by Chauris (1972c, p.28, analysis 17, and 1966b)). In general the associationof metasedimentary and orthomigmatitic lithologies in the Migmatites de Plouguerneau displays remarkable similarities to the association of metamorphic lithologies in the Complexe Métamorphique de Lannilis, and the writer concurs with Chauris (1966c, 1972c) in equating the two groups in a general way.

The question arises of the relationship between the episode of migmatisation observed in the Migmatites de Plouguerneau and the climactic metamorphic episode (M2) seen in the Lannilis Metamorphic Complex (Chapter 2).

In this connection it may be noted that Cogne and Shelley (1966) assigned the (Lannilis) metamorphism (called here M2) to a much earlier episode (Cadomian in their view) than the migmatisation in the (Plouguerneau) migmatites, which they considered to have been a Variscan (Hercynian) episode.

However in the view of the present writer there does not seem to be any evidence to support the hypothesis of such a long interval between the two episodes; it seems more straightforward to regard the Plouguerneau migmatisation as merely the result of higher grade conditions in the same tectono-metamorphic episode that gave rise to the M2 metamorphism and structures in the Lannilis rocks.

It is nonetheless likely that both the onset of high-grade conditions and the subsequent cooling were prolonged and diachronous, so that it is not justifiable to conclude that the M2 metamorphic and migmatitic phenomena were exactly contemporaneous throughout the area.

(b) New material produced during the migmatisation

(i) Leucosome-palaeosome relationships

The field relationships between the palaeosome and melanosome components on the one hand and the leucosomes, aplogranites and leucogneisses on the other suggest that the latter were invariably the more mobile. The leucocratic material is discordant to internal structures within the palaeosomes such as fine lithological banding and schistosity, while structures such as banding within the leucocratic material are approximately concordant with the margins of the leucocratic band itself.

The composition of the various leucocratic portions is more homogeneous than that of the palaeosomes, and rarely seems to be directly controlled by the composition of the immediately adjacent palaeosome; so that the leucosome of the mafic orthomigmatites is generally no more mafic than that of the intermediate palaeosome migmatites, and each of these may be as rich in alkali-feldspar as the metasedimentary migmatite leucosomes or the aplogranites. There is however some evidence that the orthomigmatite leucosomes are locally enriched in biotite or plagioclase which may be derived from the neighbouring palaeosome, and the rounded character with occasional biotite-rich selvedges, of the palaeosome blocks suggests that they have lost some material to their surroundings (see Plates 3-16 to 3-19 for evidence of metasomatism of this type).

(ii) Origin of the leucocratic portions

There is noticeable variation in character of the leucocratic material; banded and unbanded types both occur, and the variable content of garnet and biotite suggests variation in H_2O and probably Fe and Mg content. Nonetheless the leucocratic portions vary much less than the neighbouring palaeosomes, indicating that there was a significant degree of homogenisation of the leucocratic material which must have taken place prior to its consolidation. Whatever its origin, it appears to have been mobile over distances of the order of at least some tens of metres, and cannot be strictly regarded as having formed 'in situ'. It was able to move freely enough to disrupt and penetrate the orthomigmatite palaeosomes, and must therefore have been of fairly low viscosity and presumably in the form of a melt, or perhaps a mixture of molten and solid material.

As to the source of the material which went to produce the melt, one need look no further than the widespread relics of pelitic (sillimanite and biotite-bearing) melanosome in the metasedimentary migmatites for an indication of the loss from the inferred pre-existing metasediments of large amounts of quartzofeldspathic material; this loss may be explained by partial melting and resultant mobilisation of the quartzofeldspathic material. Another possible source for the aplogranitic material as suggested in the last sub-section, is the complete melting of material originally resembling the alkali-granitic Gneiss de Tréglonou.

It may be noted at this point that Cogné and Shelley (1966) considered that the migmatites (including the 'Granite de Landunvez' in the present writer's classification) in the Plouguerneau area were the result of in situ metasomatic transformation of material originally similar to the mica-schists of L'Aber-Wrac'h.

They do not appear to have regarded the granitic portions of the migmatites (or the Granite de Landunvez) as having been either molten or mobile.

In the present writer's view the work of Tuttle and Bowen (1958) and Winkler (1967) has shown that common metamorphic rocks subjected to the temperatures only a little higher than those which may be expected in high-grade metamorphism are likely to undergo anatexis, the resulting melt giving rise upon consolidation to migmatites such as those seen in the Plouguerneau area.

There clearly remains considerable scope for study of the chemical and physical properties of the leucocratic portions of the Migmatites de Plouguerneau; it is felt that such a study might throw considerable light on the origin of migmatites and granites both in the Pays de Léon and elsewhere.

D. GRANITE DE LANDUNVEZ

1. Location and distribution

In the area to the north of the Porspoder Lineament a greater proportion of the terrain is occupied by the outcrop of what is here described as the Granite de Landunvez than by that of any other lithological group. In the western part of the area, between Porspoder (7.89/53.90) and the harbour of Portsall (7.81/53.95) at least 80% of the area is occupied by the Granite de Landunvez; while in the central sector between Portsall and the chapel of St Michel (7.623/54.038) about 30% consists of Granite de Landunvez (Fig 3-A). Further east the Granite is absent or subsidiary.

The Granite de Landunvez has not been recognised south of the Porspoder Lineament. Comparable granites ('Granite de Porsguen') have however been recognised on the island of Ouessant (Chauris, 1966a) and observations by the present writer). The submarine geological survey by Andreieff et al (1973) has indicated that the association of lithologies represented on land north of the Porspoder Lineament extends for about 10 km north of the coast until the Cretaceous and Palaeogene sedimentary cover is reached; it is likely that a significant part of this submerged zone is occupied by granite similar to the Granite de Landunvez.

In the area covered by the present survey the Granite de Landunvez occurs in the form of broad (up to 2.5 km wide) belts approximately concordant with the strike of the Diorite de Portsall and the Migmatites de Plouguerneau. In the area between Presqu'île Ste Marguerite and St Michel (Fig 3-A) the belts are rather narrower (hundreds of metres) than further west, and west of Lilia quite narrow bodies (tens of metres thick) occur in the Migmatites de Plouguerneau. The belts of Granite de Landunvez are approximately parallel to the WSW trending coastline in the western part of the area, but swing to a nearly northerly strike and pass directly out to sea in the neighbourhood of St Michel.

The outcrops of Granite de Landunvez are interrupted in many places by sizable later intrusions such as the Adamellite de Ste Marguerite and other granites.

2. Contacts

(a) Contacts with the Migmatites de Plouguerneau and the Diorite de Portsall

These contacts are typically sharp and well-defined. Cross-cutting relationships are however rarely observed (e.g. at (7.810/53.968)(Fig 3-2) where the Diorite de Portsall appears to be agmatised by the Granite).

Elsewhere contacts with both the Migmatites and the Diorite are apparently concordant, i.e. parallel to the chief internal structures on either side of the contact (Plates

3-24, 3-25, 3-27). Pods or sheets of Migmatites de Plouguerneau occur as elongate enclaves or bands within the Granite de Landunvez (e.g. at Ile Carne (7.810/53.973) and at Ile Stagadon (7.70/54.02)), but the reverse relationship has not been observed. These contacts are also sharp and well-defined within a few cm. The contacts between Granite de Landunvez and Migmatites de Plouguerneau are thus quite different in character from the contacts between the various types of migmatites within the Migmatites de Plouguerneau, which are relatively ill-defined. These observations suggest that the essential character of and relations between the various migmatites were established prior to and independently of the formation of the Granite de Landunvez; the latter is thus probably allochthonous with respect to the migmatites.

(b) Contacts with the Adamellite de Ste Marguerite and related granites

Both major (e.g. east of Carrec Cros at 7.793/53.978 (Fig 3-5) and minor (e.g. at Pointe Scoune (7.830/53.966) (Fig 3-2)) bodies of Ste Marguerite type are sharply discordant to the internal structures (e.g. preferred orientation of feldspar megacrysts in the Granite de Landunvez (see also Plates 3-34 to 3-37). The Ste Marguerite granites can therefore be regarded as having been intruded into the Granite de Landunvez after the consolidation of the latter.

The structural significance of relations between the Granite de Landunvez and the Adamellite de Ste Marguerite will be considered in section F below.

(c) Contact with the Granite de L'Aber-Ildut

On account of the poverty of exposure inland, a visible contact between the Granite de Landunvez and the Granite de L'Aber-Ildut has only been closely approached at one coastal locality near Porspoder (7.986/53.903) (Fig 3-A, 4-3). Even here a narrow (15 m) screen of later aphyric granite separates the pink-feldspar megacrystic Granite de L'Aber-Ildut and the white-feldspar Granite de Landunvez, and all three granites have been deformed to some extent by an intense fracturing associated with the D4 (see below) movements along the Porspoder Lineament. However as far as the available evidence can indicate, the internal feldspar orientation in both the Granite de L'Aber-Ildut and the Granite de Landunvez appears to have been originally parallel to the contact. Chauris (1966b) has observed that the feldspar megacrysts in the Granite de L'Aber-Ildut become finer and tend to lose their pink coloration as the contact is approached. It may also be observed that within the Granite de Landunvez at this locality there occur a number of xenoliths similar to those characteristic of the Granite de L'Aber-Ildut (Chauris 1966b, p.18); although xenoliths of this type have not been observed elsewhere in the Granite de Landunvez.

It may also be recalled (Chapter 2, section D) that the marginal facies of the Granite de L'Aber-Ildut, as seen on the eastern margin at Plouguin (Figs 2-1, 1-7) is a white-feldspar megacrystic granite with xenoliths similar in type to those in the main (pink) facies of the Granite de L'Aber-Ildut, and itself resembles the Granite de Landunvez as seen adjacent to the contact at Porspoder. These observations lead one to consider the possibility that there may be a genetic connection between the Granite de L'Aber-Ildut and the Granite de Landunvez. This possibility is of considerable interest in that the date of emplacement of the Granite de L'Aber-Ildut is considered to be known within fairly close limits (see chapter 5) and such a connection offers the possibility of correlating the histories of the areas on either side of the Porspoder Lineament more closely. On the other hand the outcrop patterns of the two granites are quite different; which suggests that their origin may be different.

3. Petrography

Three main facies of the Granite de Landunvez have been recognised, namely the Trēmazan, Scoune and Valcon Bras facies. Each of the three facies has characteristic features and geographic distribution, but distinctions between the three cannot always be maintained and a fourth (Roc'h Pelleguent) facies intermediate in character between two of the others is recognised in the eastern part of the outcrop.

All three facies have a number of features in common. The rock is typically a coarse megacrystic two-feldspar biotite granite; with white perthite megacrysts generally in excess of oligoclase in the ground mass. The megacrysts generally display a planar and/or linear preferred orientation. Nebulitic and leucopegmatitic patches and bands up to a few decimetres across are common, as are biotite -rich schlieren (Plate 3-29). Myrmekite is observable in most examples.

(a) Trēmazan facies

This facies (Plate 3-29) which is the most extensive, is a continuous belt extending from Porspoder (7.89/53.90) to Tevenn Penn ar Pont (7.78/53.96) (Fig 3-1) and also in the area to north and west of the Presqu'Ile Ste Marguerite. It is characterised by an abundance of nebulitic patches, and by commonly rather anhedral or subhedral megacrysts smaller (1-2 cm) than those typical of the Scoune facies, and by the typical presence of pink garnets distributed throughout the rock at concentrations up to 2%, but usually much less. Schlieren of biotite and sillimanite may be observed at some localities. The colour index is about 10, biotite (showing minor chloritisation) and garnet being the only mafic minerals. The garnets are often coarse (2-5 mm) but anhedral or fragmentary. Muscovite is sometimes present. Perthite, sometimes showing microcline twinning, is the most abundant mineral (35-55%) in excess of oligoclase (20-3%) and quartz (20-35%). The plagioclase may show normal zoning and the quartz is either strained or mortarised. Mortar texture is characteristic in the vicinity of the Porspoder Lineament. As mentioned earlier (also in Chapter 2, section D.3.(b).(i)(2)), dark xenoliths similar to those in the Granite de L'Aber-Ildut occur in the Granite de Landunvez (Trēmazan facies) at Porspoder.

Varieties noticeably richer in biotite (15-20%) and with a higher oligoclase: perthite ratio, have been noted at Kerlaguen (7.875/53.927) (Fig 3-1; west of Pointe de Landunvez).

(b) Scoune facies

This facies (Plate 3-30) is distinguished from the Trēmazan facies by the size (2-4 cm) and more euhedral habit of the perthite megacrysts and by the general absence of garnets.

There may also be a somewhat scarcer distribution of nebulitic patches and schlieren.

It outcrops along the northwest margin of the area; in the Portsall area it outcrops to the north of the Diorite de Portsall (Fig 3-2, 3-A) and is also found further east, e.g. on the islands of Guenioc (7.744/54.00) and Ile Vierge (7.67/54.04) (Fig 3-A).

(c) Valcon Bras facies

This facies (Plate 3-31) is of minor and local extent mostly in the vicinity of Grève de Lilia (Fig 3-A) including much of the intertidal reef round Valcon Bras (7.682/54.028) (named on 1:20,000 chart only) (Fig 3-1). The rock is massive, nebulitic inhomogeneities being rare. It is characterised by the abundance (up to 5%) of coarse (up to 1 cm) garnets and of biotite (15-20%) and by an excess of plagioclase (oligoclase) over perthite. Accessory muscovite may be present. The garnets (Plate 3-32, 3-33) contain inclusions of oligoclase and biotite, and display closely spaced parallel quartz-filled fractures (Plate 3-33).

In other respects the Valcon Bras facies resembles the Trēmazan facies.

(d) Roc'h Pelleguent facies

Granites of variable character but generally intermediate between that of the Scoune and Trēmazan facies are present in a broad zone extending south and south-west from Roc'h Pelleguent (7.63/54.04) to Ile Garo (7.72/53.98)(Fig 3-A) The perthite megacrysts (Plate 3-28) are generally better crystallised than in the Trēmazan facies while garnet is locally observed. A sample adjacent to the contact with agmatites of the Migmatites de Plouguerneau at Porz Grae (7.648/54.038)(Plates 3-26 to 3-28) contains abundant oriented perthite phenocrysts with quartz in excess of oligoclase and about 12% biotite.

(e) Other granites resembling the Granite de Landunvez

Outcrops of limited extent of granite similar in some respects to the Granite de Landunvez are interbanded with the Migmatites de Plouguerneau near Enez Du (7.54/53.04) (Fig 3-4). Some of these granites are only weakly megacrystic. Their stratigraphic status is uncertain.

(f) Gneiss de Roc'h Avel

A distinctive granitic gneiss (used by Chauris, 1966b, as an example of 'granite porphyroïde' but in the present writer's view distinct from the Granite de Landunvez), forms the stack of Roc'h Avel (Landéda) (7.723/53.925)(Fig 3-A). It combines the granitic character of the Scoune facies with the presence of thin biotite-rich foliae resembling in some respects those of the Gneiss de Tréglonou.

4. Possible structural controls on the distribution of the various facies of the Granite de Landunvez.

It has been observed above (section (b)) that in the Portsall area the Trémazan facies outcrops to the south of the Diorite de Portsall while the Scoune facies outcrops to the north of this diorite. Locally, for example at Ile Carne, the Scoune facies clearly structurally overlies the Diorite de Portsall; equally clearly at Pointe de Penvir the Trémazan facies structurally underlies the diorite. Elsewhere the contact is not so clearly exposed and the structural relations between the diorite and the two granite facies are uncertain. However as far as the evidence from the above exposures goes, it appears that the diorite forms a boundary between the overlying Scoune facies and the underlying Trémazan facies. It is tempting to infer that the development of the two different facies may have been controlled in some way by the presence of the intervening diorite. It is however difficult to envisage the mechanism which may have given rise to such a control.

The richly garnetiferous Valcon Bras facies is closely associated with particularly thick belts of coarse intermediate-palaeosome agmatites (north-west of Lilia on Fig 3-A). To the north west both the Migmatites de Plouguerneau and the Granite de Landunvez dip predominantly to the NNW, while to the southeast the predominant dip is to the southeast ot SSE. This distribution suggests the presence of a major antiformal structure (of D3 age? see section G.4.(b) below) with a NE-SW trending axis in the vicinity of Ben Enet (see Fig 3-B); approximately coinciding with the most abundant outcrops of the Valcon Bras facies. The inference that the latter facies is now found in the core of a ? late antiform may indicate that development of the facies was favoured by crystallisation at a deeper structural level than that represented by either the Trēmazan or the Scoune facies. This suggestion is however rather hypothetical.

5. Origin of the Granite de Landunvez

The relatively homogeneous granitic character of the Granite de Landunvez suggests that its constituents were in a highly mobile condition prior to its emplacement and consolidation. Such mobility is most likely to have been achieved if the material now forming the granite was at least partially molten. This view contrasts radically with the conclusion of Cogné and Shelley (1966) that the Granite de Landunvez ('migmatites' in their nomenclature) was the product of in situ (solid) granitisation of pelitic metasediments. The material now forming the Granite de Landunvez may indeed have been ultimately derived from the destruction by melting of pelitic gneisses or other metamorphic rocks; but it is likely that the latter were situated at a lower structural level than that at which the granite subsequently crystallised.

The contacts between the Granite de Landunvez and the Migmatites de Plouguerneau have been described above. It has been pointed out that the nature of the contacts indicates that the essential character of and relations between the various migmatites were achieved before the emplacement of the Granite de Landunvez. The observation that the Granite de Landunvez has undergone little penetrative deformation subsequent to its emplacement (except in the vicinity of the Porspoder Lineament) suggests that the present relationship between the granite and the migmatites is much as it was immediately following the emplacement of the granite. The concordant nature of the contacts suggests that at the time of the consolidation of the granite the ductility contrast between the granite and the migmatites was rather low; in other words, if the Granite de Landunvez was emplaced as a melt, even a highly viscous melt, the Migmatites de Plouguerneau at the time must have been of rather low rigidity. One possible explanation for this state of affairs is that the Migmatites de Plouguerneau had not completely cooled after the migmatization, and that the climax of the migmatitic episode may not have been long past. With this interpretation the Granite de Landunvez is seen as derived from the melting (or partial melting) presumably at much greater depth than is now exposed, of pre-existing easily-melted crustal material such as aluminous metasediments or alkali-granitic gneisses; and the resulting melt was sufficiently mobile and unstable to collect and rise to the level at which the Migmatites de Plouguerneau had formed. At this approximate level the granite consolidated, its resultant petrographic character being possibly controlled or influenced by the structural position within the migmatite complex that the ascending mobile material had reached; so that facies of the Granite de Landunvez with varying degrees of enrichment in garnet (or loss of garnet; if the garnets are, as suggested by De Lapparent (1934), xenocrystic), and varying euhedralness of feldspar megacrysts consolidated in different structural environments.

Further work is required in order to suggest possible mechanisms for the control of granite facies in this manner.

E. ADAMELLITE DE STE MARGUERITE AND OTHER LATE GRANITIC INTRUSIONS

More than 20% of the area north of the Porspoder Lineament is occupied by a variety of granitic rocks which have one feature in common which distinguishes them from other lithological groups in the area: their margins sharply and discordantly truncate the internal structures in the formations with which they are in contact (Fig 3-B, 3-6, etc). For the purposes of the present description the area north of the Porspoder Lineament will be considered in three sectors.

1. Western and central sector

This sector extends from Presqu'Ile St Laurent (7.90/53.90) (Fig 3-B) near Porspoder in the west to Ile Venan (7.65/54.03) (Fig 3-B) north of the village of Lilia. This amounts to about two thirds of the total area north of the lineament. Two main late granitic lithologies outcrop in this area, namely, the Adamellite de Ste Marguerite and the Granite de Kern an Guen (Fig 3-B).

(a) Adamellite de Ste Marguerite

(i) Distribution

This lithology occurs in the form of a number of discrete outcrops which are fairly regularly distributed through the sector. They may be divided into two groups on the basis of their areal extent.

(1) A small number of more or less separated larger outcrops which range from 0.5 to 3.0 km in greatest dimension and from 0.5 to 2.0 km in width. The orientation of the greatest dimension does not accord very closely with the trend of structures in the host rock except in the case of the mass which trends NE-SW just west of the village of Lilia. Where the degree of exposure permits one to make adequate observations, as for instance on the reef east of Carrec Cros (7.793/53.977)(Fig 3-5) the margins of these larger bodies are steep, of rectilinear outcrop and apparently planar in form.

(2) Numerous smaller bodies and dykes (e.g. Plate 3-35) which may range from a few tens of centimetres to tens of metres in thickness. These are fairly evenly distrubuted throughout the western and central sector, and do not appear to be concentrated near the larger bodies. The primary trend of the dykes is variable, although groups of dykes with parallel trend can be found in some localities; for example near Pointe Scoune (7.82/53.91) a number of dykes of Adamellite de Ste Marguerite type trend WNW-ESE. It has been observed that the trend of the dykes more commonly oblique to the structures in the host rock than either at right angles or parallel to them. Towards the western end of the sector at Presquile St Laurent (just northwest of Porspoder) the dykes of Ste Marguerite type have been caught up (together with the host rock Granite de Landunvez) in the deformation associated with the Porspoder Lineament and rotated into sub-parallelism with the trend of the lineament itself, ENE-WSW (Fig 4-3).

(ii) Contacts

It has already been pointed out that the margins of the Adamellite de Ste Marguerite are typically discordant to the internal structures in the country rock (Plates 3-36; 3-37). The contacts are often steep. Fine-grained ('chilled') margins have not been observed in the granodiorite and no contact metamorphic effects have been observed in the country rocks. The latter feature may be explained by the fact that the country rocks are of similar grade mineralogically to that of the adamellite.

(iii) Internal Structures

(I) Banding

The adamellite is generally fairly homogeneous within a single outcrop. Occasionally compositional variation is indicated by the presence of lighter bands, either single bands or in groups which are not more than a few centimetres thick. At the north end of Presqu'ile Ste Marguerite (7.704/54.00) such bands display folds, presumably due to pre-consolidation movements as the granodiorite does not appear to have undergone post-consolidation deformation at this point. At the northern extremity of Ile de Rosservo (Fig 3-B) at HWM (7.786/53.982) compositional inhomogeneity is particularly well displayed, and the 'bands' are seen to be elongate lenses, possibly representing flattened xenoliths.

(II) Jointing

In areas where the adamellite has not been affected by the post-consolidation deformation associated with the Porspoder Lineament, it nonetheless commonly appears in the field or in hand specimen to possess a prominent planar structure (Plate 3-34, 3-35); Chauris (1972c, p.25) has remarked on this feature with the words 'des granites a grain fin qui offrent frequemment une nette foliation'. However in thin section the degree of preferred orientation of minerals such as biotite is low or imperceptible. The prominent planar structure is in fact hardly apparent in thin section (Plate 3-4) and on close inspection is seen to consist of a closely-spaced unidirectional platy jointing. This structure is so common in the Adamellite de Ste Marguerite as to be typical of it, and it is visible in most exposures which are undisturbed by later deformations. Individual joints may be a few millimetres or centimetres apart. There appears to have been little or no displacement related to the jointing. Cogné and Shelley (1966, p.24 and fig 15), (where the Adamellite de Ste Marguerite is indicated as 'Granite sombre - masse principale' and the country rock as 'Migmatites a grenats') have noted that at Ile Cézon (7.694/54.008)(Fig 3-A) the internal strucutre in the 'Granite sombre' is oblique to the neighbouring contact with the 'migmatites a grenats'. This feature has been observed by the present writer at other localities. At Carrec Cros (7.793/53.977)(Fig 3-5) the jointing is fairly intense and at quite a high angle (c.40°) tothe nearest contact; but within 5 m or so from the contact the adamellite becomes more massive, while the (weaker) jointing swings nearer to parallelism with the contact (see Figs 3-5c, 3-B). This phenomenon is not readily explicable, and would probably repay further investiga-tion. Some outcrops of the Adamellite de Ste Marguerite, for instance at Ile Tariec, (7.731/54.002)(Plate 3-40) lack the close undirectional jointing and have only widely-spaced rectangular jointing separated by massive granodiorite. Similarly massive adamellite occurs at the northern extremity of Presquile Ste Marguerite (Plate 3-38).

(III) Secondary Structures

It has been mentioned above that primary mineral orientation is weakly developed or imperceptible in the Adamellite de Ste Marguerite. However locally, and especially towards the western extremity of the sector the deformation associated with the Porspoder Lineament has resulted (e.g. in a sample from Beg ar Garo, 7.890/53.923) in the cataclasis of quartz and parallel orientation of biotite along closely spaced secondary fractures ('fracture cleavage') (Plate 4-5). This feature gives the rock a pronounced foliation.

(iv) Petrography

The texture is generally non-megacrystic; locally however sparsely distributed perthite megacrysts c. 1 cm long occur as at Grève de Lilia (7.670/54.022) and elsewhere in the eastern part of the sector. In general the rock is rather fine-grained, most grains being in the range 0.5-1.0 mm.

Biotite (10-15%) is in excess of muscovite (2-5%), the biotite being slightly chloritised in most examples. Plagioclase (35-40%) lathlike or granular in habit is generally zoned (e.g. cores An 37; rims An 25) and is the most abundant felsic mineral, in excess of anhedral interstitial string perthite, (20-30%) which sometimes shows microcline twinning, and quartz (20-25%) which is sometimes mortarised. In some variants, e.g. at Trémazan (7.853/53.952) microcline is locally in excess of plagioclase (40:25). Apatite is ubiquitous in $<$ 0.2 mm diameter rods, and there are usually a few opaque grains. Sphene has not been observed. A typical example is shown in Plate 3-39.

In an example (Plate 4-5) which has been affected by deformation associated with the Porspoder Lineament muscovite is in excess of biotite; as the muscovite is concentrated along the 'fracture cleavage' its growth may be related to the D4 deformation (see chapter 4).

(b) Granite de Kern an Guen

(i) Distribution

This distinctive granite is of restricted outcrop, mainly in the vicinity of the intertidal reefs of Kern an Guen (Figs 3-B and 3-6) (7.72/54.01) also known as 'Kerguen', which can only be reached from the mainland by boat or at low spring tides. Possibly as a result of this difficulty of access the Granite de Kern an Guen has not been recognised by earlier workers as being distinct from the Adamellite de St Marguerite.

The main outcrop forms a belt trending NE-SW for about 1.5 km, tapering in width from about 400 m at the northeast end to less than 100 m at the SW end. These are a few scattered outcrops of similar granite elsewhere in the western and central sector.

(ii) Contacts

The main body is located close to the boundary between extensive outcrops of respectively, Granite de Landunvez to the northwest, and Adamellite de Ste Marguerite to the southeast (Fig 3-A). On the Kern an Guen reef it is separated from the Granite de Landunvez by a thin (15 m) screen of Adamellite de Ste Marguerite. The relationship between the two granites is not clear at this locality; however at the north end of Ile Tariec (7.732/54.003) a contact between the two is exposed (Plate 3-40) where xenolithic blocks of the adamellite (Plate 3-41) occur near the margin of the granite. This evidence indicates that the Granite de Kern an Guen is a younger intrusive phase than the Adamellite de Ste Marguerite.

(iii) Internal structures

The granite (Plate 3-42) is typically massive and structureless except for widely spaced rectangular jointing. Locally, however, it displays closely spaced unidirectional joints similar to those typical of the Adamellite de Ste Marguerite. This feature is visible at the above-mentioned contact at the north end of Ile Tariec (7.732/54.003); the adamellite itself is uncharacteristically massive at this locality. The 'exchange' of internal structures between the Adamellite de Ste Marguerite and the Granite de Kern an Guen suggests that the two intrusions are probably genetically connected and approximately contemporaneous.

(iv) Petrography

Where massive and fresh the rock is distinctively pink in hand specimen owing to the coloration of alkali-feldspars.

The rock is non-megacrystic, with a xenomorphic granular texture. It is much coarser than the Adamellite de Ste Marguerite, grain size being generally in excess of 1.5 mm. Muscovite (5-7%) is in excess of biotite (3-5%). The biotite is more severely chloritised than the biotite in the adamellite. The most abundant felsic mineral is anhedral microcline perthite (~ 2.5 mm)(35-40%), narrowly in excess of quartz (35%). There is about 20% of zoned oligoclase (cores c. An 28, rims c. An 20). Myrmekite, apatite and a few opaque grains are seen but sphene has not been observed.

(c) Other late granites in the central and western sectors.

The occurrence of more potassic variants of the Adamellite de Ste Marguerite and of minor outcrops of granite similar to the Granite de Kern an Guen in the central and western sector has been noted. Although it has not proved possible to categorise every late discordant granite sheet seen in this sector, the majority do fit into the above classification. Some exceptions are mentioned below.

At 7.714/54.002 a light granitic sheet < 1 m thick cuts the Adamellite de Ste Marguerite. This sheet may be an offshoot of the Granite de Kern an Guen.

At 7.823/53.964 an 'en échelon' series of leucocratic granite dykes cuts the internal structures of the Diorite de Portsall at a high angle.

At 7.692/54.003 two foliated micaceous granitic sheets cut the Granite de Landunvez. These sheets, although grouped by Cogné and Shelley (1966) with their 'granite sombre' (i.e. the Adamellite de Ste Marguerite) are much coarser than the latter and resemble more closely the Granite de Kervigorn (see Chapter 2). They are shown thus on figure 3-A.

2. ST. MICHEL SECTOR

This sector extends from the eastern end of the previous sector at Ile Venan (7.65/54.03) to Le Vougo (7.555/54.029). Four main groups of late granitic intrusions can be recognised in this sector; two of these groups bear considerable similarity with the two main groups in the previous sector.

(a) Granodiorite de Trolouc'h

(i) Location and extent

There is a single outcrop of hornblende-granite at Trolouc'h (7.610/54.037)(Figs 3-1, 3-A). The exposure is limited to an area about 100m square. The rock type is distinctive and has not been observed elsewhere in the NW Pays de Lēon. It may however be compared with certain occurrences of 'diorite' in the NE Pays de Lēon, e.g. at Ile de Batz (cf Sandrēa, 1958).

(ii) Contacts

Only the steep east and west margins of this body are exposed, the granodiorite being covered to the south by superficial deposits and to north by the sea. The outcrop can probably be regarded as a short section of a 100 m thick dyke. The granodiorite penetrates and enclaves the country rock which at this locality is a belt of coarse granodioritic palaeosome agmatites. The granodiorite is itself cut by a thin (c. 1m) granitic dyke.

(iii) Petrography

The rock is massive, and possesses no obvious internal fabric. It is coarser than the Adamellite de Ste Marguerite, most grains being 1 mm. The colour index is c. 25-30, of which 15-18% is slightly chloritised biotite and 10-12% hornblende. The chief felsic mineral is severely altered andesine/oligoclase in zoned laths (30-35%), in excess of interstitial anhedral perthite and quartz (both 20-25%). Myrmekite is present. Accessions include coarse sphene (0.2-1.0 m) (up to 3%), apatite (common as inclusions in biotite) and rare hollow opaques.

(b) 'Ste Marguerite' type

A few dykes, mostly of composition comparable with that of the Adamellite de Ste Marguerite, but also including more potassic and siliceous types, have been observed in this sector. The dykes are generally within 25° of an EW trend and appear to have been intruded along sets of fractures at high angles to the strike of the host rocks (Migmatites de Plouguerneau and Granite de Landunvez). Examples can be seen almost adjacent to the margin of the Granodiorite de Trolouc'h at 7.611/54.038.

No larger bodies have been observed, and the relatively scarcity of bodies of this type distinguishes the St Michel sector from the western and central sector.

(c) Granite de Beg ar Spitz and similar types

A non-porphyritic granite occupies most of the promontory of Beg ar Spitz (7.63/54.03)(Fig 3-B). The dimensions of this body are in excess of 600 x 300 m. The Granite bears some resemblance to the Granite de Kern an Guen. It intrudes the Migmatites de Plouguerneau at this locality. Similar granites occur north of Ile Venan (near 7.652/54.036) and northwest of Porz Grae at 7.653/54.042. At the latter locality the rock locally contains sparse large enhedral rather randomly oriented megacrysts of alkali-feldspar, which suggest a comparison with the Granite de Corrējou (see below).

(d) Granite de Corrējou

A distinctive coarse megacrystic granite with aligned alkali-feldspar megacrysts has a steep-sided dyke-like outcrop at least 2.5 km long and 100-200 m thick extending from Creac'h ar C'ham (7.620/54.023) to Carrec Cromm (7.587/54.042). (Figs 3-1 and 3-A). The granite also locally penetrates the host rocks some distance from this elongate belt, e.g. at the northern extremity of Penn Enez (7.604/54.036). The main intrusion is discordant to the mean strike of the country rock migmatites, which trend slightly east of north in this sector.

The Granite de Corrējou has been compared by Chauris (1972) with outcrops of similar late megacrystic granites about 3 km southwest of Corrējou at Keridauouen (7.662/54.011). The latter outcrop has in turn been compared by the present writer with similar granites at Les Anges (Chapter 2). There seems to be a good case for grouping together these separated outcrops of distinctive megacrystic granite under the heading Granite de Corrējou, (see Fig 1-7, after Chauris, 1966b).

It is a further possibility that the Granite de Corrējou in these outcrops may represent western offshoots of the Granite de Brignogan (see next section), the western limit of whose main outcrop lies 4.5 km ENE of the nearest exposure of Granite de Corrējou. This possibility was suggested to the writer by B. Cabanis (pers.comm.).

The Granite de Corrējou has not been observed to be cut by any other of the late intrusive granitic suite, although it is cut by a coarse muscovite pegmatite at 7.604/54.036. The relations at the contact of Granite de Corrējou and a sheet of Ste Marguerite type at 7.6025/54.033 are ambiguous, but seem to indicate that the Granite de Corrējou is the later of the two.

3. GUISSĒNY SECTOR

This sector extends from Le Vougo (7.555/54.029) to the north shore of Port de Treissēny (7.50/54.05) and includes the reefs of Carrec Hir (7.57/54.04). It is shown on figure 3-4.

(a) Granitic dykes of Enez Croaz Hent

Non-porphyritic late granitic intrusions are not numerous in the Migmatites de Plouguerneau of the Guissēny area, being confined to a few ENE - WSW trending dykes which obliquely cut the E-W striking migmatites. These dykes resemble the Adamellite de Ste Marguerite, and may perhaps be regarded as a continuation of the E-W set of dykes of this type in the St Michel sector. At Enez Croaz Hent (7.538/54.050)(Fig 3-4) two dykes of this type display a prenounced variation in thickness (3 m - k5 m) resembling pinch and swell structure, coupled with a prominent planar structure parallel to the margins. A similar example is seen at Golhēdoc (7.558/54.044). It is not clear whether these structures are penecontemporaneous with the emplacement of the intrusions, or due to later deformation.

(b) Granite de Brignogan

(i) Location

The eastern limit of the area examined in the present study is the western margin of a major intrusion which, under various labels, such as Granite de Kerlouan (Chauris, 1966c), Granite de Plouescat (Fig 1-6), Granite de Roscoff etc, occupies most of the eastern half of the north coastal region of the Pays de Lēon between Guissēny and St Pol de Leon (Fig 1-2, 1-6). It is well exposed in the vicinity of the town of Brignogan (7.40/54.07), and has been the subject of a recent detailed petrological and geochemical study by Le Guen de Kerneizon (in preparation).

(ii) Contacts at the western margin

The western margin of the Granite de Brignogan passes about 1 km west of Guisséñy (7.49/54.03) and trends approximately northwest, passing out to sea through the mouth of the estuary between Enez Croaz Hent (7.53/54.04) and Loccarrec (7.53/54.06) (Fig 3-4). Several minor outcrops of Migmatites de Plouguerneau occur to the northeast of this line, e.g. at Kermarguel (7.492/54.043). Actual contacts with the country rock are not well exposed at the above lacality, but in the vicinity of Enez Aman ar Rouz (7.52/54.06) several different lithologies occur as rafts and xenoliths discordantly enclosed by the Granite de Brignogan (Plate 3-43). These enclaves include (1) At 7.524/54.0 3: banded migmatites similar to the sillimanite-free metasedimentary type of migmatites described in the earlier part of this chapter, together with augen gneisses. (2) At 7.525/54.057: agmatites with palaeosome of intermediate metaigneous type., and (3) At 7.525/54.060: a medium-grained dark biotite granite of granodiorite similar to the Adamellite de Ste Marguerite and to the Granitic dykes of Enez Croaz Hent occurs as a small (< 1 m) enclave in the Granite de Brignogan. A larger (> 10 m) sheet-like body of similar composition also occurs at this locality, but its relations with the Granite de Brignogan are unclear.

The angular nature (Plate 3-43) of these enclaves and the highly discordant relations shown by the surrounding Granite de Brignogan contrast markedly with, the relations shown by, for instance, the Granite de Landunvez towards the Migmatites de Plouguerneau. It seems that the Migmatites de Plouguerneau in the Guisséñy sector were relatively rigid at the time of the emplacement of the Granite de Brignogan, and may have already been intruded by the late non-porphyritic granitic dykes seen at Enez Croaz Hent (Fig 3-4).

The field relations of the Granite de Brignogan thus seem to indicate that it may belong to a later intrusive episode than the Granite de Landunvez.

(iii) Composition

The Granite de Brignogan is most obviously characterised by the presence of abundant aligned euhedral white alkali-feldspar megacrysts (Plate 3-43). According to Chauris (1966c) its other main constituents are oligoclase, quartz, biotite, and muscovite. Chauris (op cit) also remarks, that the megacrystic character locally dies out.

TABLE 3-1

LATE GRANITIC INTRUSIONS ASSOCIATED WITH THE MIGMATITES DE PLOUGUERNEAU AND THE GRANITE DE LANDUNVEZ

A. WESTERN AND CENTRAL SECTOR	B. ST. MICHEL SECTOR	C. GUISSÉNY SECTOR	
	Granodiorite de Trolouc'h		1
Adamellite de Ste Marguerite	Dykes of Ste Marguerite type	Granitic dykes of Enez Croaz Hent, etc.	2
Granite de Kern an Guen	Granite de Corrējou Granite de Beg ar Spitz and related types	Granite de Brignogan	3

Le Guen de Kerneizon (pers.comm) has observed that the granite commonly contains accessory andalusite. This feature offers another obvious contrast with the Migmatites de Plouguerneau and the Granite de Landunvez, as the characteristic Al_2SiO_5 mineral associated with the latter is sillimanite. The andalusite-bearing character of the Granite de Brignogan also suggests that it may be a relatively high level intrusion.

4. SUGGESTED CORRELATION OF THE LATE GRANITE INTRUSIONS NORTH OF THE PORSPODER LINEAMENT

A possible correlation of the late granitic intrusions considered in this section is given in table 3-1.

F. ASPECTS OF THE STRUCTURAL GEOLOGY OF THE PLOUGUERNEAU - LANDUNVEZ AREA

1. ORIENTATION OF STRUCTURES

This section is concerned with a qualitative description of the orientation of some of the structures in the area north of the Porspoder Lineament, but for the most part excluding structures associated with the lineament itself which are discussed in the following chapter. For convenience the area is divided into five sectors, which will be considered in sequence from west to east.

(a) Pointe de Landunvez sector

In the westernmost sector of the area studied between Porspoder (7.89/53.90) and Portsall (7.81/53.95) the Granite de Landunvez and later intrusive bodies of Granodiorite de Ste Marguerite type have commonly been deformed and earlier structures reoriented by movements associated with the Porspoder Lineament. Nonetheless enough of the rocks in this sector have escaped this late deformation to allow the earlier structures to be described.

The predominant primary structure in the Granite de Landunvez is a preferred orientation of alkali-feldspar megacrysts, which provide a combined linear and planar structure; the linear component of this structure is commonly close to horizontal and strikes at 045-065°. The planar component, which is often less obvious than the linear, is commonly near vertical or dips steeply south; this orientation is shared by the numerous enclaves of Migmatites de Plouguerneau. However, towards the western extremity of the sector, for instance at Ile d'Ioc'h (7.90/53.92) (Fig 3-A) a more gentle (30°- 60°) southerly dip is common, the strike being about 045°.

The contacts of the numerous intrusions of Adamellite de Ste Marguerite type are generally near E-W or N-S; but the internal structures (close jointing etc) are commonly oblique to both margins, and may strike NE-SW, dipping southeast at 30°- 50°.

(b) Greve de Trēompan sector

This sector extends from Pointe de Penvir (7.82/53.96) (Figs 3-1, 3p2) to Ile du Bec (Fig 3-1) (7.77/53.97) and includes the whole outcrop of the Diorite de Portsall.

The structure in the Diorite de Portsall and the Granite de Landunvez is composed of both linear and planar components. The lineation in both rock types is approximately horizontal, and swings from a strike of 060° at Pointe de Penvir to c 090° (E-W) at Ile de Rosservo (7.78/53.98). An antiform synform pair, probably of D3 age, affects both lithologies in the Ile Carne-Pointe de Penvir area (Fig 3-3). The planar component is subordinate to the linear component east of Pointe Scoune (7.820/53.967) but at Ile Carne (7.810/53.924) the planar structure dips north at 40°- 60°.

The margins of many dykes of Adamellite de Ste Marguerite in this sector strike at 100-110° as does the southern margin of the major body of adamellite near Tevenn Penn ar Pont (7.78/53.97) (Figs 3-2, 3-A). The other margins of the latter body strike at c. 360°- 020°. The internal structure (close jointing) in the adamellite, which was described in section E.1.(a) of this chapter is generally not parallel either to the margins of the body or to the structure in the host rocks, but strikes NE-SW (045-065) and dips south-east at 30°- 70°. Close to the contacts the structure becomes more nearly parallel with them, and is less intensely developed.

(c) Central sector

This sector extends from the reefs north of Lampaul-Ploudalmézeau, (Coulouarn: 7.76/53.97) in the southwest to Ile Vierge (7.69/54.04) and Ile Venan (7.66/54.03) in the northeast. This sector is larger and more complex than the other sectors, but it possesses sufficient unifying features to justify its treatment as a single unit.

Throughout much of the sector the prevailing strike of structures in the Migmatites de Plouguerneau and the Granite de Landunvez is roughly NE-SW (030°- 060°) with dips to the southeast at 30°- 65°. However there are extensive zones apparent at the 1:25,000 scale where the structure swings round to an easterly dipping N-S or even NW-SE strike; these anomalous zones can be regarded as the short limbs of a system of open easterly plunging folds (D3) which affect both the Migmatites de Plouguerneau and the Granite de Landunvez. Examples occur at Ile Trevoc'h (7.75/53.98) (Fig 3-A) at the south end of Ile Tariec (7.732/53.999) and southeast of Ile Vierge(round 7.67/54.04) (Fig 3-A). The NW-SE trending belt to the north of Ile Venan may also be considered in this category.

Along the northwest margin of the sector northwesterly dips occur at a number of localities. A significant belt with common northwest dips extends from the vicinity of the lighthouse at Ile Vierge (7.672/54.043) through Ile Valan and Plateau de Lezent to Ile Stagadon (Fig 3-1) (7.70/54.02) where northwest dips of 45°- 75° are common. Although southeast dips also occur in this belt, it appears to form the northwest limb of a major antiformal structure whose axis strikes at about 045° and passes through the vicinity of Ben Enet (7.685/54.029) (see section D.4. of this section).

Numerous dykes and larger bodies of Adamellite de Ste Marguerite and Granite de Kern an Guen intrude the Granite de Landunvez an dthe Migmatites de Plouguerneau in hhis sector. The largest body of Ste Marguerite type occupies several km^2 in the northern part of the Presqu'Ile Ste Marguerite and the reefs to the west (Fig 3-B). It is of irregular outline, with some margins trending c 100° and others near 045°. Internal structures are variable but commonly trend at 010° - 035° with moderate south-easterly dips. They are thus oblique to the margins of the body and to the structures in the country rocks. Locally the internal structure in minor bodies of Adamellite de Ste Marguerite may have almost any orientation.

(d) St Michel sector

This sector extends from Ile Venan (Fig 3-A) (7.65/54.03) in the west to Le Vougo (7.55/54.03)(Fig 3-4) in the east and consists predominantly of Migmatites de Plouguerneau and Granite de Landunvez, with minor late granite intrusions (Fig 3-A).

Throughout the sector easterly dips predominate. Between Ile Venan and Ar Villien (7.620/54.040) the strike ranges from 140° to 180°and the dip from 35° to 70° to the east. The few observations that have been made on the late Granite de Beg ar Spitz show that its most obvious internal structure strikes obliquely to and dips more steeply than the structures in the country rocks.

Between Ar Villien and Le Zorn (Fig 3-1) the strike is generally between 360° and 030° but swings to 045° near Le Zorn. Dips are between 40° and 70° to the east or southeast. Post-migmatitic minor folds have been observed; these generally have short north-dipping limbs, and plunge at a moderate angle to the northeast. The main late granitic intrusion which cuts the migmatites between Ar Villien and Le Zorn is the Granite de Corrējou. The margins and internal structure (feldspar orientation) are parallel, being vertical and striking at about 050°; its structures are thus oblique to those of the neighbouring migmatites.

In the short section between Le Zorn and Le Vougo the migmatites and leucogranites strike at 070° and dip south at 45-70°.

(e) Guisséņy sector

This sector includes the area north and east of Le Vougo (7.55/54.03) as far as the eastern limits of the area studied (Fig 3-4).

(i) Migmatites de Plouguerneau

The migmatites in this sector have predominantly northerly dips of 45-70°, striking at 070-100°. Minor post-migmatitic folds have been observed with long north-dipping E-W limbs and short easterly or north-east dipping limbs. These folds plunge at moderate angles to the east or northeast. They may be regarded as belonging to the D3 phase.

(ii) Granite de Brignogan

Close to the contact zone between the Migmatites de Plouguerneau and the Granite de Brignogan at Dibennou (7.515/54.045) (Fig 3-4) the internal structure (feldspar orientation) of the granite dips at 55-70°

north or northeast, striking at 110-130°.

Further north at Aman ar Rouz (7.52/54.06) the strike of the foliation in the granite is near E-W and it is vertical or dipping steeply south.

(iii) Conclusion

The east or northeast plunging structure in the Migmatites de Plouguerneau suggests that the main body of the migmatites underlies the Granite de Brignogan. However the attitude of the western margin of the granite is uncertain. The most prominent internal structures in the granite are primary mineral orientations sub-parallel to the structure in the neighbouring migmatites.

2. STRUCTURAL RELATIONSHIP BETWEEN THE LATE GRANITIC INTRUSIONS AND THE COUNTRY ROCKS (MIGMATITES DE PLOUGUERNEAU AND GRANITE DE LANDUNVEZ)

The previous section (F.1) included observations on the orientation of structures in the Adamellite de Ste Marguerite and other late granitic intrusions. In this section an attempt will be made to describe and account for the structural relationships between the late granitic intrusions, including the Granodiorite de Ste Marguerite, and the country rocks.

(a) Adamellite de Ste Marguerite

From figure 3-B it can be seen that major bodies of Adamellite de Ste Marguerite type intrude the older rocks at intervals of 1-3 km between Presqui'Ile St Laurent in the west and Ile Venan in the eastern central part of the area. Figure 3-B also enables one to observe that the larger bodies of granodiorite are not randomly distributed, but tend to be located preferentially where the internal structure of the country rock (Migmatites de Plouguerneau and Granite de Landunvez) undergo a change of orientation or are of variable orientation. Examples of this phenomenon can be seen in the neighbourhood of Ile de Rosservo (7.78/53.98) where the strike of the country rock swings from ENE-WSW to E-W. The extensive body of Adamellite de Ste Marguerite outcropping in the north and to the west of Presqui'Ile Ste Marguerite is located in a sector where the strike of the Granite de Landunvez and the Migmatites de Plouguerneau is variable in detail owing to the presence of a number of open post-Granite de Landunvez folds plunging to the northeast quadrant. Another large body of

Adamellite de Ste Marguerite is located southeast of Ile Stagadon (7.69/54.02) roughly coinciding with the axial zone of the Ben Enet Antiform postulated above.

The major body of Adamellite de Ste Marguerite just west of Lilia (7.66/54.02) is located where the strike of the country rocks swings from a northeast direction at Ile Wrac'h (7.885/54.017) to a NNE or northerly direction at Enes ar Vir (7.665/54.030) and Ile Venan (7.65/54.03).

Some of the larger bodies of Ste Marguerite type (e.g. at Trémazan, 7.85/53.95) are not obviously associated with any major fold affecting the country rocks. Nonetheless most major fold hinges or axes affecting the Migmatites de Plouguerneau and the Granite de Landunvez in this sector appear to have acted as loci for the preferential emplacement of post-Granite de Landunvez intrusions, especially those of Ste Marguerite type.

In this connection it is worthy of note that the development of such features as pegmatite intrusions and quartz-filled tension gashes commonly observed in folded terrains in orogenic belts are rarely observed cutting the Migmatites de Plouguerneau or the Granite de Landunvez; it appears that the spaces left during the opening of fractures at hinge zones and elsewhere on major fold structures have been occupied not by pegmatites and vein quartz but by intrusions of Ste Marguerite type.(See section G4(b) and table 3-2).

(b) Granite de Kern an Guen and other late granitic intrusions

With the exception of the Granite de Brignogan other late granitic intrusions are generally less extensive than the intrusions of Ste Marguerite type, although the latter become less abundant in the eastern part of the area studied.

At the type locality the Granite de Kern an Guen is situated within, but close to the margin of a large outcrop of Adamellite de Ste Marguerite, and like the latter may have been preferentially located in the same complex zone of open folds which affect the older country rocks in this sector.

The outcrops of Granite de Beg ar Spitz and similar types are located in a NNW trending zone of Granite de Landunvez and Migmatites de Plouguerneau which have a fairly regular dip and strike in this vicinity. The most important body of late granite in this sector is the dyke-like Granite de Corrējou, whose emplacement appears to have been rather late in the magmatic history of the area. The important and extensive Granite de Brignogan, which is the largest body of post-Granite de Landunvez granite outcropping north of the Porspoder Lineament has been intruded into the Migmatites de Plouguerneau in a zone of relatively intense folding. It is possible that the Granite de Brignogan, at least at its western margin, was, like the Adamellite de Ste Marguerite, preferentially emplaced into the country rock (Migmatites de Plouguerneau) in a sector where the latter were undergoing relatively intense post-migmatitic folding.

(c) Conclusion

To sum up the previous two sub-sections, the model favoured by the writer to account for the structural relationship between the late intrusive suite and the earlier migmatites and Granite de Landunvez is that the late adamellitic and granitic magma represented by the Adamellite de Ste Marguerite and other late intrusions, was permitted to penetrate the pre-existing rigid migmatitic and granitic terrain by the opening of fractures and cavities during a phase of large-scale open folding (D3; table 3-2), which the migmatites and Granite de Landunvez appear to have undergone. In this interpretation, the folding and intrusion appear to have been genetically related and essentially contemporaneous events. It is further considered likely that the characteristic development of closely-spaced unidirectional jointing in the Adamellite de Ste Marguerite was related in some way to the actual emplacement and consolidation of the adamellitic magma itself.

The commonly observed obliquity of the joints with respect to the margins of the body they occur in, and the control of the orientation of the margins themselves are topics whose analyses and interpretation are beyond the scope of the present preliminary study, but appear to offer fertile fields for further structural investigation, in view of the excellent conditions of rock exposure, and the now broadly understood sequence of magmatic and structural episodes in the area (see table 3-2).

TABLE 3-2

SEQUENCE OF GEOLOGICAL EVENTS IN THE PLOUGUERNEAU-LANDUNVEZ COMPLEX

PHASE OF DEFORMATION	STRUCTURAL EVENTS	LITHOLOGICAL EVENTS
D5	Late faulting	
D4	Porspoder Lineament deformation	Local mylonite
		Muscovite and tourmaline-pegmatites
D3	Major open folds, and discordant brittle fractures in Granite de Landunvez and older rocks	Emplacement of later granites (Kern an Guen, Beg ar Spitz, Corrējou, Brignogan) with local penecontemporaneous jointing
		Emplacement of Adamellite de Ste Marguerite with ? penecontemporaneous jointing. Emplacement of Granodiorite de Trolouc'h
Late D2	(Continuation of) ductile deformation of Migmatites de Plouguerneau	Emplacement of Granite de Landunvez
Climax D2	Strain associated with melting phenomena	Partial (perhaps locally complete) melting of metamorphic rocks; restricted mobilisation and subsequent consolidation of resulting melt
Early	Structures (foliation+ folds) associated with high-grade metamorphism	High-grade metamorphism
D1	No direct evidence, but inferred by analogy with Lannilis Complex	
Pre-D1		Formation and emplacement of sedimentary and igneous parent rocks; possibly including emplacement of Diorite de Portsall

G. STRUCTURAL AND MAGMATIC EVOLUTION OF THE PLOUGUERNEAU-LANDUNVEZ MIGMATITIC AND GRANITIC COMPLEX

1. INTRODUCTION

The purpose of this section is to summarise the geological history of the region which is bounded to the south by the Porspoder Lineament. Structures associated with the Lineament itself will be considered in more detail in the next chapter (chapter 4).

The history of the region is perhaps most conveniently considered if one takes as a reference datum the major metamorphic and migmatitic episode, which, by analogy with the sequence recognised already in the Complexe Metāmorphique de Lannilis, may be labelled M2.

2. PRE-M2 EPISODES

(a) Pre-M2 lithologies

The earliest group of events which can be recognised in the Complexe Migmatitque de Plouguerneau is the formation of a lithological complex of sedimentary and igneous rocks. Interspersed with lithologies which are thought to be derived from pelitic, psammitic and minor impure calcareous precursors are a variety of lithologies thought to be derived from characteristically igneous types such as quartz-biotite-diorite, metabasics, and others. The original nature of relationships between the various sedimentary and igneous types is almost unknown as far as evidence from the Plouguerneau Migmatite Complex itself is concerned.

However, the similarity between the rather fragmentary remains of pre-migmatitic lithologies in the Plouguerneau Migmatites and the better preserved metamorphic lithologies in the Lannilis Metamorphic Complex suggests that the pre-M2 rock types present in both areas were rather similar and probably had a common origin; the metasediments may have been ultimately derived from Brioverian sedimentary material, while the precursors of the Diorite de Portsall and the various orthomigmatitic lithologies may have been igneous intrusions into the Brioverian.

(b) Pre-M2 structures

Pre-metamorphic (as distinct from pre-migmatitic) structures are not easily recognisable in the Migmatites de Plouguerneau. One good example, however, is the small-scale banding, probably of sedimentary origin, in psammite at Ile Carne (7.810/53.973) which may be termed So. Deformational structures associated with the D1/M1 episode as described for the Lannilis Metamorphic Complex have not been positively identified in the area.

3. THE M2 EPISODE

(a) Metamorphic fabrics and associated structures

The linear fabric and schistosity observed in the Diorite de Portsall and the foliation present in the palaeosomes of the Migmatites de Plouguerneau may be assigned to a high-grade metamorphic episode comparable with the M2 episode as seen in the Lannilis Metamorphic Complex; it is therefore given the same abbreviated label, the suffix ($M2_1$) being added to emphasize that the metamorphic phase preceded the migmatitic phase in units where both are recognised.

The various structures formed during the metamorphic phase may be denoted by abbreviations such as $D2_1$, $F2_1$, $S2_1$, $L2_1$ etc. In practice few $F2_1$ folds can be positively identified; the folds in the Ile Carne psammite may perhaps be attributed to this phase, but the possibility that they are earlier (?F1) folds cannot be ruled out. The $M2_1$ metamorphism seems, on the basis of the mineral assemblages in the migmatites, to have been of similar character to that of the M2 metamorphism in the Lannilis Complex. Clinopyroxene has not been recorded in the Plouguerneau Complex; but it is in any case rare in the Lannilis Complex.

(b) Migmatisation

The production of various types of migmatites at the expense of the pre-existing metamorphic rocks is as indicated above a phase theoretically distinct from but probably continuous with the $M2_1$ metamorphism. The effects of this migmatisation (M2) varied considerably from one lithological unit to another, so that there is now a wide variety of migmatite types, ranging from the relatively minor development of leuco-neosome in the Diorite de

Portsall to the formation of essentially new rock in significant volumes as seen in the aplogranitic and leucogneissic types. Intermediate categories are represented by the differentiation into leucosome and melanosome seen in the pelitic metasedimentary migmatites, and by the development of agmatites consisting of blocks of metamorphic rocks more resistant to anatexis such as amphibolites, diorites and psammites, penetrated and surrounded by leucosome. The leucosomes and leucogranitic rocks which go together with the palaeosomes to form the migmatite complex seem likely to have formed as a result of partial anatexis on a regional scale of aluminous metasedimentary (i.e. pelitic) material in the pre-existing metamorphic complex, together with rather less complete anatexis of more resistant rock types (psammites, diorites) and possibly total anatexis of suitably homogeneous material of low melting point, such as alkali-granitic gneisses comparable with the Gneiss de Trēglonou in the Lannilis Complex.

It should be emphasized that the migmatisation itself was by no means a simple event; examples occur ubiquitously of, for instance, one leucosome vein cutting another, indicating that the migmatitic episode consisted of a number of phases. This feature is characteristic of migmatite terrains. It is also likely that some of the small-scale folding of migmatitic banding was itself an inter-migmatitic phase, which could be labelled $F2_2$. It is further possible that some of the folds affecting the migmatitic banding, and the flattening deformation observed in some agmatite blocks, were produced when the migmatisation s.s. had been essentially completed, but before the emplacement of the Granite de Landunvez. The folding in the migmatites has not however been studied in sufficient detail to enable a complete description or classification to be put forward.

4. POST-M2 PHENOMENA

(a) Granite de Landunvez

The contacts of the Granite de Landunvez are concordant, while the rock itself generally shows relatively little evidence of severe or penetrative deformation. It follows that the concordance of the contacts is to be regarded as an original feature of the granite. If, as the writer believes, the Granite de Landunvez is allochthonous with respect to the Migmatites de Plouguerneau, then the granite appears to have been emplaced along fractures which were more or less parallel with the orientation of structures in the migmatites. As argued above the ductility contrast between the Migmatites de Plouguerneau and the Granite de Landunvez at the time of emplacement of the latter appears to have been low; one explanation for this is that the migmatites had not completely cooled. It follows that the emplacement of the Granite de Landunvez may have occurred a relatively short (but undefined) interval after the completion of the migmatisation, and may belong to the closing stages of the same orogenic phase, i.e. M2. The migmatites may still have been undergoing (D2) strain related to the migmatisation.

However comparison of the Granite de Landunvez with the Granite de L'Aber-Ildut (p. 3/27,8) has led the writer to suggest the possibility that these two granites may be genetically related; in which case they may be temporally related as well. It has also been suggested (chapter 2.D) that the emplacement of the Granite de L'Aber-Ildut may have been associated with the D3 episode in the Complexe Métamorphique de Lannilis. In view of these discrepancies it would seem advisable at present to treat the correlation of structural, metamorphic and magmatic history between the areas north and south of the Porspoder Lineament with some caution.

(b) Adamellite de Ste Marguerite and associated structures

The emplacement of the various bodies of Granodiorite de Ste Marguerite was associated with the development of two new sets of structures in the country rocks. These were :

(i) Sharp discordant fractures, often steep, and of variable orientation, with small-scale brittle fractures in garnet crystals.

(ii) Major open folds, now plunging in may cases towards the northeast quadrant.

It is thought that the development of these structures (which may be labelled D3) controlled the sites where adamellitic magma was emplaced, while the unidirectional internal jointing in the Adamellite de Ste Marguerite itself was probably a result of movements which took place during its emplacement and solidification.

(c) Later granites of Kern an Guen, Beg ar Spitz, Corrējou, Brignogan

While outcrops of the earlier Adamellite de Ste Marguerite group of granites are concentrated in the central and western sectors of the area north of the Porspoder Lineament, more potassic granites which appear in general to be younger than the Adamellite de Ste Marguerite were emplaced in greater quantity in the eastern sector of the area. The emplacement of the later granites also appears to have been associated with the development of folds and fractures (loosely describable as D3) in the country rocks. If these granites are indeed significantly later than the adamellite, this may indicate that the tectonic activity leading to the development of (D3) open folds and brittle fractures in the eastern part of the area was somewhat later than, or at any rate diachronous with respect to similar tectonic activity further west.

Whatever the temporal relations between the structures in the two sectors, it appears the magma available for emplacement at the time of development of the structures was more potassic and perhaps more silicic in the eastern part of the area.

(d) Pegmatites

Brief mention has been made of the scarcity of cross-cutting pegmatites in the Plouguerneau-Landunvez complex. A few examples have however been noted; these commonly cross-cut the latest rocks outcropping in a given sector; but are locally affected by D4 movements associated with the Porspoder Lineament. A number of tourmaline-bearing pegmatites occur between Presqu'Ile St Laurent (7.902/53.905) and Pointe de Landunvez; a muscovite pegmatite cuts the late Granite de Corrējou at one locality (p 3/43). These pegmatites were emplaced in fractures which developed after the emplacement of the Adamellite de Ste Marguerite and the Granite de Corrējou, but prior to the latest (D4) movements associated with the Porspoder Lineament.

(e) Deformation (D4) associated with the Porspoder Lineament

All the rock types in the area are locally affected by the deformation associated with the Porspoder Lineament (D4). This major structure will be discussed in the next chapter. It may be noted that little or no retrogressive metamorphism appears to have been associated with the D4 movements.

(f) Faulting subsequent to the Porspoder Lineament deformation

By analogy with the 'post-Porspoder' faults locally exposed in the Complexe Métamorphique de Lannilis (Table 2-4) it is to be expected that comparable late faulting has affected the Plouguerneau-Landunvez complex. However, probably owing to preferential marine erosion such faults are rarely if ever exposed north of the Porspoder Lineament.

The difficulty in recognising distinctive stratigraphic horizons or distinctive lithological units whose offset could be observed means that the location and orientation of late faults can generally only be inferred from such features as linear belts with no exposure. The outer sectors of L'Aber-Wrach and L'Aber-Benoît estuaries form NW-SE trending lineaments, and may coincide with late faults. Other belts without exposure occur with trend approximately at right angles to these, and with other trends. It has not been possible to assess the sense or amount of displacement across any of these inferred late faults. Some movements may still be in progress as significant seismic activity has been recorded in the area during the present century.

CHAPTER 4

THE PORSPODER LINEAMENT

A. INTRODUCTION

B. SIGNIFICANCE OF THE LINEAMENT AS A MAJOR GEOLOGICAL BOUNDARY

C. FUNCTION OF THE LINEAMENT AS A LOCUS FOR MAJOR GRANITIC INTRUSIONS

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2. Secondary (D4) structures

   (a) Rock types affected

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   (c) Internal s uctures

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E. DISPLACEMENT ASSOCIATED WITH THE LINEAMENT

1. Sense of displacement

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F. ANALOGOUS STRUCTURES ELSEWHERE IN THE MASSIF ARMORICAIN

1. Linéament Molène-Moncontour-Alençon

2. Zone Broyée Sudarmoricaine

3. Conclusion

CHAPTER 4.

THE PORSPODER LINEAMENT.

A. INTRODUCTION

A number of references have been made in the previous chapter to the Porspoder Lineament and the deformation associated with it. The term "Porspoder Shear Belt" can be used to refer to the zone of deformation which is parallel to and to a large extent coincident with the "Porspoder Lineament". In this chapter the latter term will be used to refer to both features.

The rocks which occupy the Porspoder Lineament could be considered as forming an integral part of both the area discussed in Chpater 2 and that desribed in Chapter 3; but it is thought that the importance of the lineament in its own right justifies the devotion of a separate chapter to it. The Porspoder Lineament has been recognised and discussed by Chauris (1965a) under the description "Zone de Dislocation (or Zone Faillée) de Porspoder-Plougerneau", and by Cogné and Shelley(1966) under the description "Zone Axiale Mylonitique du Synclinal". The Porspoder Lineament can be traced for a distance of about 50 km including a submerged sector which according to Chauris (1969a) runs through the Passage de Fromveur between the islands of Ouessant (known in English as "Ushant") and Bannec (8.16/53.81 (Fig 1 - 2)). The lineament reaches the mainland at Porspoder (7.89/53.95; Fig 4 - 3), and from there can be traced in an ENE direction across the estuaries of L'Aber-Benoît (Fig 4 - 2) and L'Aber-Wrac'h at least as far as the vicinity of Kiloudern (Fig 4 - 1) (7.564/54,016). The width of the shear belt which coincides with the lineament is generally about 1 - 1.5 km.

The Porspoder Lineament may be considered in the following three aspects:

1. As a boundary zone between the main outcrop of the Lannilis Metamorphic Complex with its associated granites and the area occupied by the Migmatites de Plouguerneau and associated granites.
2. As a zone along and adjacent to which a number of major granitic intrusions broadly associated with D3 structures were emplaced subsequent to the M2 regional metamorphism and migmatisation.
3. As a belt along which deformation (D4) was concentrated subsequent to the emplacement of the granites in 2.

B. SIGNIFICANCE OF THE LINEAMENT AS A MAJOR GEOLOGICAL BOUNDARY.

It is agreed by Shelley (1964, 1966) and in Cogné and Shelley (1966), Chauris (1966c 1972c) and the present writer (Ch.3) that certain of the migmatites lying to the north of the Porspoder Lineament can be regarded as the more severely modified equivalents of the metamorphic lithologies lying to the south of the lineament. It is also a matter of agreement among the same workers that there is a more or less abrupt contrast between the lithologic character of the essentially medium to high grade metamorphic complex to the south and the essentially migmati and granitic complex to the north. These considerations suggest that there has been a significant amount of displacement of material on the one side of the lineament relative to that on the other side. The question of the sense and amount of such displacement will be considered below in section D of this chapter.

C. FUNCTION OF THE LINEAMENT AS A LOCUS FOR MAJOR GRANITIC INTRUSIONS.

It has been pointed out by Chauris (1965b,1966b) and emphasised in earlier chapters of the present work that several of the major granitic intrusions of the N W Pays de Léon possess a linear margin coinciding with the Porspoder Lineament (Figs 1 - 7, 4 - 1, 4 - 2). The Complexe Granitique de L'Aber-Ildut and the Granite de Kernilis are bounded to the north in this manner by the Porspoder Lineament, and extend in lobes to the south of it; the Granite de Landunvez also has a linear southern margin along the western mainland sector of the lineament. Relatively narrow outcrops of late granites approximately coincide with the Lineament in the L'Aber-Wrac'h sector (Fig 4 - 2). Observations of this type have led Chauris (1966 b , p.26) to suggest that the location of these granites may have been influenced or controlled by the Lineament itself. The possibility that the Porspoder Lineament may have acted as a zone of weakness permitting or favouring the passage of granitic magma is certainly worthy of serious consideration. According to such an interpretation the granites located in and along the lineament itself could be explained as the result of magma rising into and consolidating in an opening fracture; while the south-facing lobate intrusions of the Granite de L'Aber-Ildut and the Granite de Kernilis could be explained as originating from magma which having risen through the same zone of weakness spread laterally to consolidate in lacco-lithic form. It would nonetheless be a difficult matter to demonstrate that such a process did in fact occur. The weakness or absence of significant gravity anomalies associated with these granites (see gravity overlay in Chauris, 1967) is consistent with the granites having a relatively minor vertical extent.

D. DEFORMATION AND OTHER FEATURES ASSOCIATED WITH THE LINEAMENT

D. 1. Primary structures

The primary structures associated with the Porspoder Lineament are those associated with the emplacement of granitic intrusions along the lineament. These may be in turn divided into two categories:

D. 1. (a) Contacts

Contacts of granitic rocks emplaced along the lineament with older rock units such as the Mica-schistes de L'Aber-Wrac'h and the Diorite de Lannilis; and also contacts between successive granitic intrusions within the zone of the lineament itself. Where visible these contacts tend to be steep and to trend E N E. This latter trend in large part defines the trend of the whole lineament (see for example Fig 4 -2)

D. 1. (b) Internal structures

In several localities primary mineral orientation can be observed in the granitic rocks within or adjacent to the lineament. Chauris (1972c, p 16) has observed that at Porspoder (7.89/53.50) the primary orientation of feldspar megacrysts and xenoliths in the Granite de L'Aber-Ildut strikes E - W and dips north at about 75°. At the other extremity of the mainland sector of the lineament in the quarry at Kiloudern (7.564/54.016) the writer has observed the primary mineral orientation in the Granite de Kernilis strikes at 086° and dips north at about 70°. It may be noted that in both these localities (and elewhere) the trend of the internal primary structure is oblique to the trend of the lineament itself.

D. 2. Secondary (D4) structures

It is the secondary structures concentrated along the Porspoder Lineament which are its most obvious and characteristic expression. These structures have been referred to by Chauris (1965a) and Cogné and Shelley (1966). They will be described in more detail here.

D. 2. (a) Rock types affected

The rock types affected by the secondary structures are mostly the granitic rocks occurring along and near the lineament, including the Granites of L'Aber-Ildut, Kernilis, Kervigorn, Landunvez and the Adamellite de Ste Marguerite;

and also the (pre-lineament metamorphic) Diorite de Lanillis (figs 2 - 1, 4 - 1 3). Most of these rocks contain primary structures which are locally modified or obliterated by the secondary (D4) structures. It is commonly observed that the degree of development of secondary structures may display rapid variation in intensity across the strike of the Lineament (cf plates 4 - 1, 4 - 2).

D. 2. (b) Change of shape

The D4 deformation has caused change of shape of rock bodies in the vicinity of the lineament. This phenomenon is most obvious in the case of dykes of Adamellite de Ste Marguerite type at Presqu'Ile St Laurent (7.90/53.50) (Fig 4 - 3). The dykes themselves are locally thinned and their boundaries have apparently been rotated to approach parallelism with the trend of the lineament. The sense of rotation has not however been determined.

D. 2. (c) Internal structures

D. 2 (c) (i) Parallel fractures

In the field or in hand specimen the most obvious D4 effect is the development of closely spaced parallel fractures; the separation between adjacent fractures may be as much as 4 cm (eg. Plate 4 - 1, where the spacing is up to 2 cm) towards the margins of the zone affected by deformation; at the most intense (Plates 4 - 2, 4 - 3) spacing may be less than 1 mm where individual fractures can be differentiated at all. The occurrence of displacement along the fractures is indicated by for example the disruption of mica crystals which are traversed by the fractures (Plate 4 - 5). There may also be growth of new muscovite within and parallel to the fractures.

D. 2. (c) (ii) Schistosity

Particularly in the case of the finer grained granitic rocks such as the Granite de Kervigorn and also in the case of the Diorite de Lannilis the previously mentioned parallel fractures may be so closely spaced as to virtually obliterate earlier fabrics and texture and form a new penetrative schistosity, marked by parallel orientation of platy minerals or bands of cataclased minerals (Plates 4-2, 4-8).

D. 2. (c) (iii) Cataclasis and Mylonitisation

In thin sections of rocks from the vicinity of the Porspoder Lineament the most characteristic texture is the granulation or development of mortar texture in quartz (Plates 4 - 5, 4 - 6). A fine-grained mosaic of quartz may occupy fractures in other minerals such as muscovite and appears to have flowed around the margins of more resistant minerals such as feldspar (Plate 4 - 6). Biotite may also have been subjected to severe cataclasis and may form a fine-grained amalgam with quartz. Unfragmented micas (Plate 4 - 5) and amphiboles may be bent. Both alkali feldspars and plagioclase have tended to resist deformation but may have undergone minor rounding at the margins. Sphenes, even when very coarse (5mm) are generally intact. The following minerals are listed in order of increasing resistance to cataclastic deformation under the conditions represented by the D4 deformation quartz; biotite; muscovite; hornblende and feldspars; sphene.

The extreme result of cataclastic deformation is the development of a mylonite; where virtually the whole rock has been ground to a fine-grained schistose rock with only subordinate coarser relics (Plate 4 - 7). In the classifications of Higgins (1971), and Spry (1969) the majority of the rocks in the Porspoder Lineament zone are protomylonites; locally however as at Penar Creac'h (7.710/53.978) both mylonites and ultramylonites (Plate 4 - 7) occur.

D. 2. (c) (iv) Lineations

At many localities a pronounced lineation can be observed in addition to the planar structures. In some cases this may be an intersection lineation produced by the intersection of the primary and secondary foliations. In other cases a lineation may be produced by a linear aggregation of mineral grains such as mortarised quartz. Cogné and Shelley (1966, p 8, footnote) (see also Fig 4 - 4) have drawn attention to the presence of a double lineation in the severely cataclased rocks at Le Passage (7.710/53.978). This consists of (a) Subhorizontal striations (cf Plate 4 - 4) (b) Subvertical preferred orientation of c-axes of cataclastic quartz grains. Both these lineations lie in the plane of fracture cleavage. (It should be noted that the quartzes are not elongated parallel to their c-axes). The orientation of these lineations will be considered below in section (e).

D. 2. (d) Mineralogical changes

Growth of muscovite in the planes of the fracture cleavage has been mentioned above in section (c) (i). This is the most obvious new mineral growth. There is a general absence of chloritisation of biotite or hornblende. This observation appears to indicate that biotite was less prone to alteration within the Porspoder Lineament than for instance in the rocks of the Plouguerneau - Landunvez Complex away from the lineament. Temperatures may have been somewhat elevated in the axial zone of the lineament during the D4 movements; a similar case has been described by Sutton and Watson (1959).

An important mineralogical change has been noted by Barrière et al (1971a) in the alkali feldspars of the Granite de L'Aber-Ildut: as the Porspoder Lineament is approached the normally monoclinic megacrysts become of progressively greater triclinicity. Microscopic epidote veins which cut the Granite de L'Aber-Ildut at Porspoder may also be related to the D4 movements.

D. 2. (e) Orientation of secondary structures

The strike or trend of secondary foliations and lineations is commonly between 060° and 070°. Variable trends occur locally, notably at Presqu'ile St Laurent. The dominant trend is similar to the trend of the lineament itself. Macroscopically visible lineations commonly plunge at 10°-30° ENE. The direction of dip of the planar structures is more variable. For instance at Porspoder the predominant dip is about 55°-70° NNW (Fig 4-3); further east southerly dips predominate and at Kervigorn (7.72/53.79) the secondary structures dip SSE at about 55°-70°; further east again at Kiloudern (7.564/54.016) the dip is again about 70° north.

E. DISPLACEMENT ASSOCIATED WITH THE LINEAMENT

E. 1. Sense of displacement

The significance of the Porspoder Lineament as a boundary between the essentially metamorphic complex to the south and the largely migmatitic complex to the north has been referred to in section A of this chapter. In some localities, for instance Corn ar Gazel (Fig 3-A), rock associations characteristic of the Lannilis Metamorphic Complex outcrop north of the lineament (see Chapter 2); so that the lineament does not entirely separate the migmatitic zone from the metamorphic zone. Individual metamorphic units on the south cannot be directly correlated with individual migmatitic units on the north, although similar lithologies such as the Diorite de Lannilis to the south and the Diorite de Portsall to the north can be correlated in a general way. (The specific correlation between the Diorite de Lannilis and the Adamellite de Ste Marguerite suggested by Cogné and Shelley (1966) is incompatible with the present writer's view of the adamellite as a late post-migmatitic intrusion; see Chapter 3, section E).

Comparison of the distribution of lithological units outcropping on either side of the lineament gives little or no indication of the sense or amount of net displacement of the two sides. Cogné and Shelley (1966, p8) have suggested a net movement of about 1 km in a predominantly vertical sense with the southern complex being uplifted with respect to the northern. Their conclusion is based on the subvertical orientation of quartz c-axes in the mylonised rocks of the lineament (Fig 4 - 4) and on their(unacceptable to the present writer) correlation of the Diorite de Lannilis with the Adamellite de Ste Marguerite. In the view of the present writer the sense of movement within the cataclased rocks at the locality (Pen ar Creac'h, Fig 4 - 2) studied by Cognē and Shelley (1966) is more likely to be indicated by the subhorizontal or gently ENE plunging striation and lineation than by the sub-vertical quartz c-axis lineation. The sense of shear deformation of individual mica. grains at Kiloudern seems to suggest that at this locality the relative sense of movement in the shear deformation of the whole rock mass is sinistral. No firm evidence of sense of displacement has yet been obtained from the deformed dykes at Presqu'Ile St Laurent (7.90/53.95). It should be emphasised that this argument only suggests the sense of displacement during the formation of the D4 structures; ie movements post-dating the emplacement of the granites in and adjacent to the lineament. Some indication of the sense of movement during the formation of the primary structures (ie the initiation of a major fracture zone and emplacement of granites along the Porspoder Lineament) is afforded by the observation of preferred primary mineral orientation oblique to the margins of granites emplaced in the lineament zone (see section C. 1. (b) above. The E-W direction of this primary mineral orientation as seen for example in the Granite de L'Aber-Ildut at Porspoder (7.89/53.95) (Fig 4 - 3) seems to be consistent with a model whereby the granite at this locality was emplaced in an opening fracture where the displacement of material on opposite sides of the fracture had a sinistral component.

If the model of a net sinistral movement during successive phases of movement along the Porspoder Lineament is accepted then the present attitude of striations and lineation (commonly plunging at $10^{\circ} - 30^{\circ}$ to the ENE) suggests that the rocks to the north of the lineament have also undergone a net upward movement relative to those on the south, This conclusion is also consistent with the observation that the rocks to the north of the lineament are generally of higher grade and presumably formed at greater depth than those to the south; it is however incompatible with the conclusions of Cogné and Shelley (1966).

E. 2. Amount of displacement

An estimate of a net displacement across the Porspoder Lineament of about 1 km (in a vertical sense) has been made by Cogné and Shelley (1966). However their calculation is based on their correlation between the Diorite de Lannilis and the Adamellite de Ste Marguerite; as the correlation is unacceptable to the present writer their resulting calculation is also unacceptable.
The net displacement across the lineament can be divided into two successive components.
(i) Displacement prior to and associated with the emplacement of granitic rocks along the lineament.
(ii) Displacement associated with the formation of the secondary structures.
The total net displacement (i + ii) can only be directly

estimated by measuring the offset of an individual feature recognisable on both sides of the lineament. Perhaps the best example of such a feature is the presence of the petrographically similar diorites of Lannilis on the south and Portsall on the north. The closest approach of outcrops of these two formations is about 5.5km between Kervigorn (7.722/53.970) and Carrec Cros (Fig 3 - 1) (7.794/53.977). However there seems to be no justification for using this figure to estimate the amount of offset.

An estimate of the amount of displacement associated with the D4 structures can be made by integrating the amounts of offset along individual planes of displacement.

By this method $D = dN$, where

D = total displacement

d = mean displacement on individual planes

N = number of individual planes

The value of N is probably of the order of $10^5 - 10^6$ (ie between 1 and 10 per cm across a distance of 1.5 km). Unfortunately no satisfactory method for estimating d is available as it is difficult to measure the offset on a single plane. In the less severely deformed zones the displacement is probably rather less than the separation of the planes (ie less than 1 cm). If d 0.5 cm and N 5×10^5 then D would be equal to 2.5 km. However this figure can only be regarded as a crude estimate of the order of the amount of displacement associated with the secondary structures, and it would be inadvisable to attach much significance to it. The true figure is likely to be less than that estimated for the net displacement along the more important Lineament of Molēne-Moncontour by Chauris (1969b); ie less than about 20 km.

F. ANALOGOUS STRUCTURES ELSEWHERE IN THE MASSIF ARMORICAIN

F. 1. Lineament Molène-Moncontour-Alençon

Chauris (1969b) has drawn attention to another major structure with certain characteristics in common with the Porspoder Lineament, which also affects the rocks of the Pays de Léon. It is known by the name of Lineament Molene-Alencon or Lineament Molène-Moncontour (Fig 4 - 5). In the Pays de Léon it strikes E-W and intersects the coast at Pointe de Corsen (Fig 1 - 2). This lineament is on a much larger scale than the Po poder belt, being traceable for over 200 km (Figs 1 - 3, 3 - 4),and is characterised by severe mylonitisation (G. Williams pers comm; L. Chauris pers comm). As in the case of the Porspoder Lineament a number of granitic bodies are located along the Molène-Moncontour Lineament; they extend in lobes to north and south of it. The granites have been disrupted and locally mylonitised by subsequent movements parallel to the lineament and the offset of individually recognisable granites such as those of Commana and Plouaret has enabled an estimate of the post-granite displacement to be made (Chauris 1971c). This is of the order of 20 - 25 km in a dextral sense, contrasting with the probably much smaller sinistral disp cement in the case of post-granite (D4) movements on the Porspoder Lineament.

F. 2. Zone Broyée Sudarmoricaine

An even better known and more prominent lineament, known as the "Zone Broyée Sudarmoricaine" extends with an arcuate

ESE to southeast trend from the Pointe de Raz in southwest Finistère to the neighbourhood of Nantes (Fig 1 - 1). This lineament has also acted as a locus for emplacement of granites and their subsequent deformation along a well-defined shear-belt. The sense of displacement is dextral.

F. 3. Conclusion

There may have been a genetic connection between the three analogous strike-slip structures in West Finistère. The main movements on all three were roughly contemporaneous (Upper Carboniferous) are likely to have been due to similar or related controls. In this writer's opinion a control comparable to that suggested by Mackenzie (1972) and Dewey and Sengor (1979) to account for recent and present-day movements of "transform" type along the North Anatolian Shear Belt in Turkey may have given rise to this group of late Hercynian structures in the Massif Armoricain.

According to this interpretation the Porspoder and Molène-Moncontour Lineaments and the Zone Broyée Sudarmoricaine may be regarded as intracontinental faults of transform type. They may have developed so as to permit the change of shape required in a continental plate which was subjected to a continental collision. A fuller analysis of the strain history of these structures must, however, await more detailed field investigations.

CHAPTER 5

GEOCHRONOLOGY OF THE NW PAYS DE LÉON

A. INTRODUCTION

B. URANIUM-LEAD DATING

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F. NEW K-Ar DATING OF METAMORPHIC AMPHIBOLES FROM THE NW PAYS DE LÉON

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G. CONCLUSIONS

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4. Post D2/M2 orogenic episodes

CHAPTER 5 GEOCHRONOLOGY OF THE NW PAYS DE LÉON

A. INTRODUCTION

In the preceding chapters emphasis has been laid on description of the field relations, structure and petrography of the rocks of the NW Pays de Léon. Relative chronological sequences of events have been outlined (Ch.2, section E; Ch.3, section G) and a tentative correlation has been made between the events observed in the Lannilis Metamorphic Complex to the south of the Porspoder Lineament and the Plouguerneau/Landunvez Migmatitic and Granitic Complex to the north of this structure. Little indication has so far been given of the absolute age of lithological units and geological events. However it was suggested in Chapters 2 and 3 that the metasedimentary formations of the Lannilis Metamorphic Complex are likely to be the metamorphosed equivalents of the Brioverian, although suggestions of a Pentevrian (i.e. pre-Brioverian) or Palaeozoic origin for the same metasediments have been made by Cogné and Shelley (1966) and Cabanis (1976). It was also suggested in Chapter 2 that the meta-igneous formations of the Lannilis district may for the most part represent post-Brioverian intrusions (or, in the case of the mafic rocks, possibly contemporaneous volcanic horizons); once again other workers have suggested that certain of the meta-igneous lithologies may represent a basement, possibly Pentevrian on which the precursors of the metasediments were deposited (Shelley, 1964; Cabanis 1976). The field and petrographic evidence for the absolute chronology of the area is thus a matter of disagreement, and in this chapter an assessment is made of published isotopic dating of rocks from the NW Pays de Léon and adjacent areas. In addition some new K-Ar data is presented and interpreted. An outline absolute chronology of the NW Pays de Léon is presented in Table 5-5. The chronology of geological events in the SW Pays de Léon will be considered separately in Chapter 7.

B. URANIUM-LEAD DATING

1. Introduction

The only available published U-Pb dating of rocks from the NW Pays de Léon is the work of Deutsch and Chauris (1965). Their results are quoted here as given in the original publication, where they were calculated using the following decay constants:

$$\lambda\ {}^{238}U = 1.54 \times 10^{-10}\ yr^{-1}$$

$$\lambda\ {}^{235}U = 9.72 \times 10^{-10}\ yr^{-1}$$

Recalculation using the decay constants of Jaffey et al (1971) would result in a decrease in the calculated ages of about 1%. Deutsch and Chauris do not indicate how the errors which they quote were calculated.

It should be emphasized that in the above study only single samples of minerals (zircons) were analysed and therefore discordia-concordia intersection ages using multiple size or magnetic fractions (see, e.g. Pidgeon and Bowes, 1972) cannot be calculated.

2. Lithological Units predating the D2/M2 orogenic episode

The only formation in or adjacent to the NW Pays de Léon predating the D2/M2 orogenic episode from which zircons were dated by Deutsch and Chauris (1965) was an augen gneiss from Plounevez-Lochrist (Fig 5-1). This gneiss almost certainly belongs to the Plouider and Plounevez-Lochrist group of granitic gneisses referred to in Chapter 2, section 2 (a)(II)(iii) and correlated by Chauris (1972c) with the Gneiss de Tréglonou. The authors mention the presence of tourmaline in their sample; in the view of the present writer the tourmaline in this group of granitic gneisses could have been introduced during a metasomatic event distinct from and later than the main metamorphic and deformational event D2/M2. It is at least possible that this metasomatic event may have disturbed the uranium and lead systems in the zircons of the sample, so that the quoted dates may bear little relation to the true age of the mineral or the rock.

Deutsch and Chauris do not give their analytical data but their calculated ages for the zircons from this gneiss are:

$^{207}Pb/^{206}Pb$: 440 ± 20 m.y.

$^{207}Pb/^{235}U$: 364 ± 10 m.y.

$^{206}Pb/^{238}U$: 351 ± 10 m.y.

The authors (op.cit.p.616) consider that the zircons probably originally crystallised at or earlier than 450 m.y. They point out however that it is not clear whether the zircons are (i) of xenocrystic origin ("détritique") and thus possibly derived from a basement of age greater than 450 m.y., or (ii) authigenic, in which case the date gives a minimum age for the gneiss-forming event. In the view of the present writer the recognition of at least three major events (emplacement, metamorphism and metasomatism) in the history of this lithological unit makes the interpretation of a single U-Pb analysis excessively ambiguous, particularly when the apparent age is discordant as in this case.

The writer would agree with Deutsch and Chauris that the zircons in the sample are probably greater than 450 m.y. old, but the possible presence of a detrital component in the zircons means that the emplacement date of the granite precursor of the augen gneiss remains unknown, as far as the evidence from this sample is concerned. It may have been either earlier or later than 450 m.y. It is possible that the two independent U/Pb dates in the range 365-350 m.y. may represent an actual geological event at this time; they may on the other hand represent lead loss at some time subsequent to 365-350 m.y.

In the same study Deutsch and Chauris also analysed a sample of a granodioritic gneiss ('Granodiorite de Pont-Cabioc'h'; described by the authors as 'Gneiss de Brest') from the SW Pays de Léon. The significance of the virtually concordant U-Pb zircon single sample age of

$^{207}Pb/^{206}Pb$: 460 ± 70

$^{207}Pb/^{235}U$: 458 ± 30

$^{206}Pb/^{238}U$: 459 ± 15 is discussed in Chapter 7. It is sufficient at this stage to point out that if this date approximates to the date of emplacement of the Granodiorite de Pont-Cabioc'h, then the deformational and metamorphic gneiss-forming event which has affected the granodiorite would appear to have been subsequent to about 460 m.y. If this gneiss-forming event is correlatable with the D2/M2 episode in the NW Pays de Léon then the latter would also appear to have been later than c. 460 m.y. ago.

3. Lithological Units post-dating the D2/M2 orogenic episode

(a) Granite de St Renan

Deutsch and Chauris (1965) analysed a single sample of zircons from the Granite de St Renan (Fig 5-1). This granite, whose outcrop marks a convenient boundary between the SW and NW sectors of the Pays de Léon has not been studied in detail in the present work. South of Pointe de Corsen it can be observed to be intrusive into the 'Gneiss de Lesneven' (Fig 1-6). At the locality Quarry of Langongar near St Renan, Fig 5-1, where Deutsch and Chauris collected their sample the granite displays no sign, in the opinion of the present writer, of any deformational or metamorphic event comparable with the D2/M2 orogenic episode as seen in the Lannilis Metamorphic Complex. In view of this, the nearly concordant U-Pb single sample zircon age of $^{207}Pb/^{206}Pb$:

347 ± 30; $^{207}Pb/^{235}U$: 348 ± 10; $^{206}Pb/^{238}U$: 348 ± 10, which is interpreted by Deutsch and Chauris as being close to the emplacement age of the granite, seems to represent a minimum possible age of the D2/M2 episode in the NW Pays de Léon.

(b) Granite de L'Aber-Ildut

Deutsch and Chauris (1965) also analysed a single sample of zircons from the pink porphyritic facies of the Complexe Granitique de L'Aber-Ildut from the quarry of Glizit near Lanildut. The nearly concordant date of $^{207}Pb/^{206}Pb$: 278 ± 30; $^{207}Pb/^{235}U$: 272 ± 8; $^{206}Pb/^{238}U$: 271 ± 8 was interpreted by the authors as being close to the emplacement age of the granite. This date however poses a problem in that it is lower than the K-Ar date of 298 ± 9 m.y. obtained by Adams (1967a) for biotite from the same locality and the same lithology as that sampled by Deutsch and Chauris; and also lower than the Rb-Sr biotite age (303 ± 15 if recalculated to $\lambda\ ^{87}Rb = 1.42 \times 10^{-11} yr^{-1}$) obtained by Deutsch and Chauris from the same sample from which they extracted the zircons. The emplacement age may indeed have been as great as c.319 m.y. (see below, section C.3(b)). Since U-Pb systems in zircons are generally considered to be more resistant to disturbance than Rb-Sr and K-Ar systems in micas, it is surprising that such a low date was obtained for the L'Aber-Ildut Granite zircons. It is possible that in this case the U-Pb system in the zircons was more sensitive to some later disturbance than the Rb-Sr and K-Ar systems in the biotites. In any case further investigation is probably desirable to confirm and explain the earlier results.

C. RUBIDIUM-STRONTIUM WHOLE-ROCK DATING

1. Introduction

In this section and the following one all Rb-Sr dates quoted have been calculated or recalculated using $\lambda^{87}Rb = 1.42 \times 10^{-11} yr^{-1}$.

Various workers have carried out Rb and Sr analyses of whole rock samples from the NW Pays de Léon and adjacent areas. For the most part the published dates derive from analyses of single samples rather than sets of samples from a single lithological unit, and are therefore model dates (i.e. with an assumed initial Sr ratio) rather than isochron dates.

In some cases (e.g. Leutwein et al, 1969a, table 1; Adams, 1967a, table 9) samples from distinct and often widely separated lithological units have been grouped together in an attempt to obtain isochron ages. However in the absence of firm eveidence that the samples so grouped are truly cogenetic, the validity of this procedure is questionable, and in the opinion of the present writer it is inadvisable to place much reliance on the 'isochron' dates so obtained.

In those cases (e.g. Deutsch and Chauris, 1965) where no analytical data are included in the publication no critical assessment of the published dates can be made and whole rock Rb-Sr 'dates' of this nature have been ignored by the present writer. In most cases however, the original analytical data is provided and thus even where only a single sample from a given lithologicalunit was analysed some information as to the possible age and/or initial $^{87}Sr/^{86}Sr$ ratio of the sample may be obtained. In the case of single samples with relatively low $^{87}Rb/^{86}Sr$ ratio (say <10) it is not possible to calculate or estimate a date within close limits, but even for a wide range of possible ages the initial Sr ratio may be fairly closely defined. Conversely, for single samples with relatively high $^{87}Rb/^{86}Sr$ (say greater than 20) considerable variation in the (assumed) initial $^{87}Sr/^{86}Sr$ ratio has relatively little effect on the calculated date, which may thus be estimated within fairly close limits.

Additional constraints on the calculated age and/or initial ratio may be obtained by combination of published Rb-Sr analyses of minerals extracted from some of the whole rock samples with the whole rock analyses. If the Rb/Sr ratio of the mineral is sufficiently different from that of the whole rock, calculation of 'mineral isochron' dates may be possible. In general such dates would represent a minimum possible age for the particular whole rock sample. Conversely the calculated initial Sr ratio of a mineral-whole-rock pair represents a maximum for the initial Sr ratio of the whole rock system.

In certain cases there may be justification for grouping together analyses of whole rock samples which were not grouped together in the original publication, or which derive from different authors. This may be the case where there is evidence to suggest that the samples concerned are actually cogenetic. If the range of Rb/Sr ratios of the samples is sufficiently wide, an approximation (albeit not an ideal one) to a whole rock 'isochron' date (and whole rock initial Sr ratio) may be obtained. This procedure has to be applied with some caution, particularly in cases where the original analyses may not have been performed under identical conditions.

2. Lithological units pre-dating the D2/M2 orogenic episode

The single sample described by Adams (1967a) as 'Mica-gneiss from St Pabu' is in fact a sample of Gneiss de Treglonou from the quarry north of Locmajan on the south bank of L'Aber-Benoit (Adams, pers. comm.)(Fig 5-1). The high $^{87}Rb/^{86}Sr$ ratio of this sample (see table 5-1) enables one to place some constraint on the possible age of the lithological unit (always assuming the whole rock sample has remained a closed system to Rb and Sr since its emplacement or formation).

If one assumes that the minimum possible value for the initial $^{87}Sr/^{86}Sr$ ratio of the sample is 0.701, the maximum possible age of the rock is c.382 m.y. ($\lambda\ ^{87}Rb = 1.42 \times 10^{-11} yr^{-1}$) (see figure 5-2). An initial ratio of 0.703 would give an age of 377 m.y. With increasing assumed initial ratio the maximum possible age for the whole rock system is < 377 m.y. It has however been observed that much of the typical Gneiss de Tréglonou lithology in this particular quarry and elsewhere has undergone apparently metasomatic tourmalinisation at some time subsequent to the imposition of the gneissic structure. It is thus not possible from this sample alone to be certain that the calculated ages above represent the original rock-forming event. There may have been some disturbance of the whole rock Rb/Sr system associated with the tourmalinisation event.

Results obtained by workers at the University of Rennes in conjunction with B.Cabanis indicate that a suite of about seven samples of Gneiss de Tréglonou (both banded and augen-gneiss) lithology from both the Tréglonou and eastern (Plounevez-Lochrist) outcrops fall on a straight line with a whole-rock Rb-Sr isochron date of c.380 m.y. (Peucat, pers comm.; Cabanis, pers comm.). The authors however are uncertain whether to interpret this date as that of the original formation of the precursor of the Gneiss.

Until further information is obtained, possibly in the form of U-Pb zircon discordia-concordia intersections, it would seem advisable to treat these whole rock Rb-Sr dates for the Gneiss de Tréglonou with some caution. At present the only available estimates of the date of the original formation or emplacement of the precursor of the Gneiss de Tréglonou are given by this figure of c.380 m.y. and the figure of $>$ 450 m.y. derived by Deutsch and Chauris (1965) from their Plounevez-Lochrist zircon data (section B.2 above).

3. Lithological units post-dating the D2/M2 orogenic episode

(a) Complexe Granitique de St Renan-Kersaint

The Granite de Kersaint is considered by Chauris (1972c, p.18) to be cogenetic with the Granite de St Renan. However in view of the poor exposure in the interior of the Pays de Léon the relations between the two granites are nowhere clearly displayed and the evidence for cogeneticity is not absolutely conclusive.

A sample of the Granite de Kersaint was included by Adams (1967a) with 4 other granite samples, only one of which was from the Pays de Léon, in a 5-point 'isochron' with a slope giving an age of 332 ± 5 m.y. ($\lambda\ ^{87}Rb = 1.42 \times 10^{-11} yr^{-1}$). In the opinion of the present writer the Plouaret, Guingamp and Quintin Granites are too far removed from the outcrop of the Granite de Kersaint to justify the assumption of cogeneticity and a common initial Sr ratio (see Fig 1-1). Combination of Adams' two samples from the Granite de Kersaint and the Granodiorite de Trégana (from the SW Pays de Léon, Fig 5-1) enables one to calculate a two point 'isochron' date of 341 m.y. (initial Sr ratio = 0.706). The value of this figure is, however, doubtful.

Another estimate of the age of the Complexe Granitique de St Renan-Kersaint might be obtained by combining Adams sample of the Granite de Kersaint with a sample from the same complex analysed by Leutwein et al (1969a). The two samples are of widely differing Rb/Sr ratio (see table 5-1) and the resulting calculated 'age' is c.387 m.y. (Fig. 5-2, table 5-4). The initial Sr ratio in this case would be 0.701; as this value seems improbably low it seems likely that the true figure for the emplacement date of the granite complex is < 387 m.y. In any case it seems possible that not all the assumptions required for application of the isochron method are satisfied, and so not much reliance can be placed on either the date or initial ratio obtained by the above calculation.

A minimum value for the emplacement age of the Granite de St Renan is given by the $^{207}Pb/^{206}Pb$ zircon age of 347 ± 30 (or 343 ± 30 using the decay constants of Jaffey et al, 1971), and if the St Renan and Kersaint Granites are in fact cogenetic, the true age of the complex would appear to be between 343 m.y. and 387 m.y.

(b) Complexe Granitique de L'Aber-Ildut

Adams (1967a) grouped his single sample of Granite de L'Aber-Ildut (pink megacrystic facies) with 3 samples of the Trégastel (or Ploumanac'h) Granite Complex (Cotes-du-Nord), and one sample of the Granite de Flamanville (Manche) to arrive at an age of 294 ± 5 m.y. ($\lambda\ ^{87}Rb = 1.42 \times 10^{-11}yr^{-1}$) for the three complexes. However, Adams' own biotite-whole-rock pair from the Granite de Flamanville has a Rb-Sr age of 308 ± 7, which indicates that the whole rock age of that granite must be > 308 ± 7 m.y. It is in any case likely that the Granite de Flamanville, which is widely separated from the Trégastel complex, is not cogenetic with the latter, and should not be included on the same isochron. A similar consideration may apply to the Granite de L'Aber-Ildut which is separated by moree than 60 km from the Trégastel Complex. In view of this problem regarding the cogeneticity of widely separated intrusions it seems inadvisable to group Adams L'Aber-Ildut sample with his 3 Trégastel samples.

The Rb/Sr ratio of Adams' L'Aber-Ildut sample is rather low, (table 5-1) and so by itself the sample is of little value for deriving a date. However Leutwein et al (1969a) have published Rb and Sr analyses of a single sample of the Granite de Ploudalmézeau, which is the later central facies of the Complexe Granitique de L'Aber-Ildut (Fig 5-1). The Rb/Sr ratio of this sample is high enough (see table 5-1) to enable calculation of a two point 'isochron' date in combination with Adams' analysis of the megacrystic facies. (Fig 5-2). The resulting date is c.319 m.y. (error not calculated but likely to be small). In the absence of a full scale whole rock Rb-Sr isochron study of the Complexe Granitique de L'Aber-Ildut, this date is regarded by the present writer as the best available estimate of the Rb-Sr whole rock 'age' (and thus the date of emplacement) of the complex. It may be noted that a biotite whole rock Rb-Sr date of c.295 m.y. has been obtained from the Granite de Ploudalmézeau (see below, section D, 2(b)).

(c) Filons microgranitiques

Chauris et al (1977) obtained an Rb-Sr whole rock isochron date of 293 ± 5 m.y.* ($^{87}Rb = 1.47 \times 10^{-11}yr^{-1}$) for seven samples of 'Filons microgranitiques' from the sector between Ploudalmézeau and Ploumoguer (see Chapter 2, section D.3). The initial

* Note: this data was received too late to be included in the tables.

$^{87}Sr/^{86}Sr$ ratio is 0.7077 ± 0.0010. If this date is accepted as the date of emplacement of the filons microgranitiques, it represents a minimum age for the emplacement of the other facies of the Complexe Granitique de L'Aber-Ildut (the Granite de L'Aber-Ildut and the Granite de Ploudalmézeau).

These results have not been included in table 5-1 or in figures 5-1 and 5-2. Nonetheless the writer is of the opinion that this date of 293 ± 5 m.y. probably represents the most reliably established isotopic date from the NW Pays de Léon.

(d) Granite de Landunvez

The Rb/Sr ratio of the sample of Granite de Landunvez (Fig 5-1, point 9) from Grève de Tréompan analysed by Leutwein et al (1969a) is rather low (table 5-1; Fig 5-2) and so any model age calculated from their analyses is sensitive to error in the value chosen for the initial $^{87}Sr/^{86}Sr$ ratio. The authors used an arbitrary value of 0.712 to arrive at their date of 497 ± 30 m.y. However choice of a lower initial ratio of, say, 0.703 would result in a much greater calculated age of c.859 m.y.; while if the initial ratio were greater than 0.712 then the age could be considerably less than 497 m.y. The lowest possible age for the formation of the whole rock would appear to be the Rb-Sr biotite age of the same sample, viz 277 m.y. (see below). The initial Sr ratio in the latter case would be 0.717 and this figure therefore represents a maximum possible value of the ratio for this sample. In fact the true Rb-Sr whole rock isochron age must be intermediate between the biotite age and the age of the D2/M2 orogenic episode, whose climax predated the emplacement of the Granite de Landunvez. More precise dating of the emplacement of the Granite de Landunvez and the other granitic rocks to the north of the Porspoder Lineament must await further work using techniques such as Rb-Sr whole-rock isochron and U-Pb zircon dating.

D. RUBIDIUM-STRONTIUM MINERAL DATING

1. Introduction

Leutwein et al (1969a) list a number of Rb/Sr analyses of minerals separated from their whole rock samples. They calculated 'ages' for these mineral separates using an arbitrary value for $^{87}Sr/^{86}Sr$ of 0.712. However more significant results may in some cases be obtained by combining analyses of a mineral with analyses of the whole-rock that the mineral is derived from. A number of ages calculated from the data of Leutwein et al using this procedure are shown in table 5-4.

2. Lithological units post-dating the D2/M2 orogenic episode

(a) Complexe Granitique de St Renan-Kersaint

Leutwein et al (1969a) carried out Rb-Sr analyses of K-Feldspar, amphibole and whole-rock from a single sample of the Granite de Kersaint (Table 5-1, Fig 5-2). The whole-rock Rb/Sr ratio is intermediate between those of the two minerals but the whole-rock point lies well off the line joining the two mineral points on a Nicolaysen diagram. The latter line has a slope corresponding to a date of 326 m.y. ($\lambda\, ^{87}Rb = 1.42 \times 10^{-11} yr^{-1}$) with initial $^{87}Sr/^{86}Sr$ 0.710. It is not clear how much significance can be attached to this date. If it is significant it is likely to represent a 'mixed' age intermediate between the emplacement of the granite and some later disturbance.

(b) Complexe Granitique de L'Aber-Ildut

No published Rb-Sr mineral analyses are available for the outer megacrystic facies (Granite de L'Aber-Ildut).

Leutwein et al (1969a) analysed whole-rock, K-Feldspar, biotite and muscovite from a sample of the Granite de Ploudalmézeau (Table 5-1, Fig 5-2). Reliable dates cannot be calculated for the pairs whole-rock/K-Feldspar and biotite/muscovite respectively as the Rb/Sr ratios in each case are too close. Combination of their biotite analysis with their whole rock and K-Feldspar analysis gives dates of 295 m.y. and 297 m.y. respectively. Similar combination of muscovite with whole-rock and K-Feldspar gives dates of 285 m.y. and 286 m.y. respectively (Table 5-4). It is thought that the range of Rb/Sr ratios in each of these cases is sufficient to enable one to place some confidence in the significance of the calculated dates. It is not clear however what interpretation to place on the dates. If the emplacement of the Complexe Granitique de L'Aber-Ildut was, as suggested in section C.3.(b) above, at about 319 m.y., then these mineral dates may either represent the termination of a relatively long period of cooling and uplift, or

TABLE 5-1 Previously published Rb-Sr analyses of rocks and minerals from NW Pays de Lēon and adjacent areas

Author	Sample	Locality	Lithological Unit	Mineral or Whole Rock	Rb ppm	Sr ppm	$^{87}Rb/^{86}Sr$	$^{87}Sr/^{86}Sr$
Adams,1967a	1081	St.Pabu	Mica-gneiss = Gn.de Trēglonou	WR	355	33	31.0	0.8696
Adams,1967a	1116	Trēgana	Granodiorite de Trēgana	WR	20	1110	0.06	0.7060
Adams,1967a	1085	Bohars	Granite de Kersaint	WR	317	133	6.88	0.7391
Leutwein et al 1969a	8	?	Granite de Kersaint	WR	171.4	19.3	25.36	0.8409
				K-Feldspar	264.1	24.7	30.40	0.8516
				Amphibole	142.5	21.2	18.95	0.7985
Adams,1967a	1080	Melon	Granite deL'Aber-Ildut	WR	232	372	1.81	0.7160
Leutwein et al 1969a	12	Ploudal-mēzeau near water tower	Granite de Ploudalmēzeau	WR	397	23.7	48.73	0.9292
				K-Feldspar	471	35.6	37.63	0.8661
				Biotite	2309.4	9.7	934.5	4.6518
				Muscovite	1335	5.7	904.5	4.3946
Leutwein et al 1969a	6	Greve de Trēompan	Granite de Landunvez	WR	219.2	368	1.6953	0.7238
				K-Feldspar	346.3	554	1.7806	0.7211
				Biotite	838.9	17.1	147.0	1.296

alternatively some thermal or tectonic disturbance later than and distinct from the emplacement of the complex.

Another possibility is that there may have been in fact a considerable interval between the emplacement of the two facies.

(c) Granite de Landunvez

Leutwein et al (1969a) analysed whole-rock, K-Feldspar and biotite (Table 5-1) from the Granite de Landunvez (Fig 5-1, locality 9) at Grève de Tréompan (Fig 3-1). The authors suggested a model age of 350 m.y. for the K-Feldspar, but the low Rb/Sr ratio of this mineral means that any variation in their assumed initial Sr ratio of 0.712 would have a considerable effect on the calculated age. However the same authors' biotite analysis can be combined with either the whole-rock or K-Feldspar analysis to give mineral 'isochron' ages of 278 or 277 m.y. respectively (Table 5-4). The great difference in Rb/Sr ratio between the biotite and the other material enables me to place some confidence in the significance of this date. It is not immediately clear, however, what interpretation to put on the date. It is noteworthy that this date is almost 20 m.y. younger than the analogous biotite date for the Granite de Ploudalmézeau (see section (b) above). The difference between the two dates might be due to greater depth of burial and resulting slower cooling in the case of the Landunvez biotite.

E. PREVIOUS K-AR DATING

1. Introduction

K-Ar dates in the publications quoted have been calculated or recalculated using the following constants:

$$\lambda_K = 0.585 \times 10^{-10}\ yr^{-1}$$
$$\lambda_\beta = 4.72 \times 10^{-10}\ yr^{-1}$$
$$^{40}K/K = 1{\cdot}19 \times 10^{-4}$$

Application of the constants suggested by Beckinsale and Gale (1969) would result in an increase of between 6 and 7 m.y. for dates between 270 and 340 m.y.

2. Lithological units predating the D2/M2 orogenic episode: Diorite de Lannilis

Adams (1967a) obtained a date of 277 ± 8 m.y. from a sample described as biotite (K = 3.00% wt.) from the Diorite de Lannilis at L'Aber-Benoît. This date appears to represent a relatively late event in the history of the rock unit; its significance will be considered below, where the results of new K-Ar analyses of hornblendes from the same lithology are presented.

3. Lithological units post-dating the D2/M2 orogenic episode

(a) Complexe Granitique de St Renan-Kersaint

Leutwein et al (1969b) give a K-Ar date of 340 ± 15 m.y. for K-Feldspar from the Granite de St Renan at Langongar. This figure may represent a cooling date subsequent to the emplacement of the granite.

Adams (1967a) gives a K-Ar age of 303 ± 9 for biotite from the Granite de Kersaint at Bohars. This date appears to result from Ar loss in some event subsequent to the emplacement of the granite, which if this granite was contemporaneous with the Granite de St Renan, was earlier than c.340 m.y. (see section B above).

(b) Complexe Granitique de L'Aber-Ildut

Adams (1967a) reports a date of 298 ± 9 m.y. (Table 5-2) for biotite from the pink megacrystic facies (Granite de L'Aber-Ildut) at Melon (Fig 5-1, locality 7). This date may represent a 'cooling' age subsequent to the emplacement of the granite or alternatively Ar loss in some post-emplacement disturbance.

Leutwein et al (1969a and b) report dates of 282 ± 25 and 270 ± 25 for muscovite and biotite (Table 5-2) respectively from the Granite de Ploudalmézeau (Fig 5-1, locality 8). It is notable that while the Rb-Sr and K-Ar analyses give approximately the same date for muscovites from this lithology, the K-Ar date for biotite is more than 20 m.y. younger than the Rb-Sr date for the same mineral.

(c) Granite de Landunvez

Leutwein et al (1969a) give a K-Ar date of 280 ± 20 m.y. (Table 5-2) for biotite from the Granite de Landunvez at Grève de Tréompan (Fig 5-1, locality 9). The date is similar to the Rb-Sr date for

TABLE 5-2 Previously published K-Ar dates of minerals from the NW Pays de Lēon and adjacent areas

Author	Sample No	Locality	Lithological Unit	Mineral	K.Wt %	^{40}Ar 10^{-4} scc/g / ^{40}Ar $\times 10^{15}$ at/g.	% atmosph.	Date m.y.	± error m.y
Adams, 1967a		L'Aber-Benoît	Diorite de Lannilis	Biotite	3.00	0.349	2	277	8
Adams, 1967a	1137	Trēgana	Granodiorite de Trēgana	Biotite	7.85	1.023	3	300	9
Adams, 1967a	1085	Bohars	Granite de Kersaint	Biotite	7.56	0.992	2	303	9
Leutwein et al, 1969a		Langongar	Granite de St. Renan	K-Feld-spar	10.55	4.01	not measured	340	15
Adams, 1967a	1080	Melon	Granite de L'Aber-Ildut	Biotite	7.41	0.931	2	298	9
Leutwein et al, 1969a,b	12	Ploudal-mēzeau (near water tower)	Granite de Ploudalmēzeau	Biotite	7.28	2.236	not measured	270	25
				Muscovite	8.14	2.630	not measured	282	25
Leutwein et al, 1969b	6	Greve de Trēompan	Granite de Landunvez	Biotite	7.48	2.392	not measured	280	20

$\lambda_\epsilon = 0.585 \times 10^{-10}\ yr^{-1}$
$\lambda_\beta = 4.72 \times 10^{-10}\ yr^{-1}$
$^{40}K/K = 1.19 \times 10^{-4}$

biotite from the same sample (Table 5-1) and is likely to represent the same event.

F. NEW K-AR DATING OF METAMORPHIC AMPHIBOLES FROM THE NW PAYS DE LÉON

1. Purpose of Study

In view of the importance of the D2/M2 orogenic episode in the geological history of the NW Pays de Léon and the fact that little or no direct geochronological evidence of the age of this episode has yet been found, it would be useful to date minerals which apparently crystallised during this episode. With this aim in mind a joint study was undertaken by the present writer and Dr J.G. Mitchell of the University of Newcastle-on-Tyne.

2. Sampling and Analysis

Amphibole-bearing samples were collected from various dioritic and mafic lithologies in the Complexe Métamorphique de Lannilis and the Complexe Migmatitique de Plouguerneau. Sample localities are shown in Figure 5-3. Mineral separation was carried out at the University of Keele using procedures suggested by Dr D.M. Alderton. Considerable care was taken to remove impurities particularly of K-rich minerals such as biotite which was originally present in many of the samples and which might have contaminated the amphibole separates. Sphenes were also separated from two of the samples. A noticeable quantity of pyrite remained in the sphene separates, but it is not thought that the amount (< 5%) had a significant effect on the analytical results.

Analyses of K (by flame photometer) and for Ar isotopes (by mass spectrometer) were carried out at the University of Newcastle-on-Tyne. Analytical results are given in Figure 5-4 and Table 5-3.

3. Interpretation

(a) Distribution of dates using conventional calculation

Using conventional methods of calculation all the amphibole dates fall between 294 ± 4 and 255 ± 4 m.y. The most generally accepted way to interpret such dates is to conclude that whether or not the hornblendes originally crystallised during an earlier episode (such as the D2/M2 orogenic episode, which may have taken place some time in the interval 380 - 350 m.y.) they underwent during the interval

TABLE 5-3 K-Ar analyses of hornblendes and sphenes from the NW Pays de Lēon

Sample No	Locality	Lithological unit	Lithology	Mineral	Crushed mesh interval	K_2O	w/m mm^3 gm^{-1} $x10^{-3}$	%At	Date m.y.	Error
127	Kerros	Diorite de Porsal	BI-HB-DIORITE	HB	90-60	0.933	9.72	26.5	291	3
129	Kerros	" " "	" " "	HB	120-90	0.596	5.93	34.8	279	4
140	Corn Ar Gazel	Unclassified Migmatitic Gneisses	MAFIC AMPHIBOLITE (POD)	HB	90-60 120-90	0.462 0.484	4.56 4.58	33.7 42.6	277 266	4 3
161	Locmajan	Amphibolites de L'Aber-Benoît	MAFIC AMPHIBOLITE	HB	120-30	0.633	6.20	44.0	275	4
198	Locmajan	" "	" "	HB	120-90	0.678	6.12	28.5	255	4
199	Locmajan	" "	" "	HB	90-60	0.591	6.00	19.1	284	4
203	Prat Pol	Diorite de Lannilis	BI-HB-DIORITE	HB	90-60	1.510	15.35	13.8	285	3
211	Kerouartz	" "	" "	HB	120-90	1.464	15.40	11.5	294	4
214	Pont de Trēglonou	" "		HB	60-30 90-60	0.740 0.657	6.84 6.18	22.7 25.4	261 265	4 3
239	Greve de Trēompan	Diorite de Porsal	BI-HB-DIORITE	HB	120-60	1.372	13.47	11.3	276	3
282	Pointe de Penvir	" " "	HB-LEUCODIORITE	HB	90-60	1.333	13.66	16.0	287	3
313	Creach an Avel	Migmatites de Plouguerneau	MAFIC AMPHIBOLITE	HB	150-60	0.510	4.73	35.5	261	5
127	Kerros	Diorite de Porsal	BI-HB-DIORITE	Sphene (Pyrite Impurity)	120-30	0.050	0.775	78.4	420	50
214	Pont de Trēglonou	Diorite de Lannilis	PYRIBOLITE	Sphene	90-30	0.069	0.959	60.7	380	20

$\lambda_\varepsilon = 0{\cdot}584 \times 10^{-10}\ yr^{-1}$ $\lambda_\beta = 4{\cdot}72 \times 10^{-10} yr^{-1}$ $^{40}K/K = 1{\cdot}19 \times 10^{4}$ atom %

294 - 255 m.y. either (re)crystallization or loss of radiogenic argon, the latter due presumably to some thermal or other disturbance. The two sphene dates suggest that older minerals may have survived in the complex, but not enough is known about the behaviour of Ar in this mineral to be certain about this conclusion. In any case the K and radiogenic Ar contents of the sphenes are so low that one cannot attach any precise significance to these two dates.

(b) Significance of possible 'initial' Ar

The variation in the hornblende dates between c.294 m.y. and c. 255 m.y. can be accounted for in a number of different ways:

(i) Uplift and cooling of the complexes starting before 294 m.y. and coming to a close (soon) after 255 m.y.

(ii) Partial loss of radiogenic Ar in distinct episode(s) of disturbance subsequent to 294 m.y.

(iii) Variation in Ar retentivity due to variation in such physical properties as grain size, etc.

(iv) Incorporation in the hornblendes of 'initial' Ar of a different isotopic composition from that of modern atmospheric Ar.

The remarks of Hayatsu and Carmichael (1970) on the presence of 'initial' Ar in rocks which have undergone an orogenic episode, and of Pankhurst et al (1973) on 'excess' Ar in metamorphic hornblendes, suggest the fourth of the above hypotheses could account for much of the variation in the hornblende dates. Figure 5-4 shows that a best fit line (drawn by eye) through the hornblende points on a $^{40}Ar/K_2O$ diagram has a negative intercept on the Ar axis; this may indicate that small amounts of 'initial' Ar of $^{40}Ar/^{36}Ar$ ratio < 296 may have been incorporated in some of the hornblendes at the time when they commenced their accumulation of 'new' radiogenic Ar. The fact that the points diverge significantly (in excess of experimental error) from the best fit line is explicable by the possibility that the amounts of 'initial' Ar (relative to K_2O) may have varied from one sample to another. The best fit line has a slope corresponding to an 'age' of approximately 295 m.y., and all the hornblendes may have started to accumulate radiogenic Ar at this time. There is evidence that variation in the grain size of the hornblendes (as represented in the mesh size fraction obtained in the separation process) may have had some effect on the Ar retentivity and thus on the apparent age obtained, but this effect would seem to have been subordinate.

(c) Geological significance of the hornblende dates

If it is accepted that the hornblendes commenced (or recommenced) accumulation of radiogenic Ar at around or shortly after 295 m.y., the question remains: what geological phenomenon does this date represent? It should be emphasized that isotopic dates of this type essentially represent the cessation of open-system conditions; that is to say, what is being dated is the time when the level of some activity, whether thermal, tectonic or other, became insufficient to cause continued freedom of movement of the radiogenic element relative to the radioactive element. The climax of the particular episode of activity may have been at an unknown (but often assumed to be short) interval prior to the date actually obtained from the analysis.

On the assumption that the interval involved was short one can consider the followed established geological events as possible causes of the activity which ceased at around 295 m.y.:

(i) Emplacement of part or the whole of the Complexe Granitique de L'Aber-Ildut and other related granitic intrusions;

(ii) The D3 orogenic episode, involving regional tectonic and probably thermal activity in the metamorphic and migmatitic rocks of the Lannilis and Plouguerneau-Landunvez districts.

The observations of Hart (1964) on the variation in apparent ages of minerals at varying distances from the contact of a granitic intrusion enable one to conclude that the hornblende samples seem to have been taken at sufficient distances (tens of metres to several kilometres) from contacts with major granitic bodies to avoid total loss from the hornblendes of radiogenic Ar accumulated during the interval between the supposed primary crystallisation of the metamorphic minerals in the D2/M2 episode (i.e. at about 380-350 m.y.) and the emplacement of the postmetamorphic granites such as the L'Aber-Ildut complex. It is probable that the hornblende dates represent a more widespread and regional event than the intrusion of the L'Aber-Ildut complex and the most likely explanation is that the dates represent the cessation of tectonic and thermal activity subsequent to the D3 orogenic episode.

(d) Physical conditions indicated by the K-Ar data

It is concluded that the physical conditions during the D3 orogenic episode were sufficiently severe on a regional scale to cause the hornblendes either to recrystallize, or more probably, as there is little indication of the destruction of M2 hornblende fabrics and textures, simply to lose their previously accumulated radiogenic Ar.

If the prevailing temperature was the critical factor causing Ar loss, then this is likely to have been in excess of about 450°. However insufficient information is available as to the relative importance of thermal, dynamic, chemical and other factors in causing rocks and minerals to behave as open systems with respect to radiogenic elements to enable one to attribute the Ar loss in this case to thermal causes alone. Some workers (e.g. Dr J.A. Miller, pers.comm.) consider that deformation can be more important than temperature in causing Ar loss.

G. CONCLUSIONS

1. Pre-D2/M2 Lithological units

(a) Metasediments

Relatively meagre geochronological evidence is available for the history of the NW Pays de Léon prior to the D2/M2 episode. In particular no direct geochronological evidence for the age of the parent rocks of the Mica-schistes de L'Aber-Wrach and Gneiss à sillimanite de L'Aber-Benoît is available. All that can be done is repeat this suggestion that the mostly likely derivation of the metasediments is from material similar to the Brioverian, which in the southern part of the Pays de Léon is demonstrably pre-Ordovician and also pre-Granodiorite de Brest (i.e. earlier than about 550 m.y.; see below, chapter 7.)

(b) Granitic gneisses

Since the 'mica-gneiss' from St.Pabu analysed by Adams (1967a) was a sample of the Gneiss de Tréglonou, then the apparent Rb-Sr whole-rock age of this lithology is not greater than 377-382 m.y. ($\lambda\,^{87}Rb$ = $1.42 \times 10^{-11} yr^{-1}$). Confirmation of this maximum apparent age for the granitic gneisses of the NW Pays de Léon has been obtained by P. Vidal and co-workers (personal communication) in the form of an RB-Sr whole-rock isochron date of about 370 my for samples of the granitic gneisses of the Tréglonou and Plouider districts. The $^{207}Pb/^{206}Pb$ date of 440 m.y. for zircon from the granitic gneiss at Plounevez-Lochrist is not necessarily inconsistent with an emplacement age of c.380-370 m.y. for the granitic precursors of the gneisses, as the zircons could include a component inherited from older possibly detrital rocks.

Some doubt is placed on the validity of these Rb-Sr dates by the observation that these granitic gneisses have commonly undergone tourmaline metasomatism.

(c) Diorites of Lannilis and Portsall

The K-Ar sphene dates of 420 ± 50 and 380 ± 20 from the Diorites of Portsall and Lannilis may represent loss of Ar from sphenes which originally crystallised at some time prior to 420 m.y. At present these sphene dates are the only available evidence for the early history of the diorites. However, a study is in progress in which it is hoped that Rb/Sr whole rock isochron dates for the two diorite bodies may be obtained. The hornblende and biotite K-Ar dates from the diorites and other metamorphic and migmatitic rocks in the NW Pays de Léon only supply evidence for the effect of later episodes (probably the D3/M3 episode) in the geological history of the area.

2. The D2/M2 orogenic episode

The attempt to date the D2/M2 episode by K-Ar dating of hornblendes which appeared to have crystallised during this episode has proved inconclusive. However it remains possible to 'bracket' the episode fairly closely between the maximum possible Rb-Sr whole rock age of c. 377-382 m.y. of the Gneiss de Tréglonou and the virtually concordant U-Pb zircon date of c. 348 m.y. (344 m.y. using the decay constants of Jaffey et al, 1971), from the Granite de St Renan. The two independent U-Pb zircon dates of 364 ± 10 and 351 ± 10 from the granitic gneiss at Plounevez-Lochrist may represent lead loss during the D2/M2 episode, but this conclusion is tentative.

3. Post - D2/M2 granitic intrusions

(a) Complexe Granitique de St Renan-Kersaint

The U-Pb zircon date of c. 348 m.y. (or 344 m.y.) and K-Ar K-Feldspar date of 340 ± 15 for the Granite de St Renan at Langongar, together with the less reliable Rb-Sr whole rock data from both main members of the complex, indicate an emplacement age for the complex of about 350 m.y.

(b) Complexe granitique de L'Aber-Ildut

The slightly discordant U-Pb zircon dates (271 ± 8 to 278 ± 30 m.y.) from the earlier megacrystic facies of the L'Aber-Ildut complex are anomalous in that they are younger than the K-Ar biotite date (298 ± 9 m.y.) from the same facies as well as younger than the Rb-Sr whole rock isochron age of the 'filons microgranitiques' and the Rb-Sr mica dates from the Ploudalmézeau facies. It seems that the U-Pb date does not therefore indicate the date of emplacement of the granite. Both main members of the complex must have been emplaced before about 295.m.y. The only other available estimate of the date of emplacement is the Rb-Sr whole rock pair date of c. 319 m.y., but this figure must be regarded as tentative and a full scale Rb-Sr whole-rock isochron study must be awaited for a more accurate estimate.

(c) Granite de Landunvez

Field relations of the Granite de Landunvez indicate that it post dates the climax of the migmatisation which is thought to be the chief expression of the D2/M2 episode north of the Porspoder Lineament. However the only geochronological evidence yet available for the emplacement date of the Granite de Landunvez is that it is likely to be earlier than c. 277-280 m.y. (Rb-Sr and K-Ar dates of biotites from the granite) A study of the geochronology of the granite has been initiated by the writer together with B. Cabanis. A sample of the Granite de Landunvez from Grève de Tréompan has been collected for U-Pb zircon dating, and samples from Grève de Tréompan and Grève de Lilia for Rb-Sr whole rock isochron dating. The single whole rock Rb-Sr analysis by Leutwein et al (1969a) while throwing little light on the age of the granite, none the less places some constraint on the initial $^{87}Sr/^{86}Sr$ ratio of the granite which must have had a rather high value, between 0.714 and 0.717, consistent with the formation of the granite by anatectic mobilisation of old metasedimentary material.

4. Post D2/M2 orogenic episodes

There is considerable evidence in the form of U-Pb, Rb-Sr and K-Ar mineral dates of the (re)setting of mineral isotopic systems between approximately 300 and 270 m.y. (There is also some less reliable evidence of similar processes operating as late as c. 255 m.y.) It is thought that these mineral dates represent a regional episode distinct from and apparently outlasting the emplacement of the granitic complexes of L'Aber-Ildut and Landunvez. It may coincide with the latter part of the D3 deformational episode, or perhaps with a prolonged period of cooling subsequent to the D3 episode and to the emplacement of the granites. The considerable spread of mineral dates may in part be accounted for by the presence of 'initial' Ar in the hornblendes, as well as by inadequate definition of the constants used in the various isotopic systems.

Chauris et al (1977) state that the 'filons microgranitiques' associated with the Complexe de L'Aber-Ildut are not displaced by the Lineament Molène-Moncontour where they cross its outcrop, and apparently therefore postdate the last phase of movement along this major strike slip fault (Fig 4-5). These microgranites have an apparently reliable Rb-Sr wholerock age of c 293 m.y. (see above section C). If the latest (D4) movements along the Porspoder Lineament coincided with those on the Molène Lineament, then 293 $\pm$ 5 m.y. is to be regarded as a minimum age for the D4 deformation at Porspoder.

TABLE 5-4 Summary of published and recalculated isotopic dates of rocks and minerals from NW Pays de Lēon and adjacent areas

Constants	Method	Mineral or Whole Rock	Metamorphic rocks: Date m.y.	Error my	Ref	Post D2/M2 Granitic Intrusions — Complexe granitique de St Renan/Kersaint — Granite de St. Renan: Date m.y.	Error my	Ref	Granite de Kersaint: Date m.y.	Error my	Ref	Complexe granitique L'Aber-Ildut — Granite de L'Aber-Ildut: Date m.y.	Error my	Ref	Granite de Ploudalmēzeau: Date m.y.	Error my	Ref	Complexe de Plouguerneau Landunvez — Granite de Landunvez: Date m.y.	Error my	Ref.
$\lambda^{238} = 1{\cdot}54 \times 10^{-10}$ yr^{-1}	$^{207}Pb/^{206}Pb$	zircon	440	20	(1)	347	30	(1)				278	30	(1)						
	$^{207}Pb/^{235}U$	zircon	364	10	(1)	348	10	(1)				272	8	(1)						
$\lambda^{235} = 9{\cdot}72 \times 10^{-10}$ yr^{-1}	$^{206}Pb/^{238}U$	zircon	351	10	(1)	348	10	(1)				271	8	(1)						
			(Gneiss granitique de Plounevez-Lochrist																	
$\lambda^{87}Rb = 1{\cdot}42 \times 10^{-11} yr^{-1}$	Rb/Sr	Whole Rock age	382-377 Gneiss de Trēglonou		(2)	← 387 my (WR pair) →			(2)		(3)	← 319 my (WR pair) →			(2)		(3)	>277		(3)
$^{85/87}Rb = 2{\cdot}59$	$^{87}Sr/^{86}Sr$	Whole Rock apparent initial ratio	(0.701 for t = 382)			(0.701 for t = 387)						(0.708 for t = 319)						(INITIAL RATIO) >0.714 <0.717		
	Rb/Sr	amphibole							326 my (amphibole-K-feldspar pair)		(3)									
	Rb/Sr	muscovite													296 (musc-kf) 285 (musc-WR)		(3)			(3)
	Rb/Sr	biotite													297 (bi-kf) 295 (bi-Wr)		(3)	278 (bi-kf) 277 (bi-WR)		(3)
$\lambda_\epsilon = 0{\cdot}584 \times 10^{-10} yr^{-1}$	K/Ar	K-feldspar			q	340	15	(4)												
$\lambda_\beta = 4{\cdot}72 \times 10^{-10} yr^{-1}$		hornblende	294 to 255	4	(5)															
		muscovite													282	25	(3)			
$^{40}K/K = 1{\cdot}19 \times 10^{-4}$		biotite	277 (Diorite de Lannilis)	8	(2)				303	9	(2)	298	9	(2)	270	25	(3)	280	20	(3)

References: (1) Michot and Deutsch (1965), (2) Adams (1967a, (3) Leutwein et al (1969a), (4) Leutwein et al 19(6)b), (5) Present work

TABLE 5-5

Chronology of geological events in the NW Pays de Lēon

Approximate date in m.y. (rounded to multiples of 5)	Geological events in NW Pays de Lēon	
255-290	Cooling of rocks and minerals signifying close of orogenic activity	
295	Emplacement of latest members of Complex Granitique de L'Aber-Ildut (filons micro-granitiques)	
	D4 movements in Porspoder Lineament	
Greater than 295 possibly up to 320	(Emplacement of Granite (de Ploudalmēzeau (Emplacement of Granite (de L'Aber-Ildut	D3 tectonic activity
340	Cooling of Granite de St Renan K-Feldspars through Ar blocking temperature	
345	Emplacement of Granite de St Renan	
Greater than 345 Less than 380	D2/M2 orogenic episode (high-grade conditions may have persisted longer in more deep seated zones, such as that represented by the Migmatites de Plouguerneau and the Granite de Landunvez)	
Greater than 380	Emplacement of granitic intrusive precursors of Gneiss de Trēglonou and Gneiss de Plounevez-Lochrist	
Greater than 450	Origin of zircons in Gneiss de Plounevez-Lochrist	
	D1/M1 episode affecting sedimentary precursors of Mica-schists de L'Aber-Wrach, etc.	
Greater than 550	Deposition of sedimentary precursors probably 'Brioverian'	

CHAPTER 6

GEOLOGICAL RELATIONSHIPS IN THE LE CONQUET DISTRICT OF THE SW PAYS DE LÉON

CHAPTER 6

GEOLOGICAL RELATIONSHIPS IN THE LE CONQUET DISTRICT OF THE SW PAYS DE LÉON

A. INTRODUCTION

This chapter is concerned with some critical aspects of the geology of the SW Pays de Léon, particularly the mainland coastal section between Pointe de Corsen (7.92/53.79) and Pointe de St Mathieu (7.90/53.70)(Figs 1-6, 6-1, 6-3). From an examination of geological relationships in this sector and elsewhere in the SW Pays de Léon combined with a critical assessment of the geological descriptions and interpretations available in the literature, a new geological map of the whole of the SW Pays de Léon has been constructed (Fig 6-7) and with the aid of a re-interpretation of previously available geochronological data (Chapter 7) a completely revised interpretation of the geological history and geochronology of the area will be presented.

The area is located some 12 km or so south of the areas discussed in chapters 2 to 5, being separated from the Complexe Métamorphique de Lannilis and the Porspoder Lineament by the outcrops of the Complexe Granitique de L'Aber-Ildut and the Complexe Granitique de St Renan-Kersaint as well as by the relatively poorly exposed areas of metamorphic terrain ('Gneiss de Lesneven' and part of the Gneiss de Tréglonou) which lies between Tréglonou, Plouguin and Coat-Méal (Fig 1-7). The area attracted the attention of the author because it presents the opportunity for observation in excellent coastal exposures of a metasedimentary and metaigneous complex ('Complexe Métamorphique du Conquet') comparable with the predominantly high-grade metamorphic and migmatitic complexes of Lannilis and Plouguerneau already described in Chapters 2 and 3, but with a greater proportion of rocks of lower metamorphic grade than those found in the NW Pays de Léon. The area thus provides an opportunity for establishing a link between the high-grade rocks of the NW Pays de Lēon and the low-grade Brioverian sediments, (Quartzophyllades de L'Élorn) which outcrop at the southern margin of the Pays de Lēon. For the purposes of the discussion in the present chapter the rocks of the SW Pays de Lēon will be divided into two main categories. The first and larger category for which the term 'Complexe Mētamorphique du Conquet' will be used, comprises the older formations known in the literature as Gneiss de Brest, Gneiss de Lesneven, Granodiorite de la Pointe des Renards, Mica-schistes du Conquet, and the Quartzophyllades de L'Élorn. The second, smaller, category comprises later intrusions such as the Granodiorite de Trēgana, the Granite de St Renan and various post-metamorphic basic dykes. Discussion of the metamorphic geology of the SW Pays de Lēon is however deferred until Chapter 8, where the metamorphic geology of the whole of the western part of the Pays de Lēon will be discussed. The present chapter is thus concerned for the most part with the classification of and relationships between the various lithological divisions in the area.

B. PREVIOUS GEOLOGICAL WORK IN THE SW PAYS DE LĒON

A considerable amount of geological literature concerns the SW Pays de Lēon. The area is included within the 1:80,000 Brest geological survey sheet (Barrois, 1902a); the lithological divisions on the revised (2nd) edition of this sheet are briefly described in a 'notice explicative' (Waterlot after Barrois, n.d.). De Lapparent (1934) published more detailed descriptions of specific features, including the petrography and structure of the Le Conquet staurolite schists and the relationships between the various granodiorites at Trez Hir (Fig 6-1, 6-2). Berthois (1954) described the petrography of the 'Gneiss de Brest', while Michot and Lavreau (1965) described the 'Gneiss de Brest' and its setting. All the above authors apparently considered that the 'Gneiss de Brest' originated by an in situ transformation (granitisation) of (originally arkosic) sedimentary material.

A turning point in the development of understanding of the geology of the SW Pays de Lēon was reached with the recognition by R.T. Taylor (Bradshaw et al, 1967; Bishop et al, 1969; Taylor 1969) of the intrusive nature of the contacts between the 'Gneiss de Brest' and the Quartzophyllades de L'Élorn. This reinterpretation has now gained general acceptance (Michot and Deutsch, 1970; Chauris, 1972c, Cabanis et al, 1977).

Taylor (1969) also provided detailed descriptions of the various lithologies outcropping in the SW Pays de Lēon between the city of Brest in the east and the west coast between Pointe de St. Mathieu and Pointe de Kermorvan (Figs 6-1, 6-2). He also recognised, in addition to the granodioritic 'Gneiss de Brest' a second intrusive granodiorite which he termed 'Renards Granodiorite' or 'Pointe des Renards Complex'. He considered that the main orogenic and metamorphic episode in the area intervened in time between the emplacement of the two granodiorites, and that both the granodiorites and the intervening orogenic episode were produced during the Cadomian orogeny.

Taylor's geological mapping, which did not extend in detail further north than the Pointe de Kermorvan, nor include offshore islands, was continued by L. Chauris (1969a, 1972c) who recognised a similar association of granodioritic gneiss and granodiorite in the islands of Beniguet, Quéménès and Trielen in the southern part of the Molène Archipelago (Fig 6-3). In the 3rd edition of the 1:80,000 Brest geological map, Chauris (1972c) extended this two-fold subdivision to the mainland sector north of Pointe de Kermorvan which had not been covered in detail by Taylor, using the term 'Gneiss de Lesneven' in an equivalent sense to Taylor's use of the term 'Gneiss de Brest' in the Le Conquet area. Chauris also used the term 'Granodiorite de la Pointe des Renards' for the non-gneissose granodiorite (equivalent to Taylor's 'Renards Granodiorite').

The geochronological literature concerning the SW Pays de Lēon will be considered in Chapter 7. It should be noted however that Michot and Deutsch (1970) incorporate descriptions of the petrography and zircon morphology of their samples in their U-Pb geochronological study.

C. COMPLEXE MÉTAMORPHIQUE DU CONQUET

1. GRANODIORITE DE BREST

(a) Definition

It will be seen from Figure 6-7 that a large proportion of the outcrop in the SW Pays de Léon and the islands of the Molène Archipelago has been included by the present writer within a single lithological unit for which the term 'Granodiorite de Brest' is used. Included under this heading is (i) the greater part of the lithology described by Barrois (1902a,b), Bishop et al (1969), Taylor (1969) and Chauris (1972c), as 'Gneiss de Brest'(Figs 1-5,6-2,6-3);(ii)the greater part of the unit described by Waterlot (after Barrois, n.d.) as 'gneiss granulitiques (x^by^1) and by Chauris (1966b, 1969a) as 'Gneiss de Ploumoguer (Fig 1-7);(iii) that part of the unit described by Chauris (1972c) as 'Gneiss de Lesneven' which lies south of the outcrop of the Complexe Granitique de St Renan-Kersaint (Figs 1-6, 6-3); (iv) the whole of the formation described by Bishop et al (1969) as Pointe des Renards Complex (Fig 6-2), by Taylor (1969) as Renards Granodiorite; and by Chauris (1972c) as Granodiorite de la Pointe des Renards (Fig 6-3). Included by other workers with the 'Gneiss de Brest' but excluded from the 'Granodiorite de Brest' are certain gneisses also of granodioritic character but of distinctly different mineral composition such as the 'Granodiorite de Pont Cabioc'h' (see below). Included within the 'Gneiss de Lesneven' by Chauris (1972c) but excluded from the 'Granodiorite de Brest' are a relatively minor proportion of lithologies such as banded migmatites and sillimanite gneisses which appear to be of sedimentary origin.

(b) Contact relationships of the Granodiorite de Brest

(i) Relationships with the Quartzophyllodes de L'Élorn

Bishop et al (1969, p.316) describe undisturbed contacts at the southern margin of the 'Gneiss de Brest' (i.e. the 'Granodiorite de Brest' in the writers classification) where the adjacent Brioverian sediments ('Quartzophyllades de L'Élorn') are hornfelsed by the granodiorite and contain pseudomorphs of typical contact metamorphic minerals such as andalusite and cordierite. From this evidence it has become generally accepted that the 'Gneiss de Brest' in this sector is of intrusive magmatic origin. In the writer's opinion the original relationships of the Granodiorite de Brest with neighbouring metasediments in other sectors is likely to have been similar to that now seen at the southern margin; however away from the southern margin the intensity of post-emplacement metamorphism and deformation increases so that the primary relationship is obscured.

(ii) Enclaves in the granodiorite

Throughout the outcrop of the Granodiorite de Brest enclaves or xenoliths of other lithologies can be found, and these are particularly abundant in some sectors, notably at Plage des Blancs Sablons (7.89/53.74). The enclaves have been described in some detail by Taylor (1969, sections 4.ii and 9.v). The most common type are psammites and semi-pelitic schists presumably of metasedimentary origin. Also extremely common are xenoliths of quartz, either granular quartzite or as coarse masses resembling vein quartz. Enclaves of other rock types are also found; including mafic rocks such as the amphibolite at Pointe des Renards (7.908/53.727). Where subsequent deformation has not been too severe the relationship between the granodiorite and these enclaves retains a sharp cross-cutting character suggestive of an intrusive origin. However the granodiorite is also characterised by an abundance of micaceous schlieren whose relation with the granodioritic material is less clearly defined, and it has been suggested that these are either remnants of pelitic material which have been partially absorbed by the magma, or may represent the unmelted portions of pre-existing lithologies which gave rise to or contributed towards the production of the granodioritic magma by a process of anatexis.

(iii) Relationships with belts of metasedimentary schist and migmatite

Between Pointe de St Mathieu (7.90/53.70) and Anse de Porsmoguer (7.90/53.78) are a number of metasedimentary belts up to 400 m thick (Figs 6-2, 6-5, 6-6), which are interbanded with wider belts of Granodiorite de Brest. The metasedimentary lithologies comprise garnet-mica-schist, staurolite-garnet-mica-schist, sillimanite gneiss and banded migmatite, and are strongly foliated showing evidence of severe deformation and medium to high grade regional metamorphism. Near the contacts with these metasedimentary belts, and also commonly elsewhere, the granodiorite is equally strongly foliated. Where metasediments and granodiorite are adjacent the foliation in both lithologies is sensibly parallel with the contact between them, the latter however being typically ill-defined and difficult to pinpoint.

The observed concordant contacts between the Granodiorite de Brest and the adjacent metasedimentary belts are interpreted as representing original intrusive contacts, the present parallelism being the result of severe deformation during a medium to high grade metamorphic episode. This interpretation is essentially the same as that put forward by Bishop et al (1969), who considered the Le Conquet Schists

(Fig 6-2) to have been first, like the Quartzophyllades de L'Élorn, intruded by the 'Gneiss' (Granodiorite) de Brest, and then during a subsequent episode, metamorphosed simultaneously with, but at a higher grade than, the Quartzophyllades.

(iv) Relationships between various facies of the Granodiorite de Brest

It has been indicated above (Section C.1.(a)) that granodioritic lithological units known in the previous literature under a number of different headings, viz. 'Gneiss de Brest', 'Granodiorite de la Pointe des Renards', 'Gneiss de Lesneven', etc., have been grouped by the present writer under the single heading 'Granodiorite de Brest'. The term 'Gneiss' has been used by previous workers in this area where the rock in question has a prominent foliation, whereas the terms 'Granodiorite de la Pointe des Renards' (Chauris, 1972c) or 'Pointe des Renards Complex' (Bishop et al, 1969) have been used where the rock in question is relatively massive with little or no planar fabric. Examinations of numerous well exposed bodies of 'Granodiorite de la Pointe des Renards' between Pointe des Renards (7.907/53.727) and Anse de Porsmoguer (7.90/53.78) (Fig 6-1, 6-3) has shown that the 'Granodiorite de la Pointe des Renards' is only seen directly in contact with the following:

(a) Gneisses of granodioritic composition ('Gneiss de Brest' or 'Gneiss de Lesneven')

(b) Later cross-cutting intrusions of various types

(c) Various enclaves in the granodiorite itself

The enclaves have been discussed in section (ii) above. The cross-cutting intrusions will be discussed below (section (v)).

However in the view of the present writer the gradual and transitional nature of these contacts is better explained if one concludes that the foliated granodiorite ('Gneiss de Brest/Lesneven'; Plates 6-2, 6-4) is the result of penetrative deformation under metamorphic conditions of what was originally massive granodiorite similar to the 'Granodiorite de la Pointe des Renards' (Plates 6-1, 6-3). According to this interpretation the 'Granodiorite de la Pointe des Renards' consists merely of zones of anomalously low deformation within the otherwise typically strongly foliated and apparently severely deformed 'Gneiss de Brest/Lesneven' (Fig 6-5). In this view therefore the bulk of the material of all three units as now seen in the SW Pays de Lēon would therefore seem to have originated as a single granodiorite intrusion into the Brioverian. This intrusion, for which the title 'Granodiorite de Brest' is suggested, is considered to have undergone inhomogeneous deformation under metamorphic conditions during an orogenic episode later than and distinct from the episode which gave rise to the production and emplacement of the granodioritic magma itself.

(v) Contacts with later intrusions

A number of later intrusions cut the Granodiorite de Brest. The following groups are recognised:

(1) Metamorphosed and deformed basic dykes

(2) Unmetamorphosed basic dykes

(3) Pegmatites

(4) Granitic rocks

Contacts between the rocks of these groups and the Granodiorite de Brest will be discussed in subsequent sections of this chapter which deal with the various later intrusions (sections C.4.(b), C.5 and D.)

(c) Petrography

The petrography of the Granodiorite de Brest has been described in the literature, briefly by Bishop et at (1969 p.315-317) and Chauris (1972c, p. 22-23) and in more detail by Taylor (1969, chapters 3 and 9). (It should be noted that in all these cases separate descriptions are given of the 'Gneiss de Brest' and 'Renards Granodiorite' facies).

Where least affected by post-consolidation deformation (Plates 6-1, 6-3) the rock is a non-megacrystic coarse-grained granitoid consisting of plagioclase (sodic oligoclase), quartz and biotite, with minor ($<5\%$) muscovite and alkali-feldspar, together with the usual accessories.

In the more strongly foliated varieties (Plates 6-2, 6-4) the schistosity is defined by the parallel orientation of micas, this schistosity in some cases being crossed by a later cleavage of 'strain-slip' type. Quartz commonly displays undulose extinction, but generally lacks mortar texture in the specimens examined by the writer. Plagioclase may be more or less sericitised. As mentioned above, the rock typically contains abundant biotitic schlieren.

(d) Nature and origin of the Granodiorite de Brest

As defined above (section C.1.(a))(Fig 6-7, 7-5) the outcrop of the Granodiorite de Brest is of considerable extent, occupying about 70% of the surface of the SW Pays de Lēon, and extending both westwards to the Molēne Archipelago and eastwards beyond the city of Brest towards the eastern margin of the Pays de Léon. It appears to have originated as a plutonic batholithic intrusion, with features such as its abundance of biotitic schlieren suggesting an origin by anatexis of pre-existing supracrustal lithologies. It displays remarkable similarity to certain of the rocks described by Brown (1974, 1978) in the St Malo district of northeast Brittany as 'diatexites' (Chauris, pers.comm. and observations by the present writer). The similarity is such that one might conclude that both groups of rocks (Granodiorite de Brest and St Malo diatexites) are likely to have been formed by similar processes and in a similar environment. This is not however to suggest that the two groups are of the same age or belong to the same geotectonic regime. The St Malo diatexites are considered by Brown to tbe of Pentevrian age (i.e. pre-Upper Proterozoic), although this view is not universally accepted (Brun and Martin, 1978). The question of the date of the emplacement of the Granodiorite de Brest will be considered in Chapter 7.

2. OTHER GRANODIORITIC GNEISSES IN THE SW PAYS DE LĒON

(a) Granodiorite de Pont Cabioc'h

Michot and Deutsch (1970) describe a sample of 'Gneiss de Brest' from an inland quarry on the western outskirts of Brest at Pont-Cabioc'h (Figs 6-1, 6-7). The typical lithology at this locality, which is also mentioned by Taylor (1969, p.70) is schistose and contains garnet and greenish-blue amphibole. Since the presence of amphibole has not been recorded in any of the abundant coastal exposures of the typical Granodiorite de Brest, there seems to be a prima-facie case for considering the granodioritic gneiss at Pont-Cabioc'h to be distinct from the Granodiorite de Brest. Some additional support for this view is given by comparison of the Rb/Sr ratios of whole rock samples of granodiorites from the SW Pays de Lēon analysed by Adams (1967a)(Fig 7-6). Most of Adams' samples, which were collected for the purpose of Rb-Sr isotope geochronology, are of typical 'Granodiorite de Brest' lithology, including samples of both 'Gneiss de Brest' and 'Granodiorite de la Pointe des Renards' type. However two of Adams samples are stated to have been collected near Penfeld (Fig 6-1) (i.e. in the vicinity of Pont

Cabioc'h) and these two samples have Rb/Sr ratios of 0.08 and 0.24; while the remaining 18 samples of Granodiorite de Brest collected by Adams from elsewhere in the SW Pays de Léon have Rb/Sr ratios ranging from 0.51 to 1.60 (Fig 7-6). This discrimination on the basis of a single trace element ratio does not prove that the bulk chemistry is significantly different; nonetheless it does indicate that the outcrop in the vicinity of Pont-Cabioc'h represents a body of granodioritic gneiss which is distinct in certain chemical features from the Granodiorite de Brest.

In view of the distinct petrography and possibly also chemistry of the Pont Cabioc'h gneiss, it is suggested that the term 'Granodiorite de Pont Cabioc'h' be introduced to refer to this lithology. The Pont Cabioc'h quarry lies in an area of limited natural exposure, so the extent of the outcrop of the Granodiorite de Pont-Cabioc'h cannot be easily ascertained. It may be of quite limited extent, and there is no evidence that it exceeds a few km^2 (Fig 6-7).

Geochronological data on the Granodiorite de Pont Cabioc'h is discussed in Chapter 7.

(b) 'Granodiorite de St Marzin'

Taylor (1969, p.150) has described 'albitised' zones in the 'Gneiss de Brest' at various localities, notably near Pointe de Creac'h Meur (7.83/53.70) and Fort St. Marzin (7.87/53.70)(Fig 6-1). Taylor suggested that the leucocratic albite-granodioritic gneisses at these localities may have originated by metasomatic alteration of the much more mafic biotite-oligoclase 'Gneiss de Brest' (i.e. the typical foliated Granodiorite de Brest). Only a brief inspection of one of the localities (Fort St Marzin) has been made by the present writer. Here the contact between the leucogranodioritic gneiss and the typical Granodiorite de

Brest lithology seems to be sharp and distinct, lacking the gradual transition that one might expect at a metasomatic front. This observation leads the present writer to ask whether some at least of the 'albitised' zones may not represent material of composition originally different from that of the Granodiorite de Brest. Material of this type is, as indicated by Taylor, quite abundant in the vicinity of Fort St Marzin and the provisional label '? Granodiorite de St Marzin' is suggested, thus avoiding the genetic connotations of the term 'albitised'.

It is to be noted that the '? Granodiorite de St Marzin' is apparently distinct from another lithology which also outcrops near Fort St Marzin and which is shown as 'leucocratic adamellite' on Taylor's map (1969, p. 176); this lithology is described by him under the heading 'leucocratic minor intrusions' (Taylor 1969, p.144-146).

3. METASEDIMENTARY ROCKS IN THE COMPLEXE MÉTAMORPHIQUE DU CONQUET

In this section only those metasediments outcropping to the west and north of Anse de Bertheaume (7.81/53.72) will be considered (Fig 6-1). The relationships of the metasediments occurring to the south and east (i.e. the Quartzophyllades de L'Élorn) with the Granodiorite de Brest, have been referred to in section C.1.(b)(i) of this chapter. Discussion of the regional metamorphic assemblages observed throughout the whole western Pays de Léon is deferred until chapter 8.

(a) Form and contacts

The distribution of the metasedimentary schists in the SW Pays de Léon has been discussed previously in section C.1.b(iii) and is shown in Figs 6-5 to 6-7. As indicated, the schists form belts or sheets up to 400 m thick whose margins and internal schistosity are essentially parallel with that of the adjacent Granodiorite de Brest. At some localitites (e.g. 7.897/53.735) concordant mafic sheets a few metres thick occur within the metasedimentary schists.

(b) Petrography and structure

The staurolite-garnet-mica schists of Le Conquet (Plates 6-5, 6-6) have attracted the interest of many mineralogists and geologists, and petrographic descriptions are available in the work of De Lapparent (1934), Taylor (1969 p.209-217) and Chauris (1972c, p.23-24). Even a brief examination of the rocks indicates a complex history of deformation and crystallisation. De Lapparent (op cit, p.4.) observed that the main metamorphic foliation cuts across one set of folds and is itself affected by another set, and Taylor (op cit) has recognised up to four phases of deformation in the schists (see table 6-1). Bradshaw et al (1967) (see table 6-3) suggested that the main schistosity in the schists may have been produced contemporaneously with or prior to the intrusion of the Granodiorite de Brest, while the almandine-amphibolite facies metamorphic assemblages were produced in a post-Granodiorite de Brest episode in which the earlier schistosity underwent 'concordant metamorphic overprinting' (p.587, table 1). They indicate (op cit p.585) that the post-Granodiorite de Brest episode was the more intense, although they assign the folds to which the schistosity is axial planar to the earlier episode. Bishop et al (1969, p.319) conclude that the main metamorphism in the schists was associated with a deformation which produced a foliation in both the schists and the Gn iss de Brest (Granodiorite de Brest) (Table 6-2), and the present author's interpretation of the geological history of the area is based on an acceptance of this latter conclusion.

In the northern sector of the SW Pays de Lēon, the metasedimentary material outcropping in the coastal section between Pors Illien (7.887/53.759) and Anse de Porsmoguer (7.90/53.78) is at higher grade than the staurolite-garnet-mica schists of Le Conquet and includes sillimanite gneisses and banded migmatites (Fig 6-6, Plate 6-7). These outcrops are not extensive, most of the sector being occupied by the Granodiorite de

Brest, which is locally rich in sillimanite-bearing enclaves. No detailed descriptions of the metasediments of this sector are available in the literature, and the writer has not had an opportunity to study them in detail.

(c) Origin of the metasediments

Bishop et al (1969) conclude that the staurolite-garnet-mica schists of Le Conquet are the higher-grade metamorphic equivalents of the Brioverian Quartzophyllades de L'Élorn. This conclusion seems the most likely possibility, and it may be extended to include the yet higher grade sillimanite gneisses and migmatites of the Illien-Anse de Porsmoguer section (Fig 6-6). The regional metamorphic episode responsible for the observed distribution of metamorphic assemblages in the SW Pays de Léon is considered by Bishop et al (1969) to be identifiable with the late-Precambrian Cadomian orogeny. Geochronological arguments bearing upon the age of this metamorphism will be discussed in the next chapter.

4. METABASIC ROCKS IN THE COMPLEXE MÉTAMORPHIQUE DE CONQUET

(a) Enclaves in the Granodiorite de Brest

As indicated earlier the most abundant enclaves or xenoliths in the Granodiorite de Brest are schists and psammites of metasedimentary type together with numerous inclusions of quartzite possibly derived from quartz veins. Occasional mafic xenoliths are also observed. A prominent example of the latter occurs at Pointe des Renards (7.908/53.727) where a block of strongly foliated mafic amphibolite about 2m x 1 m occurs in relatively massive unfoliated Granodiorite de Brest. In the cliffs west of Pen ar Prat (7.900/53.775)(Fig 6-1) there is an occurrence of clinopyroxene-granulite interbanded with amphibolite. Isolated mafic enclaves like these are widespread, though not abundant, in the massive Granodiorite de Brest, and it is likely that certain of the mafic sheets which are now concordant with the Granodiorite de Brest where the latter is strongly foliated may represent deformed mafic xenoliths.

The mafic enclaves represent mafic rocks which were formed and metamorphosed prior to the emplacement of the Granodiorite de Brest. It is not clear what original relationship these mafic rocks may have had with the metasedimentary rocks of the area. It seems probable however that both groups underwent the same early regional metamorphic episode (referred to as M1 in section E and chapter 8) which reached amphibolite facies in the neighbourhood of Pointe des Renards.

(b) Filons de Kermorvan

(i) Field relations

Bishop et al (1969 p. 316-7) and Taylor (1969, in chapter 7 (p.191-194), and 10 (p.260-263)) record two sets of metamorphosed basic minor intrusions in the SW Pays de Léon.

According to these authors the earlier of the two sets intrudes the 'Gneiss de Brest' (Granodiorite de Brest) at various points between Le Minou (Fig 6-1) and Pointe de St Mathieu. Taylor (1969, p.191-4) describes the petrography of these intrusions in some detail (see also Chapter 8 below) The intrusions have a distinctively metamorphic mineral composition with such minerals as actinolite, chlorite and garnet being prominent. Taylor (op.cit. p 193) states that the degree of foliation developed in the amphibolites is very variable.

The second of the sets recognised by Bishop et al (1969) and Taylor (1969) is a set of dykes only recognised in the vicinity of Pointe des Renards (7.900/53.727) and Pointe de Kermorvan (7.91/53.74). These dykes intrude the 'Pointe des Renards Granodiorite' (Granodiorite de Brest) and where least deformed trend approximately N-S. Every dyke of this set examined by the present writer displays evidence of deformation under metamorphic conditions, although the intensity of foliation may vary from point to point along the dykes. When traced laterally away from zones where they cut unfoliated granodiorite the dykes may first display open folds (as at Pointe des Renards) and then pass into highly schistose sheets which are concordant with the neighbouring schistose granodiorite (Fig 6-4).

According to Taylor the typical mineralogy in the second set is calcic andesine, amphibole, biotite, quartz and locally garnet. It has not been established whether the mineral composition varies with the intensity of foliation of the dykes.

Taylor considered that the two sets of dykes he recognised represented distinct and non-contemporaneous phases of basic dyke intrusion separated in time by the emplacement of the 'Pointe des Renards Granodiorite'. However if one accepts the present author's conclusion that the 'Gneiss de Brest' and the 'Pointe des Renards Granodiorite' are essentially a single unit, namely the 'Granodiorite de Brest', then there seems to be no longer any justification for separating the metamorphosed basic dykes into two distinct groups; all the basic dykes which were intruded into the Granodiorite de Brest and subsequently underwent deformation and metamorphism together with the country rock can be grouped under a single heading. The present author suggests the term 'Filons de Kermorvan' to refer to this group. Their distribution along the coast north from Le Conquet is shown in Figure 6-6.

Dykes which can probably be grouped with the 'Filons de Kermorvan' have also been described by Chauris (1969a, p.129) in the southern part of the island of Beniguet (7.99/53.72)(Fig 1-2, 6-7). In view of the fact that for example, at L'Ilette (7.915/53.743)(Fig 6-4) clearly discordant members of the Filons de Kermorvan group can be traced within a few metres into schistose mafic sheets, concordant with the foliated granodiorite, it is likely that some of the isolated thin concordant mafic sheets observed within the foliated granodiorite elsewhere, particularly between Plage des Blancs Sablons and Anse de Porsmoguer, may represent severely deformed members of the Kermorvan group. It should be emphasised that the present author still recognises the presence of two non-contemporaneous sets of metabasic rocks in the SW Pays de Léon namely:

(1) metabasic enclaves in the Granodiorite de Brest

(2) metamorphosed basic dykes which cut the Granodiorite de Brest

Unambiguous representatives of both sets can be observed in close proximity at Pointe des Renards (7.908/53.727).

(ii) Affinities of the Filons de Kermorvan

The question is now raised as to whether the Filons de Kermorvan can be correlated with any other mafic dykes elsewhere in the Massif Armoricain, or with any other possibly genetically related geological phenomena. (The question of the absolute age of the Filons de Kermorvan will be considered below in Chapter 7).

The lamprophyre (kersantite) and dolerite sheets which are concentrated in the syncline of Middle and Upper Devonian rocks of the Rade de Brest (Chauris 1972c, p.14) and of which a few representatives intrude the rocks of the SW Pays de Léon, are undeformed and unmetamorphosed and therefore most unlikely to be contemporaneous with or genetically related to the Filons de Kermorvan. The same consideration applies to the important post-orogenic dolerite dyke which traverses the SW Pays de Léon between Pointe de Brenterc'h (7.901/53.770) and Porsmilin (7.807/53.727)(Fig 6-7). There is a possibility that the intrusion of the Kermorvan dykes may be connected in some way with the formation of basic pillow lavas and hyalotuffs, together with apparently contemporaneous basic intrusive sheets in the Caradocian of the Presqu'ile de Crozon (Bishop et al, 1969, p.324-5). The present outcrop of these Caradocian volcanics is only about 15 km southeast of the southern margin of the SW Pays de Léon. While any such correlation is highly tentative, there does not seem to be any conclusive geological argument to dismiss the possibility of a genetic relationship between the Kermorvan dykes and the Caradocian volcanics. This tentative conclusion is also consistent with, although not proven by, the available geochronological data (see Chapter 7).

(c) Other metabasic rocks in the SW Pays de Léon

Other metabasic rocks, which cannot easily be assigned to either of the two categories above, also occur in the Le Conquet Complex. An example is the coarse grained rather Leucocratic amphibolite sheet at Porz Liogan (7.896/53.718). The structure and mineralogy of this sheet is described by Taylor (1969, 263-266). Its composition and texture make it easily distinguishable from the other metabasic rocks in the area. Its emplacement clearly predates the main metamorphic and deformational episode, but its original relationship with the Granodiorite de Brest is not clear.

5. PEGMATITES AND FOLIATED GRANITIC SHEETS

(a) Pegmatites

Pegmatites are not common in the Complexe Mētamorphique de Conquet. However one prominent example, between one and two metres thick, intrudes the foliated Granodiorite de Brest on the west coast of the Presqu'ile de Kermorvan (7.914/53.742)(Fig 6-6). This pegmatite dyke is folded; it appears therefore to have been affected by the deformation undergone by the country rock. It may be contemporaneous with or earlier than the main metamorphic and deformational episode.

Chauris (1969c, p.129) uses the term 'lenticulaire' to describe a 2 m thick pegmatite cutting (granodioritic) gneiss on the west coast of the island of Beniguet (7.994/53.723). His term suggests the possible presence of pinch and swell or boudinage structure which may indicate that the pegmatite has undergone a phase of deformation.

(b) Foliated granitic sheets

Foliated granitic sheets, mostly less than a few metres thick, and generally concordant with the foliation of the country rock, are abundant in the SW Pays de Léon. Some examples are described by Taylor (1969) p. 144-146). Some of these sheets appear to have been affected by the deformation and metamorphism undergone by the country rocks. However it has not been possible to study these sheets in sufficient detail to present an adequate account of their field relations.

D. POST-METAMORPHIC INTRUSIONS

1. INTRODUCTION

Relatively brief mention will be made in this section of the more important of the igneous intrusions in the SW Pays de Léon which appear to have been emplaced subsequently to the major deformation and regional metamorphism (D2/M2 in section E below), which has affected the Complexe Métamorphique du Conquet. (Certain of these late intrusions do however display evidence of local deformation). The writer has not studied the petrography of these intrusions and the reader is referred to the literature for fuller accounts.

2. GRANITE DE ST RENAN

The outcrop of this granite, which according to Chauris (1972c) is cogenetic with the Granite de Kersaint, marks the northern limit of the Complexe

Mētamorphique du Conquet in the SW Pays de Lēon (Figs 1-6, 6-7). The boundary is of roughly E-W trend, and meets the coastline south of Pointe de Corsen at 7.911/53.786. Here the contact is sharp and near vertical. The Granite de St Renan appears to be intrusive into the schistose Granodiorite de Brest at this point.

The petrography of the granite is described by Chauris (1972c, p.19). It is generally a non-megacrystic alkali-leucogranite with muscovite and either biotite or, less commonly, tourmaline. A number of dykes and minor sheets of Granite de St Renan type cut the Granodiorite de Brest further south than the contact mentioned above, for instance at 7.900/ 53.778 and at 7.898/53.765 (Fig 6-6).

Geochronological data on this granite is discussed in Chapters 5 and 7.

3. GRANITE DES ROSPECTS (OR GRANITE DES PIERRES NOIRES)

Taylor (1969, p 356-7) describes a distinctive granite which outcrops on a small group of reefs and stacks just off the south coast of the Pays de Lēon near Pointe de St Mathieu and known as 'Les Rospects' (7.887/53.699) (Fig 6-1, 607). Chauris (1969a, p. 121-3; 1972, p.22) recognised that the outcrop of this granite was much more extensive than that observed by Taylor, including a large number of reefs and stacks extending for about 12 km west of Les Rospects, and introduced the term 'Granite de la Chaussēe des Pierres Noires' which is used on the 1:80,000 geological map (3rd Edn., 1972) (Fig 6-3). The contact zone between the Granite des Rospects and the Granodiorite de Brest on the mainland is poorly exposed and apparently occupied by a shear belt. A modal analysis by Taylor indicates that it is a leucocratic muscovite-alkali-granite.

Taylor (1969) placed the granite among the Variscan suite on litho - structural grounds, while Chauris (1972c) suggested that it might be of Precambrian age. No geochronological data are available.

4. GRANODIORITE DE TRÉGANA

Taylor (1969 p.343-352) and Chauris (1972c, p 21) describe this distinctive intrusion which has a NE-SW trending outcrop extending on either side of the Anse de Bertheaume for a total length of about 10 km (Figs 6-2, 6-3, 6-7). The portions outcropping to the NE and SWZ respectively of the Anse de Bertheaume are offset by a late NW trending fault in the vicinity of Porsmilin (7.893/53.727).

The Granodiorite de Trégana displays clearly visible intrusive contacts with the Granodiorite de Brest. It is an almost hololeucocratic albite-granodiorite, with minor muscovite, chlorite, microcline and some biotite schlieren. (Chauris, 1972). The granite is clearly post-metamorphic and is considered by Taylor to be an early member of the Variscan granite suite, possibly contemporaneous with the Granite de St Renan. The absolute age of the Granodiorite de Trégana is discussed in the following chapter.

5. LAMPROPHYRIC AND ASSOCIATED DYKES

Taylor (1969)p.358-9) has described rare minettes and kersantites in the SW Pays de Léon. Examples occur to the east of Pointe du Petit Minou and at Le Dellec (Fig 6-1). These dykes are probably outlying members of the late Hercynian lamprophyric suite which is centred on the Devonian rocks of the Rade de Brest (Chauris, 1972c, p.14).

The writer has recorded an unfoliated dyke about 4 m thick which cuts the Granodiorite de Brest between Plage des Blancs Sablons and Pors Illien at 7.886/53.750 (Fig 6-6). The rock contains megacrysts of euhedral quartz and altered feldspar, with radial aggregatesof white mica in a fine-grained dark matrix.

The affinities of this dyke are uncertain; it may be related to the

Rade de Brest lamprophyric suite.

6. DOLERITES OF PORSMILIN AND BRENTERC'H

A northwest trending vertical dolerite dyke about 40 m thick cuts the Granodiorite de Trégana at Porsmilin (7.893/53.727). This dyke has been described by Taylor (1969, p 361). A dyke of similar trend and thickness and approximately aligned with the Porsmilin dyke cuts the Granodiorite de Brest at Pointe de Brenterc'h (7.900/53.771)(Fig 6-6); and the two outcrops are considered by Chauris (1972c) to be parts of the same dyke (Figs 6-3, 6-7).

Another northwest trending dolerite dyke which is possibly related to the Porsmilin-Brenterc'h dolerite has been recorded by Chauris (1969a, p.129 and map 4) on the island of Lédênez de Quéménès (just north of Quéménès, fig 1-2).

Geochronological data on the dolerites of the SW Pays de Léon is referred to in the following chapter.

E. STRUCTURAL METAMORPHIC AND MAGMATIC EVOLUTION OF THE SW PAYS DE LÉON

1. INTRODUCTION

It is appropriate at this point to summarise the geological history of the SW Pays de Léon in the light of the geological observations and conclusions both of earlier workers and of the present writer.

The most comprehensive previous attempt to construct the geological history of the SW Pays de Léon is that of Taylor (1969 p 287-311). Correlation of Taylor's chronology with that of events in the Brioverian and Palaeozoic terrain of central Finistère is provided by Bradshaw et al (1967) and Bishop et al (1969).

TABLE 6 - 1 DEFORMATIONAL, IGNEOUS AND METAMORPHIC EVENTS IN THE S.W. PAYS DE LÉON

After Taylor, 1969, p.289, Table 13-1

Fold phases	Surfaces	Features of folds and surfaces	Igneous and metamorphic events
CnF_1	S0	Bedding traces of the Lower Ēlorn sediments. First Cadomian fold phase. Isoclinal folds with approximately N-S axial trend, probably upright	
		No axial planar surface to these folds recognised	
CnF_2		Second Cadomian fold phase. Isoclinal folds with ENE - WSW axial trend, northerly overturning, steep westerly plunge	Basic intrusions (Dellec diorites) preceding the "Gneiss de Brest"
	CnS_2	Axial planar cleavage to CnF_2 folds, probably present when "Gneiss de Brest" intruded	
			Intrusion of "Gneiss de Brest" and leucocratic suite, albitisation, intrusion of basic dykes
	CnS_2'	Metamorphic schistosity axial planar to CnS_2 folds but development postdates folding	Onset of main phase of regional metamorphism
CnF_3		Symmetamorphic deformation, folds schistosity and produces penetrative lineation and rotational structures in porphyroblasts. Axial planes parallel to the existing schistosity. Variable plunge	
Late micro-folds	Strain-slip surface	Refolds CnS_2' axial planes dip more steeply than the schistosity. NE-SW axial trend. Post metamorphic rotation of porphyroblasts	Postdates main phase of regional metamorphism. Age relative to the Pointe des Renards complex not known. Formation of Pointe des Renards complex. Later basic intrusions. Albitophyre intrusions. Later regional metamorphism.

Correlation of events affecting the Brioverian over the area of west Finistère. — In the Baie du Ris the following series of events have been recognised:— Sedimentation followed by first, second and third foldings. Associated with the second folds is a strongly developed schistosity. This forms the best correlation with the sediments farther north at the moment and is taken to be of *Fe* age. The first folding (of which little is known so far) would then be the equivalent of *pre-Fe* farther north. The third folding is a strongly developed strain slip cleavage which is probably to be correlated with the strain slip micro folds.

Southwestern Pays de Léon	Elorn valley	Baie de Douarnenez
sedimentation	sedimentation	sedimentation + pillow lavas
pre-Fe folding	*pre-Fe* folding	*pre-Fe* folding
Fe folding (Se schistosity) and intrusion of Gneiss de Brest	Fe-folding (Se schistosity) and intrusion of Gneiss de Brest	Fe-folding (Se schistosity) and probably "cross-folding"
minor intrusions and metasomatism in Gneiss de Brest	— ? —	— ? —
metamorphism to lower almandine amphibolite facies. Concordant metamorphic overprinting of *Se* schistosity	metamorphism to low greenschist facies. Concordant metamorphic overprinting of *Se* schistosity	metamorphism to lowest greenschist facies in Crozon and to south. Grade rises again Baie du Ris
late metamorphic shear folds	— ? —	— ? —
strain slip micro folds	———	strain slip micro folds
development of the Renards Granite Complex	———	———
static regional metamorphism	— ? —	———

— — — interval between Cadomian Orogeny and deposition — — — of the Grès Armoricain.

Palaeozoic sedimentation over the area. Epeirogenetic earth movements along lines of Cadomian weakness. Variscan deformation by slip on *Se*.

Cataclasis, retrogressive metamorphism and the development of kink-bands affect the Brioverian probably as a result of the Variscan deformation.

N.B. The use of *Fe*, *pre-Fe* and *Se* was preferred to the more usual terminology of $F_{1,2}$ etc. & $S_{1,2}$ etc. to avoid the necessity of awkward numerical changes at a later date when the full sequence of structural events has been unravelled.

TABLE 6-2

EVENTS AFFECTING THE BRIOVERIAN OF WEST FINISTÈRE

After Bradshaw et al, 1967.

		Fold Phases	Metamorphic Events	Other Events
				Brioverian sedimentation
Pre-Cambrian	Cadomian movements	CnF_1 Tight, often recumbent folds with angular hinges. Axial trend roughly NW–SE. CnF_2 Upright folds with rounded hinges which refold CnF_1 structures. Regional development of CnS_2 cleavage parallel to axial planes of CnF_2 folds. Fold trend ENE–WSW. MAIN CADOMIAN FOLD PHASE.		
				Intrusion of leucogranite veins. Emplacement and albitization of Gneiss de Brest granodiorite. Intrusion of basic dykes.
		CnF_3 Small angular shear folds with axial planes parallel to lineation in Gneiss de Brest.	CnM_1 Regional metamorphism to almandine amphibolite facies. Growth of garnet and staurolite porphyroblasts. Development of synmetamorphic foliation parallel to CnS_2	Foliation of Gneiss de Brest
				Intrusion of Pointe des Renards granodiorite. ?Development of strain-slip folds. Intrusion of basic dykes.
			CnM_2 Static metamorphism. Growth of garnet in basic dykes cutting Pointe des Renards granodiorite.	
Palaeozoic	Variscan movements			Erosion: peneplanation. Lower Palaeozoic and Devonian sedimentation.
		VF_1 Main Variscan fold phase. Upright asymmetrical folds overturned towards the south. late VF_1 Cross-warps on VF_1 folds, causing fold culmination and depression and corrugation of fold limbs.		Intrusion of Tregana granodiorite (age uncertain).

TABLE 6-3

GEOLOGICAL HISTORY OF SW PAYS DE LÉON

After Bishop et al, 1969.

In this section use will be made of a relative chronological nomenclature (see table 6-4) comparable with that already used for the rocks of the NW Pays de Lēon in chapters 2 to 5. It should be emphasised however that although a correlation of events between the northwest and southwest sectors of the Pays de Lēon is suggested and implied by this procedure, such a correlation is not necessarily proven as yet; difficulties in proving such a correlation are presented by the probable existence of significant transcurrent displacement along the Molēne-Moncontour Lineament which separates the two areas, and by the extensive intervening areas occupied by the post-D2/M2 granite complexes (Figs 1-6, 8-1).

2. PRE D2/M2 EVENTS

(a) Brioverian deposition (So and So' surfaces)

In the opinion of Bishop et al (1969) and Taylor (1969, p 289) the earliest structure recognisable in the rocks of the SW Pays de Lēon is the compositional banding in the Brioverian Quartzophyllades de L'Ēlorn. This structure may be termed So and clearly represents sedimentary bedding. The compositional banding observed in the higher-grade metasediments such as the Mica-schistes du Conquet and some of the enclaves in the Granodiorite de Brest is analogous with So in the Quartzophyllades de L'Ēlorn and probably is at least in part of sedimentary origin, although perhaps modified by such processes as transposition and syn-metamorphic deformation. The abbreviation So' may be used to refer to such possibly modified versions of So.

(b) The early metabasic rocks

The mafic enclaves in the Granodiorite de Brest represent a group of basic rocks which may have been associated with the pre-Granodiorite de Brest (Brioverian) sedimentary formations. These mafic rocks, although widely distributed, appear to have been subordinate in quantity to the

TABLE 6 - 4

SEQUENCE OF GEOLOGICAL EVENTS IN THE SW PAYS DE LĒON

	Dolerite Dykes		Post Hercynian
POST D3	Localised shear belts and mylonitisation (cf D4 in NW Pays de Lēon)	Development of kink bands in schistose rocks, with chloritisation of biotite	Late Hercynian
D3	Emplacement of granitic plutons of Trēgana, Les Rospects, St Renan	F_3 and F_3' folds affecting S_2 surfaces in metamorphic rocks	Mid-Hercynian
D2/M2	Regional metamorphism of intermediate low pressure type with production of S_2, L_2 and F_2 structures		Early Hercynian 'Bretonic'
	Intrusion of doleritic Filons de Kermorvan		? Caradocian sub-volcanic activity
	Emplacement of Granodiorite de Brest and possibly other major intrusions		Cadomian orogeny
D1/M1	Regional metamorphism with production of S_1 and F_1 structures in metasedimentary and metabasic rocks		
	Early (? pene-) contemporaneous basic rocks Deposition of semi-pelitic sediments possibly by turbidity currents		Brioverian volcanic activity and sedimentation

sediments. By analogy with the well-documented Brioverian volcanics of Penn Ar Vir in central Finistēre (Darboux, 1974; Bishop et al 1969, p 315), some of the early metabasic rocks in the SW Pays de Lēon may be derived from volcanic or subvolcanic material (pene-)contemporaneous with the pre-Granodiorite de Brest sediments. Alternatively they may represent an unrelated later intrusive group.

(c) The D1/M1 orogenic episode (S_1 surfaces)

Both the metasediments and the early mafic rocks have undergone deformation and metamorphism prior to the emplacement of the Granodiorite de Brest. Taylor (1969, p 233) records schistosity and a metamorphic mineralogy (garnets and micas) in metasedimentary xenolithic inclusions in the 'Pointe des Renards Granodiorite' (Granodiorite de Brest). As indicated above (section C.4.) a metabasic xenolith in the Granodiorite de Brest at Pointe des Renards retains clearly visible pre-granodiorite foliation of metamorphic origin, the metamorphism in this case having reached the almandine-amphibolite facies. Locally a distinct phase of folding prior to the D2/M2 folds can be recognised in the Brioverian and metasedimentary schists of the SW Pays de Lēon (Pre Fe of Bradshaw et al, 1967 and CnF_1 of Bishop et al, 1969).* Folds in this category have been recognised at several localities by Taylor (1969 p 292). They have been most easily recognised in the Quartzophyllades de L'Ēlorn but Taylor illustrates one example in the Mica-schistes du Conquet. The present writer has observed a set of folds apparently refolded by the D2/M2 folds in the Mica-schistes du Conquet at Porz Liogan (locality shown on Fig 6-1). It is possible that the formation of this early set of folds was contemporaneous with the formation of the early fabrics in the metasedimentary and metabasic enclaves in the Granodiorite de Brest. Taylor (op cit, p 293 and 322) suggests that some of the early folds appear to

* Tables 6-2, 6-3.

have had an original trend approximately N-S. * Although only a few folds in this category have been recognised in the SW Pays de Léon, and their significance is not clearly established, the evidence from the enclaves is sufficient to justify the recognition of a pre-Granodiorite de Brest orogenic episode, which may be termed Dl/Ml, with associated planar structures S_1, and possible folds F_1. This episode may be identifiable with the Cadomian orogeny (see Chapter 7).

(d) Emplacement of the Granodiorite de Brest

The next recognisable event in the history of the SW Pays de Léon is the emplacement of the Granodiorite de Brest. This extensive pluton of batholithic proportions may have originated from the anatexis of large quantities of metasedimentary and other material at a deeper level in the crust than that now exposed.

This anatexis, which may have been a deep-seated expression of the Dl/Ml episode (although there is no obvious demonstration that this was the case), would have been followed by accumulation of magma, its ascent in the crust, and intrusion and consolidation in the (originally Brioverian) supracrustal rocks.

It has been pointed out by some workers (Roach, pers comm; Hanmer, pers comm) that the concordant association of the apparently anatectic Granodiorite de Brest with sillimanite grade metasediments and migmatites in the sector north of Illien (Fig 6-6) might suggest that the postulated anatectic episode in which the granodioritic magma originated was contemporaneous with the sillimanite grade metamorphism.

* It may be pointed out that folds such as these could have been produced in a non-metamorphic environment, for instance as 'slump' folds in a sequence of greywacke type sediments.

However in the opinion of the writer, and as will be discussed further in Chapter 8, the sillimanite grade metamorphism seen in the relatively minor quantities of sillimanite gneisses and leuco-neosome migmatites in the sector north of Illien is more simply explained as the higher grade equivalent of the medium-grade regional metamorphism seen in the Le Conquet sector; and since the latter metamorphism quite clearly affects not only the schists and the Granodiorite de Brest, but also the Filons de Kermorvan which must have intruded the Granodiorite at a significant interval after its consolidation, this metamorphism cannot be regarded as contemporaneous with or genetically related to the much earlier anatexis which produced the granodiorite itself.

(e) Filons de Kermorvan

The Kermorvan dykes intrude, and therefore postdate the Granodiorite de Brest. Their original trend may have been close to N-S in some cases, but is uncertain owing to rotation and shearing during the D2 deformation. There are grounds for considering that these may be genetically and temporally related to the Caradocian basic volcanism of the Presqu'Ile de Crozon, although proof of such a relationship is lacking.

(f) Pre-D2/M2 lithologies of uncertain relative age

(i) Granodiorite de Pont-Cabioc'h

As indicated earlier the Granodiorite de Pont-Cabioc'h occupies a relatively restricted outcrop in the north-east sector of the SW Pays de Léon (Fig 6-7). It appears to be of igneous origin and to have undergone the D2/M2 episode, but its relationship vis-a-vis the Granodiorite de Brest is uncertain. Geochronological data is reviewed in the next chapter.

(ii) Granodiorite de St Marzin

As indicated above the field evidence at one locality suggests that the leucocratic granodioritic gneisses at St Marzin are at least in part distinct in origin from the typical Granodiorite de Brest. However, it has not been possible to reach any conclusions regarding the relative age of the two granodiorite lithologies, or the origin of the leucocratic type.

(iii) Diorite de Dellec, etc.

Taylor (1969, p 111-112) describes the amphibolitic dioritic bodies outcropping at Dellec (Figs 6-1, 6-3, 6-7). He considers that the diorites are enclaves in the 'Gneiss de Brest' (Granodiorite de Brest) and therefore older than it. They may be temporally or genetically related to the early mafic bodies referred to above (section (b)).

Chauris (1969a, p 128) has described a diorite, possibly of similar type to those at Dellec, which outcrops on the isolated reef of Ar Zerrou, SW of the island of Trielen (Fig 1-2), and which is apparently associated with the granodiorite gneiss (? Granodiorite de Brest) of the Molēne Archipelago.

3. THE D2/M2 OROGENIC EPISODE

All the lithological units referred to in section 2 appear to have undergone a major episode of metamorphism and deformation which was responsible for some of the most prominent fabrics and mineral assemblages present in these rocks. The metamorphic mineral assemblages attributable to this episode will be discussed more fully in Chapter 8, in which comparison is made with the M2 metamorphism in the NW Pays de Lēon. For simplicity the same abbreviations D2 and M2 are used to refer to the chief orogenic episode in both the western sectors of the Pays de Lēon, although it should once again be emphasised that contemporaneity between the two sectors cannot be considered to be proven as yet.

The grade of the M2 metamorphism increases rather rapidly in a northerly or northwesterly direction as one passes from the low (chlorite) grade of the Brioverian and the southern margin of the Granodiorite de Brest, to staurolite grade round Le Conquet and Trez Hir, and sillimanite grade, with development of migmatites north of Illien.

The intensity of the combined D1 and D2 foliation seen in the metasedimentary belts remains consistently high once the low grade/medium grade boundary is passed (Fig 8–1), but the intensity of the S2 foliation in the Granodiorite de Brest is strikingly inhomogenous, with, particularly in the Le Conquet sector (Fig 6–5), but also as far north as Pointe de Brenterc'h (Fig 6–1), belts of almost undeformed granodiorite alternating with belts of schistose granodiorite.

The distribution of these belts of anomalously low deformation in the granodiorite appears to be related to, and possibly controlled by the distribution of the thicker belts of metasediment which comprise the Mica-schistes du Conquet. It appears that part of the bulk strain imposed during D2 in the whole of the SW Pays de Léon which was taken up by the rocks in the Le Conquet sector was distributed inhomogeneously on account of the presence of alternating belts of two types of material which were of the same order of thickness but of widely different competences. This variation in competence led to most of the strain being taken up by the less competent material, i.e. the metasediments, leaving the central portions of the intervening more competent granodiorite belts almost undeformed (Fig 6–5).

The minor structures produced during the D2/M2 episode are by no means simple and much work remains to be carried out on this aspect. Comparison of the descriptions of the structures classified by Taylor (Table 13.1, p.289; reproduced here as Table 6-1) as CnF_2, CnS_2, CnS_2 and the penetrative lineation component of his CnF_3 (sic) with structures observed by the present writer in the field and in hand specimen, has led to the conclusion that all the above listed structures may have been produced during a single major episode approximately coinciding with the development of the M2 metamorphic assemblages, and therefore classifiable as D2 structures in the present writers' scheme.

The most prominent structure which can be assigned to D2 is a metamorphic schistosity (S_2) (and locally a lineation: L_2) which is expressed as a preferred orientation of micas and chlorites, and a co-planar linear preferred orientation of (e.g.)amphiboles and quartz aggregates which plunges at moderate angles to ENE or WSW. The S_2 schistosity is axial planar to a set of tight to isoclinal folds which, according to Taylor, and also in the observation of the present writer, are confined to the metasedimentary formations (Quartzophyllades de l'Ēlorn and Mica-schistes du Conquet). Throughout much of the SW Pays de Lēon the S_2 schistosity strikes east-north east and dips at moderate to steep angles to the south. However significant variations in both dip and strike occur, and can largely be attributed to a post-D2 fold phase (D3). North of Pors Illien more intense post-D2 folding has caused greater variation in the trend of the S_2 schistosity, which commonly strikes near N-S in this sector (Fig 6-6).

Taylor (op.cit) has described rotational growth of garnet and staurolite porphyroblasts related to the growth of the (S_2) mica schistosity in the Mica-schistes du Conquet. The staurolite grade metamorphism (M2) thus appears to be an integral part of the D2 deformational episode in this sector.

4. POST-D2/M2 EVENTS

(a) Introduction

In this section the phases of folding which affect and therefore post-date the D2/M2 schistosity are considered together in the first sub-section, while the various post D2/M2 granitoid plutonic rocks are grouped together in the second sub-section. It should, however, be emphasised that while there is enough evidence available to arrange the fold phases in a chronological sequence, there does not appear to be enough evidence at present to demonstrate the relative age of the granitoid plutons compared either with each other or with the phases of post-S_2 folding seen in the metamorphic rocks. It should be further pointed out that some quite intense although localised, deformation affects the granitoid plutons themselves.

(b) Post D2/M2 folding and Kink Bands

The S_2 metamorphic schistosity in the metamorphic rocks of the SW Pays de Lēon is affected by at least two sets of post-metamorphic folds. These folds are described by Taylor (1969, p 296-301) under two main headings 'CnF_3' and 'late microfolds', to which he adds a third category, late kink bands.

Taylor's description of the CnF_3 and late microfolds is as follows:

> 'The CnF_3 folds (in the Le Conquet schists) are usually tight similar folds with angular hinge ... amplitudes of the order of 20-40 cm. are common ... The axial planes of the folds are always parallel to the schistosity ... there does not appear to have been anappreciable development of a new schistosity parallel to the axial planes ...'

'This (late microfold) deformation produces (particularly in the Le Conquet schists) a crenulation of the CnS_2 (i.e. S_2 in the present writer's classification) in those places where the rocks are most strongly foliated ... The amplitude of the folds varies from 1 or 2 mm to c. 1 cm. Characteristically the axial planes of the folds dip to the SE at a higher angle than the CnS_2 surface ...'

Crenulations of this type are shown in plates 6-5 and 6-6. While Taylor has clearly demonstrated the presence of more than one set of post-S_2 folds on the basis of the amplitude and style of the folds, it is not clear that these two sets are necessarily non-contemporaneous. In view of this uncertainty the writer prefers to group these two sets of folds (for which the abbreviations F_3 and F_3' may be used) together under the general heading of 'D3' structures.

The lack of retrograde metamorphism associated with the F_3 and F_3' folds has been noted by Taylor, and may indicate that, at least in the Le Conquet area, the temperature was not much lower during the D3 deformation than during the D2/M2 episode.

Major and minor folds which can broadly be assigned to D3 are particularly well developed in the sector between Illien and Anse de Porsmoguer, where they typically plunge at a moderate angle to the north east.

Late kink-bands are a prominent feature in the Mica-schistes du Conquet and the more strongly foliated varieties of the Granodiorite de Brest, and were recorded by De Lapparent (1934). They are described by Taylor (op.cit.p.304) who records that biotite is retrogressed to chlorite between the kink-planes. The chloritisation may indicate that the formation of the kink-bands took place at a significant interval after the formation of the F_3 and F_3' folds, and at a significantly reduced temperature.

(c) Post D2/M2 Granitoid Magmatism

The granitoid plutons of St Renan, Les Rospects and Trēgana (Fig 6-7), although locally deformed, show no sign of the development of S_2 metamorphic fabrics typical of the rocks of the Complexe Metāmorphique du Conquet. In the case of the St Renan and Trēgana plutons the granitoids appear to cut obliquely across the D2 structures, and the intrusion of the whole group can be regarded as a post D2/M2 episode. However cross-cutting relationships between any of these three plutons or their minor offshoots do not appear to have been recorded, and so their relative age cannot be ascertained on that basis at present. Their age relative to that of the F_3 and F_3' folds is also uncertain. Folds of the F_3 and F_3' types have not been recorded in the granitoids, but theoretical considerations make it improbable that relatively homogeneous and massive lithologies such as these would register small scale folds even if the episode which produced such folds in other lithologies post-dated the emplacement of the granitoids.

(d) Localised Deformation of the Post-D2/M2 Granitoids

(i) Granite de St Renan

The Granite de St Renan, notably in the vicinity of Pointe de Corsen, (Figs 6-1, 6-3) shows the local development of closely-spaced vertical E-W fractures along which some transcurrent movement appears to have taken place. According to Chauris (1969b) this deformation is the local expression of the Molēne-Moncontour lineament, (or North Armorican Shear Belt). Chauris (pers.comm.) has reported intense mylonitisation of the Granite de St Renan in inland exposures. These structures are analogous to the D4 structures in the NW Pays de Lēon (Chapter 4).

(ii) Granite des Rospects

Taylor (1969 p 301) has recorded a narrow (15m) E-W vertical mylonitised zone which affects the contact between the Granite des Rospects and the "Gneiss de Brest" (Granodiorite de Brest). It is possible that this zone, and other similar zones observed within the outcrop of the Granodiorite de Brest, may represent loci of movement similar in type to an possibly genetically connected with the more extensive zones of deformation observed in the Granite de St Renan some 10 km to the north.

(iii) Granodiorite de Trēgana

Deformation comparable with the mylonitic zones in the St Renan and Les Rospects Granites has not been reported from the Granodiorite de Trēgana. It does not however necessarily follow that the Trēgana pluton is younger than the others.

(e) Faulting

(i) Molēne-Moncontour Lineament

Some of the effects of transcurrent movements along this major structure have been briefly mentioned above in the conclusion of Chapter 4. It is likely that movement took place at more than one period : G.D. Williams (pers.comm) has reported that in the Guingamp area of North Brittany the most intense deformation associated with this same lineament predated the emplacement of the Hercynian Granite de Quintin, although minor movements continued after its emplacement.

(ii) Other faults

It is not proposed to add to the description and analysis of faults in the SW Pays de Lēon presented by Taylor (1969 p 304-308). On p. 305 he mentions the presence of abundant NE and NW trending strike-slip faults as well as some ENE trending faults. He also states (p 308-9) that ".. the faulting in the SW Pays de Lēon postdates the Trēgana granodiorite and the lamprophyre dykes and precedes the intrusion of the Porsmilin dolerite. Small movements reactivating existing faults may postdate the dolerite."

(f) Lamprophyre and Dolerite Dykes

As indicated above the intrusion of the lamprophyre dykes of the SW Pays de Lēon predated the main phase of faulting in the SW Pays de Lēon, and was probably associated with other late Hercynian magmatic phenomena such as the emplacement of granitoid plutons.

The dolerite dykes of Porsmilin-Brenterc'h postdate the main phase of faulting; and apparently belong to a later, post-Hercynian geotectonic regime of crustal dilation.

CHAPTER 7

GEOCHRONOLOGY OF THE SW PAYS DE LÉON: A NEW INTERPRETATION

CHAPTER 7

GEOCHRONOLOGY OF THE SW PAYS DE LĒON: A NEW INTERPRETATION

A. INTRODUCTION

In Chapter 5 an attempt was made to relate published and new geochronological data concerning the NW Pays de Lēon to the sequence of geological events established on field evidence and described in Chapters 2 - 4. In this chapter a similar attempt will be made to relate geochronological data from the literature to the sequence of geological events in the SW Pays de Lēon which was outlined in Chapter 6. No new data is presented, but it has been found that there is considerable scope for the reassessment and reinterpretation of data which is already in the literature. A revised (although still tentative and incomplete) absolute chronology of geological events in the SW Pays de Lēon will be presented.

As a preliminary to an interpretation of the isotopic age data of the SW Pays de Lēon, it is appropriate to review certain key aspects of the stratigraphic setting of the region, so that the absolute chronology of events in the predominantly medium to high grade crystalline terrain of the SW Pays de Lēon may be compared with the Precambrian and Palaeozoic stratigraphy of the less altered supracrustal terrain to the south.

B. STRATIGRAPHIC SETTING OF THE S W PAYS DE LĒON.

B.1. The relationship between the Quartzophyllades de L'Ēlorn, the Quartzites de la Roche Maurice and the Granodiorite de Brest.

The development up to about 1965 of ideas concerning the stratigraphical relationships between the Pays de Lēon and the adjacent areas of Late Precambrian and Palaeozoic rocks to the south is summarised by Bradshaw et al (1967, p 570 - 1). Barrois argued in several publications from 1900 onwards that the Quartzophyllades de L'Ēlorn could be correlated with the Brioverian of Normandy and that the orthoquartzite formation (Quartzites de la Roche Maurice) (Fig 7 - 2) which flanks the Quartzophyllades to the south was of Ordovician age, being overlain in turn by the Devonian rocks of the Plougastel and Crozon peninsulas. According to this interpretation the geological relations at the southern margin of the Pays de Lēon were similar to that seen on the southern flank of the Palaeozoic synclinorium of central West Finistère, where a quartzite formation (known as the Grēs Armoricain), lithologically similar to although thicker than the Quartzites de la Roche Maurice, unconformably overlies the Brioverian rocks of the Baie de Douarnenez (Fig. 7 - 1).

Subsequently, with the work of Pruvost et al (1943) and Delattre (1952) the view became current that both the Quartzophyllades de L'Ēlorn and the Quartzites de la Roche Maurice are younger than the adjacent Lower Devonian rocks, and therefore themselves of Devonian or Carboniferous age.

Bradshaw et al (1967) and Bishop et al (1969) argued cogently in support of Barrois' original interpretation of the stratigraphic position of the Quartzophyllades de L'Elorn and the Quartzites de la Roche Maurice. According to these authors, the Quartzites de la Roche Maurice are correlatable with the Gres Armoricain and therefore of Lower Ordovician, probably Arenigian age (Fig 7 - 2).

Subsequent to the work of Bishop et al, sedimentary rocks occurring stratigraphically between the Quartzites de la Roche Maurice and the sediments of Devonian age to the south have yielded Silurian fossils, (Chauris et al, 1970a) so that the quartzites are now generally accepted as the basal member of an apparently conformable (or paraconformable) sequence of Ordovician, Silurian and Devonian rocks, the Devonian sequence being complete up to and including Fammenian 11 (Babin et al, 1972, p 7 - 13).

Chauris and Hallegouet (1973b) have further correlated certain other quartzites, which outcrop to the north of the main outcrop of Quartzophyllades de L'Elorn, with the Quartzites de la Roche Maurice. In their view the Quartzophyllades de L'Elorn occupy the core of a tight anticline, while these "Quartzites de la Roche Maurice" on the northern limb of the antiform overstep unconformably onto the "Gneiss de Brest" (presumably Granodiorite de Brest), where the quartzites are now preserved in the cores of tight faulted synclines. These conclusions of Chauris and Hallegouet also implied that the "Gneiss de Brest" in the area they studied (between Landerneau and Brest) was uplifted and unroofed prior to the deposition of the (Arenigian) quartzites. The assignment of the Quartzophyllades de L'Ēlorn to the Brioverian has gained general acceptance, although the acceptance is not universal (see Babin et al,1972,p13).

Although views on the origin of the "Gneiss de Brest" have undergone a considerable change, from the early hypothesis of in situ granitisation of Quartzophyllades de L'Ēlorn which was accepted by most workers from Barrois (1900) to Chauris and Michot (1965), to the presently accepted opinion that the "Gneiss de Brest" is intrusive into the Quartzophyllades; nonetheless it has always been agreed that the deposition of the Quartzophyllades preceded the formation of the "Gneiss de Brest". So that if the Lower Ordovician age for the Quartzites de la Roche Maurice is accepted, then the Granodiorite de Brest has a stratigraphic age intermediate between the Brioverian and the Ordovician.

B. 2. Some important features of the Palaeozoic supracrustal rocks of West Finistère

B. 2. (a) The Ordovician to Devonian succession of the Rade de Brest area

The stratigraphic succession of Ordovician to Devonian rocks in West Finistère has been summarised by Babin et al (1972, p 7 - 13). The succession generally commences with a prominent white orthoquartzite formation (Grès Armoricain and Quartzites de la Roche Maurice) although further south in the Baie de Douarnenez, the orthoquartzites are underlain conformably by red and green clastic sediments (the Telgrùc formation).

The work of Bishop et al (1969) has shown that the ortho-quartzite thins towards the north as the present outcrop of the Granodiorite de Brest is approached. This feature may indicate a progressive marine transgression towards the north during the Lower Ordovician, with the Pays de Léon forming a positive feature relative to the area in the south.

The remainder of the Ordovician and Silurian succession is relatively thin and consists for the most part of neritic sediments with possibly some hiatuses representing periods of non-deposition. Volcanic horizons are rare, the only significant episode of volcanism occurring in the Caradocian, when an association of basic pillow lavas, hyalotuffs, and minor intrusions was formed in a belt which now outcrops for about 50 km from Châteaulin to Lostmarc'h in the Presqu'Ile de Crozon. (Bishop et al, 1969, p 325; Chauris, 1972c p 21 - 2). Philippot (1963) (quoted in Bishop et al, op cit) pointed out that the volcanic rocks die out rapidly to the north of the Presqu'Ile de Crozon, where the stratigraphically equivalent horizon consists of sediments showing features such as "slumps" and penecontemporaneous convolutions, indicative of deposition under unstable conditions, which may have been caused by earth movements genetically related with the volcanism further south.

The Devonian of the Rade de Brest area consists of a sequence of varied fossiliferous neritic sediments, whose total thickness appears to be rather greater than that of the Ordovician and Silurian combined. The sequence appears to be virtually complete from Gedinnian to Famennian II.

B. 2. (b) The relationship between the Carboniferous of Châteaulin basin and older rocks: the "Bretonic" phase

The Carboniferous rocks of the Châteaulin basin outcrop in an extensive zone to the east of the town of Châteaulin, (synclinorium de Châteaulin, Fig 1 - 4). According to Darboux et al (1977 and pers comm) the succession consists predominantly of semi-pelitic or "culm" facies rocks of Upper Viséan and Lower Namurian age. A conglomerate at the base of the sequence contains pebbles of black shales similar to those in the nearby Devonian. Stille (1924,1928) originated the use of the term "Bretonic" to refer to the tectonic episode intervening between the Devonian and the Carboniferous in Brittany. More recent work has been summarised by Darboux et al (1977), who produced a number of arguments underlining the importance of a tectonic episode which broadly corresponds to Stille's Bretonic phase. These arguments include:

(i) the absence of the Tournaisian and probably the Lower Viséan from the Palaeozoic sequence within the Châteaulin Basin.

(ii) the fact that the Viséan and Namurian succession outcrops not in the cores of the synclines of Devonian rocks of the Rade de Brest, but in an eccentric position with respect to the latter, overstepping from Lower Devonian onto Brioverian rocks.

(iii) the presence in the Carboniferous basal conglomerate of pebbles of black shales similar to those within the neighbouring Devonian.

(iv) the recognition by Darboux and Garreau (1976) of polyphase folding in the Devonian of West Finistère, contrasting with the single phase of folding and cleavage formation in the Carboniferous.

B. 2. (c) The Upper Carboniferous rocks of South Finistère

Minor outcrops of conglomerates and carbonaceous deposits containing plant fossils thought to be of Stephanian age occur within partly fault-bounded basins near Quimper and near Pointe du Raz (Fig 1 - 3). These basins lie within the Zone Broyée Sudarmoricaine in the axial zone of the South Armorican Metamorphic belt in South Finistère (Fig 1 - 3). The sediments unconformably overlie the mylonised granites of the Zone Broyée, and their deposition appears therefore to post-date the main period of mylonisation. The Stephanian rocks have undergone minor deformation as a result of late movements along the shear belt. Comparison of the mildly deformed state of these rocks with the relativelyseverely cleaved and folded Visean-Namurian of the Châteaulin basin suggests that a major orogenic episode affected the rocks of central and south Finistere during the interval between the Lower Namurian and the Stephanian. There is however no direct evidence to indicate that the Pays de Léon, which lies some 40km to the north of the nearest Stephanian outcrops, was affected by the same orogenic episode.

A prominent sub-Stephanian unconformity is also recognised in the Laval area of the eastern Armorican Massif (Fig 1 -4).

C. GEOCHRONOLOGY OF THE SW PAYS DE LĒON

C. 1. Introduction

Isotopic dating of rocks from the SW Pays de Lēon has been undertaken by a number of different workers at several different centres: work at Bruxelles has been carried out by Deutsch and Chauris (1965), Michot and Deutsch (1970) and Cabanis et al (1977); that at Oxford by Adams (1967a, 1976); and at Nancy by Leutwein et al (1969a,b,; 1972). More recently unpublished work has been carried out by workers at the University of Rennes together with B. Cabanis (pers comm). Data and interpretations in the literature will be discussed where referred to in the appropriate sub-section below, which are arranged according to the particular method (parent-daughter element pair) employed. The locations of samples used for U - Pb and Rb - Sr geochronology of the "Gneiss de Brest" and associated lithologies are shown in Figure 7 - **5** .

C. 2. U - Pb dating

C. 2. (a) Pre - D2/M2 Lithological units

With the exception of a recent analysis reported by Cabanis et al (pers comm) all the available U - Pb data on minerals (zircons and monazites) from the pre - D2/M2 formations of the SW Pays de Lēon are included in the paper by Michot and Deutsch (1970, table 1,p 221 and Fig 5). These are reproduced as Figures 7 - 4 and 7 - **3** in the present work. No analytical data are given in their table, but the analytical results are plotted on the U - Pb concordia diagram. The subscripts "a" and "b" refer to fractions separated according to their radioactive properties.

C. 2. (a) (i) Quartzophyllades de L'Ēlorn (sample I)

Sample 1 in Michot and Deutsch (1970) is from the Quartzophyllades de L'Ēlorn, which the authors consider to be Brioverian. They consider two alternative hypotheses to account for the discordant dates obtained:

(1) assuming only recent lead loss has taken place, the zircons are about 1500 m.y. old.

(2) the zircons consist of a mixture of two groups of zircons, one group being > 1500 m.y. old.

The authors record (p 219) that the zircons are predominantly rounded; this can be taked to indicate that they are in large part of detrital origin. The present writer concludes that a significant proportion of the zircons, and presumably also of the rock material of the Quartzophyllades de L'Ēlorn as a whole, was ultimately derived from the erosion of a terrain which had already constituted continental crust during the Lower Proterozoic (pre - 1700 m.y.; Fig 7 - 4). This conclusion is of some interest, particularly in view of the known presence of basement c 2000 m.y. old in the Channel Islands area (Calvez and Vidal, 1978).

C. 2. (a) (ii) Mica-schistes du Conquet (sample II)

From the lithological descriptions given by Michot and Deutsch (1970, p 227) it is argued by the present writer that Michot and Deutsch's sample III, which they state to be relatively poor in rounded zircons of probable detrital origin, may well represent a schistose facies of the Granodiorite de Brest rather than being a sample of (metasedimentary) Mica-schistes du Conquet as they suggest. In view of this their sample III will be considered in the next sub-section dealing with the Granodiorite de Brest.

The authors record that the zircons in their sample II, which is of more typical Mica-schistes du Conquet, are of heterogeneous morphology, comprising both "stubby" and, in smaller quantity "rounded" forms; the rounded forms may represent inherited detrital material, while the stubby forms may be of metamorphic origin.

The authors point out that the metamorphism which produced mica-schists has not obliterated the evidence of the great age (probably >1500 m.y.) of part of the zircon population. They attribute the discordance to the influence of the superimposed Cadomian and Variscan orogenies.

Comparison of the zircon and monazite U/Pb isotopic ratios and calculated ages of samples II and III given in table 1 and figure 5 of Michot and Deutsch (op cit) leads the present writer to suspect the possibility that the monazite dates given in table 1 of that publication may have been accidentally reversed. If this is the case, then the monazite dates for their sample II (Mica-schistes du Conquet) would display a discordance pattern remarkably similar to that of the zircon dates for the same sample;like the zircons, the monazites would appear to have retained clear evidence of great age (probably > 1500 m.y.) which has not been obliterated by the later metamorphic episodes undergone by the schists.

C. 2. (a) (iii) Granodiorite de Brest (sample IV, and probably sample III).

Michot and Deutsch (op. cit.) record that their sample IV, which comes from the southern margin of the pluton(Fig. 7 - 3) close to the contact with the Quartzophyllades de L'Élorn and where the post-intrusion metamorphic grade is relatively low (just within the biotite grade), contains a significant proportion of elongated zircons probably of magmatic origin, in addition to the more abundant stubby or almond-shaped types.

The zircons of both radioactive fractions of sample IV display rather similar discordance patterns with $^{207}Pb/^{206}Pb$ dates $\geqslant$900 m.y.. The discordance may reflect the heterogeneous nature of the zircons, with one population inherited from the possibly supracrustal sedimentary parent rock of the anatectic granodiorite and another population having been newly crystallised or recrystallised at the time of the formation and emplacement of the granodiorite at some time near to or later than 600 m.y.. A close estimate of the date of emplacement cannot however be obtained from this sample.

If sample III, which comes from the area affected by D2/M2 staurolite-grade metamorphism and severe deformation, is indeed a highly schistose (and therefore presumably highly deformed) sample of the Granodiorite de Brest, then it is likely to have undergone this severe deformation during the D2/M2 staurolite-grade metamorphism of the adjacent Micaschistes du Conquet. In any case the zircons retain little evidence of any history going back as far as the zircons of samples I, II and IV, and if the suggested accidental reversal of monazite dates between samples III and IV actually occurred, then the same conclusion applies to that mineral as to the zircons.

Both the zircons and (probably) the monazite dates of sample 111 seem to reflect mainly the effects of a severe disturbance at around 350 m.y. or less on a composite population originally comparable with that of sample 1V, one original component being presumably ofdetrital origin, the other of magmatic origin. The severe disturbance at around 350 m.y. or less may have been the D2/M2 episode, although the discordance of both the zircon and the monazite dates prohibits any precise estimate of the date of this disturbance.

C. 2. (a) (iv) Granodiorite de Pont Cabioch (sample V).

In Chapter 6 it was argued on petrographic and chemical grounds that the lithology at Pont-Cabioch described by previous workers as "Gneiss de Brest" is best considered as a separate intrusion, possibly of different age and origin from the "Granodiorite de Brest"; and the term "Granodiorite de Pont-Cabioch" was suggested in order to refer to this lithology (Fig. 6 - 7).

Deutsch and Chauris (1965) (also reported in Michot and Deutsch 1970) obtained a virtually concordant single sample U - Pb zircon date of c.460 m.y. ($^{206}Pb/^{238}U$: 459 ± 15m.y.; $^{207}Pb/^{235}U$: 458 ± 30 m.y.; $^{207}Pb/^{206}Pb$: 460 ± 70 m.y.) The close approach to concordance seems most easily explained if one concludes that the zircons crystallised at around 460 m.y., and that this was the date of emplacement of the granodiorite. However as only a single fraction of zircons was analysed the possibility remains that the zircons (and their matrix) originally crystallised somewhat earlier than 460 m.y. and were affected by a post-460 m.y. disturbance. Such a disturbance might have been that which gave rise to the pronounced composite linear/schistose fabric and metamorphic mineral assemblage of the rock observed at the sample locality. Another possibility is that the c.460 m.y. event may have been the tectono-metamorphic disturbance responsible for the fabric and mineralogy; however it seems unlikely that even a severe event of this type would have completely obliterated the evidence of an earlier magmatic origin of the granodiorite. There is no evidence of any ancient detrital component in the zircons of this sample.

C. 2. (a) (v) "Gneiss de Brest" (Landivisau).

Cabanis et al (pers. comm.) report a U - Pb zircon age of c. 450 m.y. from a sample of "Gneiss de Brest" collected west of Landivisiau (some 30 km east of Brest (Fig. 7 - 1), i.e. outside the S W Pays de Léon). The present writer has not had an opportunity to compare the lithology or analytical data with those of the samples dealt with by Deutsch and Chauris (1965) and Michot and Deutsch (1970). Nonetheless the similarity with the zircon date of the Granodiorite de Port-Cabioch is noteworthy.

Cabanis et al also draw attention to the fact that the U - Pb zircon date of the "Gneiss de Brest" near Landivisiau is very close to the Rb - Sr whole rock isochron age obtained by Barriere et al (1971b) for the Trondhjēmite de Douarnenez, which is a major pre-metamorphic granodiorite pluton occupying an analogous position on the southern flank of the Palaeozoic-Brioverian synclinorium of Central Finistère to that of the Granodiorite de Brest on the northern flank; (Fig. 7 - 1 ; shown as "granite" west of Douarnenez).

C. 2. (b) Post-D2/M2 lithological units.

The only post D2/M2 lithology in or near the S W Pays de Lēon for which a U - Pb date is available is the Granite de St. Renan (Quarry of Langongar). This granite, which together with the Granite de Kersaint forms a convenient boundary between the metamorphic complexes of the northwest and southwest sections of the Pays de Lēon, appears without much doubt to postdate the D2/M2 deformation of the Granodiorite de Brest. The significance of the zircon U -Pb date of this granite is discussed in Chapter 5. Analogous arguments to those presented there indicate that the D2/M2 episode in the S W Pays de Lēon was earlier than the apparently concordant U - Pb zircon age of this granite, viz about 350 m.y. (344 m.y. using the decay constants recommended by Steiger and Jaeger, 1977).

C. 3. Rb - Sr dating.

C. 3. (a) Pre-D2/M2 Lithological units.

C. 3. (a) (i) Whole-rock Rb - Sr dating: the Granodiorite de Brest.

Three attempts have been made to obtain Rb/Sr whole-rock isochrons from the Granodiorite de Brest (sensu lato). Two of these attempts (Adams, 1967a, and Cabanis et al, 1977) involved samples collected from the "Gneiss de Brest", while the other involved samples from the "Renards Granite" (Granodiorite de la Pointe des Renards).

Adams (1967a.; also reported in Bishop et al, 1969 p. 340; Adams, 1976, p.238) collected 14 samples of "Gneiss de Brest" from an area extending for about 35 km from Le Conquet to the neighbourhood of Landerneau. It is possible that 2 of Adams' samples (1088,1089) were of "Granodiorite de Pont-Cabioch" rather than "Granodiorite de Brest",(Fig. 6 - 7, 7 - 5) (see also present work, Chapter 6).

Cabanis et al (1977) collected 14 samples of "Gneiss de Brest" from an area exctending for about 70 km from near Pointe de St. Mathieu to Ile Callot (north of Carantec) at the eastern extremity pf the Pays de Léon (Fig. 7 - 5). Their samples fall into two petrographic and compositional groups, one of which, comprising 5 samples from a limited area to the west of Landivisiau, are stated to be of more magmatic character and have Rb/Sr ratios of c.0.5 or less, while the other 9 samples are stated to be a mixture of magmatic and metamorphic material and have Rb/Sr ratios ranging from about 1 to 2. The latter group appears to include the typically rather inhomogeneous Granodiorite de Brest type, while the former group is now thought to be a distinct intrusive phase comparable with the Trondhjémite de Douarnenez (Cabanis et al, 1977, p.884).

Both attempts, that of Adams (1967a) and that of Cabanis et al (1977),result, when the data points were plotted on Nicolaysen diagrams, in arrays of points whose best-fit lines have slopes corresponding to an "isochron" age of approximately 675 m.y.($\lambda^{87}Rb = 1.42 * 10^{-11} yr^{-1}$) (Adams: 675 ± 39 m.y.; Cabanis et al 671 ± 11 m.y.) (Fig. 7 - 5). However the intersection of the best fit line with the $^{87}Sr/^{86}Sr$ axis indicated apparent initial $^{87}Sr/^{86}Sr$ ratios of 0.7081 ± 0.0013 in the case of Adams, and 0.702 (error not quoted, but unlikely to exceed 0.002) in the case of Cabanis et al.

Cabanis et al (op. cit.) pointed out that although the calculated ages were similar, the significant difference in apparent initial Sr ratios was unacceptable if the rocks belonged to the same lithological unit. This argument, together with their observations on the heterogeneous nature of their own set of samples, led Cabanis et al to reject the c.675 m.y. "dates" obtained by both Adams and themselves.

The present writer is in agreement with the arguments of Cabanis et al on this matter; further support to their conclusions is given by the present writer's arguments concerning the heterogeneous nature of the set of samples collected by Adams (see Chapter 6). Both "isochrons" are in this view, spurious, the similarity of the slopes arising from the combination in both cases of two groups of samples from different lithological units; the distribution of points and resulting slopes of the best fit lines in the Nicolaysen diagrams being controlled more by the difference between the mean Rb/Sr ratios of the two groups of samples than by the age of the rocks concerned.

Cabanis et al (op. cit.) in comparing their five samples of magmatic type from the Landivisian area with the Trondhjēmite de Douarnenez, remark that the latter has a fairly well-estab.-

lished Rb/Sr whole rock isochron age of 472 24 m.y. (λ ^{87}Rb = $1.42 \times 10^{-11} yr^{-1}$) with an initial $^{87}Sr/^{86}Sr$ ratio of 0.7047. They point out that their five samples would fit reasonably well on the Douarnenez isochron, and that the age of the Landivisiau samples might well be similar to that of the Douarnenez pluton.

The present writer would however point out that such an age for the Landivisiau samples would not necessarily apply to the remainder of the "Gneiss de Brest", i.e. the Granodiorite de Brest (sensu stricto). An opportunity to obtain a Rb/Sr whole rock age for the latter is however presented by Adams' (1967a) analyses of six samples of "Renards Granite", i.e. relatively unfoliated and undeformed Granodiorite de Brest; all the samples having been collected within a radius of 1.5 km from Le Conquet. Adams' calculated age was 548 40 m.y. (2σ error) (λ $^{87}Rb = 1.42 \times 10^{-11} yr^{-1}$) and he concluded that the "Renards Granite" was emplaced at this date. An additional check on this date was carried out by the writer by recalculating the data for the six samples (kindly made available by Dr. Adams) using a more recently available programme (P2CHRON) (made available by permission of R J Pankhurst). The resulting best fit line has a slope corresponding to an age of 552 ± 58m.y. (same λ ^{87}Rb value). Although the "mean" values obtained using the two programmes are closely similar, the 2σ errors are rather large, and it appears that some of the points deviate significantly from the best fit line. This feature may possibly be explained by the observation that the Granodiorite de Brest near Le Conquet typically contains numerous semi-pelitic enclaves and biotitic schlieren, which would make sampling of completely homogeneous and uncontaminated "magmatic" material difficult. The enclaves and schlieren, being commonly richer in biotite, and therefore probably richer in Rb than the rock as a whole may have given rise to an inhomogeneous distribution of radiogenic Sr during the post-emplacement metamorphic history of the complex (the whole of the sector from which these six samples come was subjected to conditions in the upper part of the staurolite grade during the M2 metamorphism).

In spite of these reservations it appears to the present writer that a figure of c.550 ± c.50 m.y. is at present the best available estimate of the emplacement age of the six samples from Le Conquet area collected by Adams, and by extension the emplacement age of the Granodiorite de Brest as a whole. It is felt, however, that the observed small-scale heterogeneity of the Granodiorite de Brest may mean that special techniques may be required in order to exclude non-magmatic material and thus obtain a more accurate isochron age.

The conclusions that the "Pointe des Renards Granodiorite" and the greater part of the "Gneiss de Brest" represent a single intrusion, namely the "Granodiorite de Brest", and that the latter was probably emplaced at around 550 ± 50 m.y. entail that the major orogenic episode (D2/M2) instead of being a Cadomian episode bracketed between c.675 and c.550 m.y. as envisaged by Adams (1967a, 1976 and in Bishop et al, 1969) has instead an older age limit of c.550 ± 50 m.y., so far as available evidence from the Granodiorite de Brest is concerned. It should be emphasised that the U - Pb zircon date of c.460 m.y. of the Granodiorite de Pont-Cabioc'h provides a still later "terminus post quem" for the D2/M2 episode in the S W Pays de Lēon.

C. 3. (a) (ii) Ordovician and Silurian sediments of Crozon.

Bonhomme et al (1968) obtained an Rb - Sr whole rock "isochron" age of 315 ± 25 m.y. with initial Sr ratio of 0.713 ± 0.005 (an alternative calculation of 320 ± 19 m.y. is also given in their publication) from argillaceous fractions of six samples from six different stratigraphic horizons (two mid-Ordovician, two upper Ordovician and two Silurian) in the Anse du veryac'h area of the Presqu'Ile de Crozon. They remarked that the rocks were of very low metamorphic grade, containing significant quantities of kaolinite and montmorillonite.

If the isochron age they obtained represents a real geological event, the latter may have been a tectonic and perhaps minor thermal disturbance related to the D3 deformation in the Complexe Metāmorphique du Conquet; and possibly coinciding with the pre-Stephanian orogenic episode for which the evidence was given in section B. 2. (c).above.

C. 3. (a) (iii) Rb - Sr mineral dates.

Relatively few Rb/Sr mineral dates on rocks from the S W Pays de Lēon appear in the literature.

Michot and Deutsch (1970) report an Rb - Sr mica date (model age) for each of the five samples from which they extracted zircons and monazites for U - Pb analyses. No Rb - Sr data are given in their publication, but as the Rb/Sr ratios of the minerals are likely to have been quite high, the importance of any error in the assumed initial Sr ratio is diminished, and it is thought that some confidence may be placed in the quoted dates. They fall into two groups.

(1) Three biotite dates of between 300 and 280±15m.y. from, respectively sample II (Mica-schistes du Conquet), sample III (schistose ? Granodiorite de Brest from Le Conquet) and sample V (Granodiorite de Pont-Cabioch) come from portions of the metamorphic complex which appear to have undergone severe deformation and medium (staurolite/garnet) grade metamorphism during the D2/M2 episode. However since these Rb - Sr biotite dates are significantly younger than the suggested minimum possible age of the D2/M2 episode (c.344 m.y., given by the U - Pb zircon date of the post D2/M2 Granite de St. Renan) the biotites appear to have undergone Sr loss or homogenisation during a period significantly later than the D2/M2 episode. It is not clear however whether the dates represent the termination of a prolonged period of cooling and uplift, or an episode of disturbance at around 300 - 280 m.y.. If the latter is the case, then the disturbance may possibly coincide with the D3 deformational event; and would broadly correspond to the major post-Namurian, pre-Stephanian orogenic episode for which the evidence is mentioned in subsection B. 2. (c) above.

(2) More ambiguous results were obtained by Michot and Deutsch (op. cit.) in the case of their sample IV (Granodiorite de Brest from Hildy) (Rb - Sr biotite date of 396 ± 12 m.y.) and sample I (Quartzophyllades de L'Élorn from Kerisbihan or Portzic lighthouse) (Rb - Sr muscovite age of 460 ± 10 m.y.).

Both these samples come from near the southern margin of the

Granodiorite de Brest, in a zone which has undergone relatively minor post-emplacement deformation and low (chlorite/ biotite) grade metamorphism. Both dates, and certainly the biotite date seem to be "mixed"; resulting from the incomplete redistribution of radiogenic Sr during some episode or episodes subsequent to the original crystallisation of the minerals. The muscovite has been less affected than the biotite by these later events, but this may be explained by the fact that the muscovite comes from a zone in which the M2 metamorpnism did not exceed Chlorite grade. The coincidence of the muscovite date with the U - Pb zircon dates from the Granodiorites of Pont-Cabioc'h and Landivisiau raises the possibility that the muscovite date is related to the emplacement of these plutons; but such a hypothesis is tentative.

Leutwein et al (1969b) report a single Rb - Sr biotite date of 340 5 m.y. for "Gneiss de Brest" from near Landivisiau; this figure may reflect D2/M2 and later orogenic redistribution of radiogenic Sr, or perhaps the influence of the Complexe Granitique de St Renan-Kersaint whose emplacement took place at around this time. (The Rb/Sr ratio given is high enough for the calculated date to be insnsitive to considerable variation in the assumed initial Sr ratio of 0.712).

C. 3. (b) Post - D2/M2 lithological units.

C. 3. (b) (i) Complexe granitique de St Renan - Kersaint.

Rb - Sr analyses of rocks and minerals from the Granite de St Renan and the Granite de Kersaint have already been considered in Chapter 5. Arguments and conclusions similar to those concerning the significance of Rb/Sr dates from the St Renan - Kersaint Complex in the history of the NW Pays de Lēon are also applicable to the SW Pays de Lēon.

C. 3. (b) (ii) Granodiorite de Trēgana

Adams (1967a) has included one sample from the Granodiorite de Trēgana with a sample from the Granite de Kersaint and three samples from the other granites outside the Pays de Lēon to construct an Rb - Sr isochron for the early Hercynian granites (333± 5 m.y.). This isochron age is of doubtful validity for the reasons suggested in Chapter 5. There does not seem to be any real evidence to support the linking of the Granodiorite de Trēgana with the geographically and compositionally distinct Granite de Kersaint. If the Trēgana pluton is taken on its own, we have only the single Rb - Sr whole rock analysis by Adams (1967a, table 9, sample 1116). The Rb/Sr ratio of this sample is so low that very little ^{87}Sr can have accumulated in it since its emplacement; so no estimate of the date of emplacement can be made from this analysis. The initial $^{87}Sr/^{86}Sr$ is however easily established, being virtually equal to the present-day value (0.706). This figure indicates a significant crustal component in the parent rocks of the granodiorite.

C. 4. K - Ar dating

C. 4. (a) Pre - D2/M2 lithological units

C. 4. (a) (i) Diorite de Dellec

Adams (1967a) obtained dates of 485 16 m.y. and 461 15 m.y. for two hornblende samples from this diorite, which is an enclave in the Granodiorite de Brest, occurring near the southern margin of the latter in an area of low-grade M2 metamorphism. The dates are significantly younger than the best estimate of the date of emplacement of the surrounding country rock (550 ± 50 m.y. if the Adams (1967a) isochron is applicable), and probably earlier than the D2/M2 episode. The dates may be mixed ages reflecting partial loss of radiogenic Ar in D2/M2 events or later. (The K contents of the samples are very low raising the possibility of significant experimental error; an error of 25 - 35 m.y. in the calculated age).

C. 4. (a) (ii) Amphibolite (near Les Rospects)

Adams (op. cit.) obtained a K - Ar date of 316 ± 11 m.y. for the hornblende from a minor amphibolite sheet associated with the Granodiorite de Brest near Les Rospects. Whatever the earlier history of the sheet, the date clearly reflects partial or complete post D2/M2 Ar loss, possibly related to D3 deformation.

C. 4. (a) (iii) Granodiorite de Brest

Adams (op. cit.) carried out K - Ar analyses in two biotites and one muscovite from the Granodiorite de Brest.

Two samples from the medium grade (staurolite, approaching sillimanite) grade M2 metamorphic zone near Le Conquet give dates significantly older (muscovite 336 ± 10 m.y.; biotite 343 ± 10 m.y.) than that from the low-grade southern margin at La Maison Blanche (biotite 300 ± 9). It may be noted that the pattern dispalyed by these K - Ar mica dates is thus the reverse of that seen in the Rb - Sr dates. In the presumably more deep-seated zone at Le Conquet radiogenic Ar was retained more readily in the later thermo-tectonic history of the area than radiogenic Sr in the same mineral group; while in the lower grade zone near the contact between the Quartzophyllades de L'Ēlorn and the Granodiorite de Brest radiogenic Sr was retained more readily than radiogenic Ar. This pattern is not easily explained; but may result from inverse variation in the importance of two separate controls on the redistribution of radiogenic isotopes in minerals. It may have been the case, for example, that elevated temperature in the more deep-seated zone at Le Conquet was more effective in redistributing Sr than Ar, while possible increased severity of brittle deformation in the shallower zone near the southern margin of the Granodiorite de Brest may have been more effective in redistributing Ar than Sr.

Leutwein et al (1969b) report a K - Ar age of 317 ± 8 m.y. for biotite from "Gneiss de Brest" near Landivisiau. (Rb

- Sr age of the same sample is 340 ± 15 m.y.; see subsection above). Like Leutwein's other K - Ar dates this one was probably obtained without making allowance for the ^{36}Ar retained in the sample after laboratory preparation. If this was the case then the corrected date of this sample should be slightly less than 317 ± 8 m.y. . The date appears to reflect prolonged post-D2/M2 cooling or disturbance during a post-D2/M2 event (presumably D3).

C. 4. (a) (iv) Mafic rocks from the Baie de Douarnenez

Reference may also be made at this point to two K - Ar dates from basic rocks associated with the Brioverian of the Baie de Douarnenez, as although the area lies well to the south of the Pays de Léon, the dates may be significant in an interpretation of the geochronology of West Finistère as a whole.

Adams (1967a, table 9, sample no. 1234) obtained a K - Ar date of 375±12 m.y. from a whole rock sample of a (? metamorphosed) basic dyke near Douarnenez, while Leutwein et al (1969a, sample 1) obtained a K - Ar date of 352± 20 m.y. from a whole rock sample of Brioverian pillow lava from Pen-Ar-Vir. Both these dates probably reflect the influence of the D2/M2 episode on rocks that are much older (pre-Ordovician in the case of the pillow lava).

C. 4. (b) Post - D2/M2 lithological units

C. 4. (b) (i) Complexe granitique de St Renan-Kersaint

K - Ar dates reported by Adams (1967a) and Leutwein et al

(1969b) from the granites of Kersaint (biotite:303 ± 9 m.y.) and St Renan (K - feldspar:340 ± 15 m.y.) have been referred to in Chapter 5. The feldspar date appears to represent post-emplacement cooling; while the biotite reflects subsequent (? D3) disturbance, or the end of a period of slow cooling and uplift.

C. 4. (b) (ii) Granodiorite de Trégana

Adams' (1967) K - Ar biotite date of 300 ± 9 m.y. is a minimum age for the emplacement of the Granodiorite de Trégana.

C. 4. (b) (iii) Lamprophyres

Leutwein et al (1972) report dates of 285 ± 5 m.y., 282 ± 5 m.y. and 254 ± 5 m.y., for whole rock samples of lamprophyres (kersantites) from the Rade de Brest area. The earlier dates may be close to the emplacement age of the lamprophyre suite.

C. 4. (b) (iv) Dolerites of Porsmilin and Brenterc'h

A number of K - Ar whole rock analyses have been published of the Porsmilin and related post-Hercynian mafic dykes of West Finistère. (Some samples are from outside the Pays de Léon).

Leutwein et al (1972) report four dates ranging from 195 ± 10 to 205 ± 10 m.y.. One of these (204 ± 6) is from Brenterc'h. All Leutwein's figures may need to be reduced slightly because of the possibility of "initial" ^{36}Ar retained after sample heat treatment.

Adams' (1967a) single date of 191 ± 6 m.y. for a single whole rock sample from Porsmilin may be nearer to the age of emplacement of these dolerites.

D4 CONCLUSIONS

In table 7 - 1 an attempt is made to correlate the sequence of geological events in the Complexe Métamorphique du Conquet and associated intrusions with (i) the absolute time scale (as indicated by the discussion in this chapter) and (ii) the contemporaneous sequence of events in the supracrustal terrain which lies to the south of the Pays de Léon (outlined in section B above).

TABLE 7-1

OUTLINE GEOLOGICAL HISTORY OF THE SW PAYS DE LÉON AND ADJACENT AREAS TO THE SOUTH

TIME B.P. (m.y.)	GEOLOGICAL EVENTS IN SW PAYS DE LÉON	GEOLOGICAL EVENTS IN CENTRAL AND SOUTH FINISTÈRE (MAINLY SUPRACRUSTAL)	STAGE	SYSTEM
c191 ± 6	Dolerites of Porsmilin and Brenterc'h	Dolerites of Crozon and Douarnenez		TRIASSIC
		Terrestrial sedimentation of Pointe du Raz, Quimper	STEPHANIAN	
c.280	Few Lamprophyre Dykes	Lamprophyres and Dolerites of Rade de Brest		
c.280	Final Cooling of Biotites below Sr blocking temp. in more deep-seated zones			
c.300 -320	(? Emplacement and) cooling of Granodiorite de Trégana ? D3 folding	"Sudetic" folding and cleavage of arboniferous in Bassin de Châteaulin	LOWER STEPHANIAN WESTPHALIAN UPPER NAMURIAN	CARBONIF-EROUS
		'Culm' Facies sedimentation in Bassin de Châteaulin	LOWER NAMURIAN UPPER VISÉAN	
c340	Cooling of Alkali-feldspar through Ar retention temp. in Granite de St Renan			
c.345 - 360	Emplacement of Complexe Granitique de St Renan-Kersaint			
c.350 - < 380	D2/M2 Orogenic folding and metamorphism	"Bretonic" folding and cleavage of Famennian and older sediments		
		Neritic Sedimentation	FAMENNIAN FRASNIAN GIVETIAN COUVINIAN EMSIAN SIEGENIAN GEDINNIAN	DEVONIAN
			LUDLOVIAN WENLOCKIAN (VALENTIAN)	SILURIAN
	? Mafic Dykes of Kermorvan (Uncertain Date)	Shallow water volcanic activity	(ASHGILLIAN) CARADOCIAN	
		Marine Sedimentation	LLANDEILIAN LLANVIRNIAN	ORDOVICIAN
	Uplift and unroofing of Granodiorite de Brest and other intrusions	Marine Transgression and sedimentation	ARENIGIAN	
c.450 - 460	Emplacement of Granodiorites of Landivisiau and Pont Cabioc'h	c.460–470 Emplacement of Trondhjémite de Douarnenez		
? c.550 ± 50	Emplacement of Granodiorite de Brest			(L. CAMBRIAN)
	Early (? D1/M1) Folding and Metamorphism	"Cadomian Orogeny"		UPPER PROTERO-ZOIC
	Brioverian	Sedimentation with pillow lavas and Basic Minor Intrusives		
pre-1700	Precursors of Brioverian Sediments ("Pentevrian")			LOWER PROTERO-ZOIC

CHAPTER 8

THE M2 METAMORPHISM IN THE WESTERN PAYS DE LÉON: A CROSS SECTION THROUGH A HIGH-GRADE METAMORPHIC BELT IN THE HERCYNIDES

CHAPTER 8

THE M2 METAMORPHISM IN THE WESTERN PAYS DE LÉON: A CROSS SECTION THROUGH A HIGH-GRADE METAMORPHIC BELT IN THE HERCYNIDES

A. INTRODUCTION

Previous chapters have dealt with specific sectors of the western Pays de Léon from a general geological and geochronological point of view. In this chapter the writer's intention is to describe and analyse a single major metamorphic episode as it is manifested in the western Pays de Léon as a whole. The eastern limit of the area of concern is a N-S line running approximately through Landerneau and Lesneven. The analogous metamorphism in that part of the Pays de Léon which lies east of this line has been discussed by Cabanis (1974, 1975) and Cabanis and Fabriès (1972).

As indicated in chapter 1, 1:80;000 geological maps of the western Pays de Léon were produced by Barrois (1893, 1902). Boundaries of some of the metamorphic formations were mapped, but Barrois made little attempt to study the metamorphism of the area as such. However later publication by Barrois (1934) and de Lapparent (1934) include descriptions of some metamorphic rocks from the Pays de Léon. Shelley (1964, 1966) and Cogné and Shelley (1966) described some aspects of the metamorphism of the Lannilis and Plouguerneau areas of the NW Pays de Léon, and certain of the metamorphic rocks of the SW Pays de Léon have been described by Michot and Lavreau (1965), Bradshaw et al (1967), Bishop et al (1969), Chauris (1969a), and Michot and Deutsch (1970) among others. By far the most detailed of any study in the region to date is that of Taylor (1969) on the SW Pays de Léon. Brief descriptions of most of the main metamorphic formations in the western Pays de Léon are included in the 'notices explicatives' to the 2nd edition of the Plouguerneau 1:80,000 sheet, and to the 3rd edition of the Brest 1:80,000 sheet (Chauris, 1966c, 1972c).

Much discussion in the literature has centred on the question of the 'age' of the metamorphic rocks of the Pays de Léon; particularly as to whether the most prominent regional metamorphism was a Precambrian or Hercynian (i.e. Upper Palaeozoic) episode. This aspect has been discussed earlier in the present work and is not an essential concern of the present chapter, which is mainly concerned with the metamorphism itself, irrespective of its age. Nonetheless it is necessary to assume for the purposes of this chapter that the climactic metamorphic assemblages now observed in the Western Pays de Léon originated for the most part in a single major episode, for which, in the present writer's classification, the abbreviation 'M2' is used.

Various workers (Barrois, 1934; Bishop et al, 1969) have contributed towards the view that the staurolite-garnet-mica schists of the Le Conquet district originated by the metamorphism of material originally similar to the Quartzophyllades de L'Élorn (or Brioverian) which outcrop along the southern margin of the Pays de Léon. This concept was taken further by Bishop et al (op cit); and expressed in detail by Taylor (1969), who considered that certain of the ortho-gneissic or (meta)igneous rocks of the SW Pays de Léon, such as the 'Gneiss de Brest' were likewise the result of syn-metamorphic deformation of what were originally igneous intrusions emplaced into the Quartzophyllades de l'Élorn.

A comparable approach to the metamorphic rocks of the Lannilis area of the NW Pays de Léon was made by Shelley (1964) and Cogné and Shelley (1966) who considered that the 'migmatitic mica-schists' (Gneiss de L'Aber-Benoît) of the L'Aber-Benoît sector were the higher grade metamorphic equivalents of the Mica-schistes de L'Aber-Wrac'h, and that the 'amphibolite quartzique ' (Diorite de Lannilis) represented a metamorphosed volcanic formation. According to these authors the migmatites and associated granites of the central part of the Plouguerneau-Landunvez sector of the NW Pays de Lēon originated through the granitisation, or in situ transformation into granite, of material originally resembling the metamorphic formations of the Lannilis district.

In the eastern part of the Pays de Lēon zones of increasing metamorphic grade have been mapped by Cabanis (1975, 1976), who has traced the low-grade formations of the Morlaix district into the high-grade terrain of the central Pays de Lēon. However, other workers have suggested that the distribution of metamorphic and structural zones in the Morlaix district is more complex than suggested by Cabanis (R.A. Roach and N. Griffiths, pers.comm.).

The present chapter attempts to combine the various earlier descriptions of the metamorphism in the Western Pays de Lēon with the writer's own observations so as to present an analysis of the area considered as part of a single metamorphic belt (sections B to D). An attempt is also made to account for the observed distribution of metamorphic zones and isograds in terms of the possible reactions and physical conditions which may have given rise to them (section F), and to place the M2 metamorphism of the Pays de Lēon in its regional and geotectonic context (section G).

B. LITHOLOGIES AFFECTED BY THE M2 METAMORPHISM

B.1. INTRODUCTION

About 50% of the outcrop of the western Pays de Lēon consists of generally undeformed and unmetamorphosed granitic (sensulato) rocks, (Figs 1-5, 8-1). These granites include the Complexe Granitique de L'Aber-Ildut; the Granite de Landunvez; the Adamellite de Ste Marguerite; the Granite de Kernilis and the Granite de Brignogan in the NW Pays de Lēon; the Granodiorite de Trēgana and Granite des Rospects in the SW Pays de Lēon; and the Complexe Granitique de St

Renan-Kersaint straddling the boundary between the NW and SW sectors. These granites are of various ages and types, but all have the one feature in common that their emplacement appears to postdate the climactic metamorphism in the various metamorphic and migmatitic complexes which they intrude. These granites will not be considered further in this chapter. The remainder of the western Pays de Lēon is occupied by metamorphic and migmatitic complexes containing a variety of lithological types but all showing the effects of the major deformational and metamorphic episode for which the writer uses the term D2/M2.

B.2. METASEDIMENTARY LITHOLOGIES

These occupy only a relatively small proportion ($<$25%) of the total area of metamorphic and migmatitic rocks, but are important as sensitive indicators of metamorphic grade. They consist predominantly of interbanded psammites, pelites and semi-pelites, with minor amounts of other compositions such as calcareous types. Arguments have been presented in Chapter 2 which suggest that these metasediments are for the most part likely to be the higher grade equivalents of the Brioverian (Quartzophyllades de L'Ēlorn). Included in this category are the lithological units referred to in the literature as 'Mica-schistes du Conquet' (Chauris, 1972c) and 'Mica-schistes de L'Aber-Wrac'h (Chauris, 1966c). In addition, some portions of the composite formation described as 'Gneiss de Lesneven' by Chauris (1972c), notably that portion described as 'Mica-schistes migmatitiques' by Cogné and Shelley (1966) and for which the present writer has introduced the term 'Gneiss (à sillimanite) de L'Aber-Benoît; and also some portions of the 'Migmatites de Plouguerneau' (Chauris, 1966c) may also be grouped under the heading of metasedimentary lithologies.

TABLE 8-1

METAIGNEOUS LITHOLOGICAL UNITS IN THE WESTERN PAYS DE LĒON

Original rock type	Present metamorphic unit
Alkali-granite	Gneiss de Trēglonou Gneiss de Plounevez-Lochrist
Granodiorite	Granodiorite de Brest (formerly known as 'Gneiss de Brest' or 'Gneiss de Lesneven') Granodiorite de Pont Cabioc'h
Diorite (or Biotite-diorite)	Diorite de Lannilis Diorite de Portsall Diorite de Dellec
Mafic	Filons de Kermorvan Amphibolites de L'Aber-Benoît Granulites a clinopyroxène de Brendaouez

B.3. METAIGNEOUS LITHOLOGIES

These are more extensive and varied then the metasediments. In most cases their original field relations with the metasediments and with each other have been obscured by subsequent deformation and by the poverty of exposure. However the Granodiorite de Brest, which occupies a considerable outcrop in the SW Pays de Léon and in the Molêne Archipelago has been shown by Bradshaw et al (1967) to be intrusive into the Brioverian and locally retains a contact metamorphic aureole. The metabasic Filons de Kermorvan are in turn intrusive into the Granodiorite de Brest, while the Diorite de Dellec is described by Taylor (1969) as an enclave in the same Granodiorite. It seems likely to the present writer that, in spite of the inconclusive evidence, most of the other metaigneous rocks of the Western Pays de Léon were also post-Brioverian intrusions; a possible exception is provided by certain metabasic rocks which may represent contemporaneous volcanic horizons within the Brioverian. Alternative views have been put forward: for instance Shelley (1964) and Cabanis (1976) considered that the Diorite de Lannilis and the Gneiss de Tréglonou respectively represent inliers of (metaigneous) basement upon which the metasediments were deposited.

The chief metaigneous lithologies in the Western Pays de Léon are listed in table 8-1.

C. PRE-M2 METAMORPHIC EPISODES

C.1. M1 (CADOMIAN) REGIONAL METAMORPHISM

According to the present writer's interpretation of the geological evolution of the region, the Brioverian Quartzophyllades de L'Élorn, together with associated basic volcanic rocks, underwent an important orogenic episode (D1/M1) prior to the emplacement of the Granodiorite de Brest and possibly also before the emplacement of many of the other metaigneous units. This episode probably occurred near the beginning of the Phanerozoic and if so can be identified with the late Pre-Cambrian Cadomian orogeny which was originally defined in the Caen area of Lower Normandy. In much of the Western Pays de Lēon the metamorphism associated with this episode was apparently less severe than the succeeding M2 metamorphism, and so assemblages and fabrics produced during the Cadomian episode have tended to be superseded and obliterated. However, it may have reached amphibolite facies in the neighbourhood of Le Conquet, where a gneissose amphibolite (probably produced during M1) occurs as an enclave in almost undeformed Granodiorite de Brest. More commonly, for example in the Mica-schistes de L'Aber-Wrac'h and in the Quartzophyllades de L'Ēlorn (Taylor, 1969) a fold phase can be recognised in the metasediments which precedes that associated with the M2 metamorphism, and can probably also be assigned to the D1/M1 or Cadomian episode.

C.2. CONTACT METAMORPHISM ASSOCIATED WITH THE METAIGNEOUS ROCKS

In general later deformation and metamorphism, particularly during the D2/M2 episode has been so severe as to obliterate any contact metamorphic aureoles that may have surrounded the pre-D2/M2 igneous formations. However adjacent to the southern margin of the Granodiorite de Brest, Taylor (1969) has described petrographic features in the Quartzophyllades de l'Ēlorn which are characteristic of contact metamorphism. These include pseudomorphs after chiastolite (op.cit.p.53) and the presence of oligoclase similar to that in the adjacent intrusion (Bishop et al, 1969).

D. THE M2 METAMORPHISM

D.1. DATE OF THE M2 EPISODE

Evidence has been presented in earlier chapters which suggests that the M2 metamorphic episode took place during the 'Bretonic' phase of the Hercynian orogeny, that is to say approximately at the limit of the Devonian and the Carboniferous c.360-350 m.y. b.p. It is also thought probable that the main episode of folding, cleavage formation and low-grade metamorphism in the Lower Ordovician to Upper Devonian supracrustal succession which occupies the area just to the south of the Pays de Lēon was contemporaneous and genetically related with the D2/M2 episode in the Pays de Lēon.

However, for the purposes of the main sections of the present chapter it is not necessary to know or assume the exact age of the metamorphic episode which is being considered; or to correlate it with events recognised elsewhere. It is merely assumed that the M2 metamorphism was a single, if prolonged, episode and that it took place at some time subsequent to the incorporation of the various supracrustal and igneous lithological units referred to in section B above into a single complex.

D.2. GENERAL DISTRIBUTION OF M2 ISOGRADS

For convenience of description the metamorphic and migmatitic rocks of the Western Pays de Lēon have been divided into three groups labelled low-, medium- and high-grade respectively. The usage of these three terms is as follows: (1) the term 'low-grade' is used for rocks which have not reached biotite grade, and so contain chlorite rather than biotite, and (generally) albite rather than more calcic plagioclase; (2) the term 'medium-grade' is used for rocks which have reached the biotite isograd, and which (generally) also contain oligoclase/andesine rather than albite; a convenient subdivision is made between rocks (a) below and (b) at staurolite grade; (3) the term 'high-grade' is used for rocks which are characterised by (a) the abundance of sillimanite and scarcity or absence of muscovite and staurolite and (b) the development of migmatites.

It will be seen from the accompanying map (Figure 8-1) that the low-grade assemblages occur near the southern margin of the Pays de Léon, in the vicinity of and to the east and south of Brest. Medium-grade assemblages, are found in two separate areas: the first lies immediately to the north and northwest of the low-grade area and is centred on the area of Anse de Bertheaume and Le Conquet; while the other is an 'outlier' surrounded by high-grade rocks and post-metamorphic granites in the area of L'Aber-Wrac'h. High-grade terrains occupy much of the central and northern parts of the Western Pays de Léon. The observed lateral variation in grade is thought likely to be due to post-M2 (possibly D3) folding and later tilting of isograds which may originally have been more nearly horizontal (compare the conclusions of Winchester (1974) on folded isograds in the Caledonian metamorphic terrain of Scotland).

D.3. LOW-GRADE ASSEMBLAGES

Information on the low-grade assemblages of the Brest area is mainly derived from the unpublished work of Taylor (1969). The writer is indebted to Dr Taylor for permission to refer to this unpublished data.

Some metamorphic assemblages attributable to the M2 episode found in the vicinity of Brest are listed in Table 8-2.

Some particularly noteworthy effects of the low-grade M2 regional metamorphism in the Brest area are:

(a) The conversion of an andalusite-biotite-oligoclase hornfels from the contact aureole of the Granodiorite de Brest to a sericite-chlorite-albite assemblage.

(b) Local chloritisation and albitisation of the biotite-oligoclase granodiorite itself.

TABLE 8-2

SOME LOW-GRADE REGIONAL METAMORPHIC ASSEMBLAGES IN THE BREST AREA OF THE SW PAYS DE LĒON

Author	Locality	Grid Ref	Rock Type	Assemblage	Subfacies (Winkler, 1967)
Michot and Deutsch (1970, p.225)	Kerisbihan Quarry		semi-pelite	Sericite/ muscovite, chlorite, quartz, plagioclase	
Taylor (1969, p.207)	(L'Ēlorn)		semi-pelite	Quartz, sericite, chlorite, albite.	Qtz-ab-ep-chlor (or Qtz-ab-musc-chlor)
Taylor (op.cit p.41) (after Renouf)	"		semi-pelite	Quartz, sericite, chlorite, altered oligoclase, rock fragments	
(op.cit p.207)	Quarry 'north of Baradozic'	'935,612' '947,625'	grano-diorite	Quartz, chlorite, albite (An9) sericite	"
(op.cit p.55-6)	"		hornfels	Quartz, chlorite, muscovite, albite (An6)	"
(op.cit p.192)	West of Le Minou	'520,128'	basic dyke (margin)	Albite, actinolite, chlorite, epidote (+ sphene, apatite)	"
(op.cit p.192)	"	"	basic dyke (centre)	Actinolite, zoned plagioclase (An 22-28) quartz, biotite, epidote (+ sphene, carbonate) (feldspar 'not at equilibrium') (Transitional from medium-grade)	?Qtz-ab-ep-bi

In general the low-grade regional metamorphic assemblages found in the Brest area are characteristic of the qtz-ab-ep-chlor, and to a lesser extent the qtz-ab-ep-bi subfacies of the greenschist facies of Winkler (1967). Possible metamorphic reactions and the physical significance of the assemblages will be discussed below in section F.

D.4. MEDIUM-GRADE ASSEMBLAGES

The area of low grade assemblages passes north-westwards into a zone characterised by the presence of biotite rather than chlorite, oligoclase/andesine rather than albite and, in rock of suitable bulk composition, garnet and staurolite. It is not easy to strictly delimit metamorphic boundaries and isograds because the most widespread and abundant lithology is biotite-granodiorite which is rather insensitive to variation in metamorphic conditions once the chlorite grade is exceeded. A similar problem arises in the L'Aber-Wrac'h medium-grade 'outlier', where the common biotite-hornblende (meta)-diorite lithology is not a sensitive metamorphic indicator. In the S.W. Pays de Lēon a zone where staurolite is absent from pelitic schists is succeeded by a zone where it is present.

Some observed assemblages are listed in tables 8-3, 8-4 and 8-5.

Among the noteworthy features of the medium-grade M2 metamorphic assemblages of the western Pays de Lēon are:

(i) the preservation of compositional banding with alternating pelitic and psammitic bands probably of sedimentary origin.

(ii) the appearance in the S.W. Pays de Lēon of oligoclase at a significantly lower grade than staurolite

(iii) the extreme rarity of kyanite (only recorded at one locality in the staurolite zone)

(iv) the incoming of sillimanite, often associated with quartz veins in the higher-grade sector of the staurolite zone

(v) the appearance of recrystallised tourmaline in the staurolite zone

(vi) the presence of clinopyroxene in some mafic and calc-psammitic bands in the L'Aber-Wrac'h area.

(vii) the scarcity or absence of andalusite and cordierite as regional metamorphic minerals

(viii) the abundance and size of garnet and staurolite porphyroblasts in the Mica-schistes du Conquet

TABLE 8–3

SOME MEDIUM-GRADE REGIONAL METAMORPHIC ASSEMBLAGES IN THE SW PAYS DE LÉON (staurolite-free zone)

Author	Page	Locality	Co-ordinates (if given)	Rock-type	Assemblage
Taylor (1969)	208	'300 m SE of Trégana Granodiorite/Gnèiss de Brest boundary on coast'	449,154	basic dyke	plagioclase (An 32), hornblende, quartz, biotite (? ± epidote)
"	192	West of Le Minou	520,128	basic dyke (centre)	actinolite, zoned plagioclase (An 22-28) quartz, biotite, epidote (± sphene, carbonate)(feldspar 'not at equilibrium'). (Transitional from low grade)
"	207	NW of Coat Uelen	625,280	schist	garnet, biotite, etc.
"	209	W of Fort St Marzin		schist	garnet, biotite, etc, (associated rocks with plagioclase, An 28)
"	209	between Pte de St. Mathieu and Glas Enez		schists	muscovite, garnet, biotite
Michot and Deutsch (1970)	226	Pont Cabioc'h		hornblende-granodiorite	plagioclase, hornblende, biotite, garnet, (epidote)
Chauris (1969)	125	Beniguet		schist	garnet, muscovite, biotite
Taylor (1969)	209	between Pointe de St. Mathieu and Glas Enez		basic sheet	(calcic plag.)
Taylor (1969)		general		Granodiorite de Brest	quartz, biotite, oligoclase; (± muscovite, alkali-feldspar).

TABLE 8-4

SOME MEDIUM-GRADE REGIONAL METAMORPHIC ASSEMBLAGES IN THE SW PAYS DE LĒON (staurolite-zone)

Author	Page	Locality	Co-ordinates	Rock-type	Assemblage
Taylor(1969)	208	(between Porsmilin and Trez Hir)		schist	staurolite-bearing, associated with 'albitised' rocks
"	208	Mescam (by road)	408,284	schist	garnet, staurolite, etc.
De Lapparent (1934)	5	Le Conquet		schist	garnet, staurolite, biotite, muscovite, quartz, ilmenite, tourmaline
Michot and Deutsch(1970)	227	Le Conquet		granodioritic gneiss	biotite, plagioclase, quartz
Bishop et al (1969)	317	Le Conquet (generally)		schist	garnet, staurolite, biotite, muscovite, plagioclase, opaque ± tourmaline
Taylor(1969)	211	100 m S of Pors Fontaine (one locality only)		pelite	andesine, staurolite, biotite, quartz, kyanite (kyanite replaced by sillinamite; both replaced by muscovite)
"	213	Plage de Portez	064,204	pelite	sillimanite (nucleating on biotite)
"	213	Plage de Portez; also outhside of Le Conquet estuary		quartz veins	margins of fibrolite
Taylor(1969) also Bishop et al(1969)	276 317	Pointe des Renards		basic dyke	garnet, labradorite, amphibole, quartz, biotite, ± epidote
Michot and Deutsch(1970)	226	Le Conquet		schist	quartz, biotite, muscovite, garnet, staurolite ± sillimanite (epigenised)
Taylor	276	Kermorvan		basic dyke	calcic andesine (An50), pale amphibole, quartz, biotite

TABLE 8-5

MEDIUM-GRADE REGIONAL METAMORPHIC ASSEMBLAGES IN THE L'ABER-WRAC'H AREA

Author	Locality	Rock-type	Assemblage
Present work	general	schist	muscovite, biotite, oligoclase, quartz.
"	general	psammite	garnet, sodic plagioclase, quartz, ± biotite, muscovite
"	Keradraon (Le Traon)	calcareous psammite	garnet, clinopyroxene, andesine, quartz.
"	Kerouartz Prat Paul etc.	biotite-diorite	biotite hornblende, oligoclase, quartz, sphene
"	Brendaouez	mafic	(a) garnet, clinopyroxene, labradorite, quartz (b) hornblende, clinopyroxene, andesine, quartz (also scapolite)

D.5. HIGH-GRADE ASSEMBLAGES

High-grade assemblages attributable to the M2 episode are more extensive in the western Pays de Lēon than those of low and medium-grade. They occur in three distinct areas which are separated by outcrops of post-M2 granites:

D.5.(a) The S.W. Pays de Lēon

D.5.(a)(i) Transitional zone

Between the Le Conquet Estuary and Pors Illien metasedimentary belts and screens within the Granodiorite de Brest no longer contain obvious staurolite; this mineral is absent or rare, while both sillimanite (which has already made an appearance in the upper part of the staurolite zone) and muscovite, which is particularly abundant and may be secondary after sillimanite, become more prominent. Garnet remains abundant in pelites which thus typically contain garnet, biotite, quartz, muscovite, and sillimanite. Mafic rocks may contain minor biotite in addition to hornblende.

The Granodiorite de Brest retains the same mineralogy as at lower grades, but muscovite becomes locally more prominent. No significant development of migmatitic banding has been observed in any lithology. According to the descriptions of Chauris (1969a) a similar association is found in the offshore islands of Quémēnēs, Trielen and Litiri.

D.5.(a)(ii) Zone of sillimanite and migmatites

North of Pors Illien the predominant lithology remains foliated biotite granodiorite (Granodiorite de Brest). But here sillimanite becomes abundant and prominent both in metasedimentary bands, which may show migmatitic segregation, and in some portions of the granodiorite which are rich in metasedimentary inclusions. Locally it may be difficult to distinguish material of metasedimentary origin from that of meta-igneous origin. Both appear to have undergone severe deformation and local migmatitic segregation at sillimanite grade. This lithological association continues to crop out on the west coast as far as the intrusive contact of the Granite de St. Renan; similar gneissic and migmatitic rocks also occur as enclaves within the latter granite, and, according to Chauris (1969a, p.129) are also associated with the Granite de St. Renan on the island of Molēne.

TABLE 8-6

HIGH-GRADE METAMORPHIC ASSEMBLAGES OF L'ABER-BENOIT

Lithological unit	Lithology	Assemblage
Gneiss de L'Aber-Benoît	Pelitic	biotite, quartz, plagioclase, ± sillimanite, muscovite, alkali-feldspar (commonly showing quartzo-feldspathic lamination)
	Psammitic	garnet, plagioclase, quartz
Gneiss de Trēglonou	Alkali-granite	garnet, biotite, alkali-feldspar, quartz, + accessory muscovite, plagioclase
Diorite de Lannilis	Biotite-diorite	sphene, hornblende, biotite, oligo-clase-andesine, quartz
Diorite de Lannilis	Mafic	sphene, plagioclase, hornblende or clinopyroxene
Amphibolites de L'Aber-Benoît	Mafic	quartz, andesine, hornblende, + accessory sphene, pyrrhotite, other opaque

D.5.(b) L'Aber-Benoît sector of the Complexe Métamorphique de Lannilis

The L'Aber-Benoît sector which forms the southern and larger sector of the Complexe Métamorphique de Lannilis, is bounded to the south by the Complexe Granitique de St. Renan-Kersaint, to the west by the Complexe Granitique de L'Aber-Ildut, and to the east by the Granite de Kernilis. The southern inland sector between Coat-Méal and Plouguin (Figs 1-2, 1-7) has not been studied by the writer. There are few natural exposures except along the banks of L'Aber-Benoît itself, where the assemblages shown in Table 8-6 occur.

Shelley (1964) and Cogné and Shelley (1966) considered that the migmatitic and sillimanite-bearing semipelitic rocks of L'Aber-Benoît (or 'mica-schistes migmatitiques') were the higher grade equivalents of the muscovite-biotite-schists of L'Aber-Wrac'h. Alkali-granitic gneisses also have an extensive outcrop north and east of Lesneven, where they are known as Gneiss de Plounevez-Lochrist, locally displaying augen structure.

Nodules some tens of cm in length essentially composed of sillimanite fringed with muscovite are found as residual blocks associated with the Gneiss de Tréglonou near Guelet ar C'hoat (Chauris, 1972c).

Barrois, in the 'notice explicative' to the 2nd edition of the Brest 1:80,000 sheet, records the occurence of cordierite (altered to praseolite or chlorophyllite) in gneisses in the central Pays de Léon, but localities and associations are not indicated.

D.5.(c) Complexe Migmatitique de Plouguerneau

The Complexe Migmatitique de Plouguerneau, which has been described in Chapter 3, is considered to be in part the migmatitic equivalent of the Complexe Métamorphique de Lannilis. The migmatitic complex has been shown to be confined to the area north of the Porspoder Lineament. Migmatites predominate between Guissény in the east and Presqu'ile Ste Marguerite in the centre. Further west, migmatitic and metamorphic rocks and minerals occur as enclaves in the Granite de Landunvez, ranging ranging in size from several km long (Diorite de Portsall) to single garnet crystals, probably of xenocrystic origin (De Lapparent, 1934) (cf. plates 3-32, 3-33).

In the Migmatites de Plouguerneau metasedimentary material is for the most part recognisable as sillimanite-biotite schlieren and psammitic pods in a leucogranitic matrix. These are generally subordinate in

TABLE 8-7

SOME MINERAL ASSEMBLAGES OBSERVED IN THE COMPLEXE MIGMATITIQUE DE PLOUGUERNEAU

Bulk Composition	Assemblage	Widespread (W) or Local (L)
(a) Paleosome and Melanosome		
Mafic	andesine, hornblende, quartz (± biotite)	W
	labradorite, hornblende, quartz	L
	andesine, chlorite, quartz, sphene	L
	andesine, biotite, quartz	L
Intermediate and Granodioritic	andesine, biotite, quartz (± sphene, muscovite)	W
	andesine, hornblende, biotite, quartz, sphene	Common in Diorite de Portsall; rare elsewhere
Impure calcareous	labradorite, pale-green amphibole, quartz biotite, muscovite	L
	quartz, clinozoisite, labradorite, muscovite, biotite, garnet	L
Psammitic (some calc-psammitic)	quartz, labradorite, garnet (± sphene amphibole)	widespread as a group, but variable
	quartz, muscovite, chlorite, sphene	
	quartz, biotite, muscovite	
	quartz, alkali-feldspar, biotite, muscovite, plagioclase, garnet	
Pelitic and Melanosome	biotite (± muscovite ± quartz, feldspar)	W
	biotite, sillimanite, garnet (± quartz, plagioclase, muscovite)	widespread as a group
	biotite, sillimanite, muscovite	
	biotite, sillimanite, alkali-feldspar, oligoclase, muscovite	
	biotite, sillimanite, alkali-feldspar, corundum	L
(b) Leucosome	alkali-feldspar, quartz, sodic plagioclase (± garnet, biotite, muscovite, chlorite	W
	andesine, hornblende, quartz	L

quantity to material which appears to be of igneous origin, generally dioritic or granodioritic, but with rare mafic rocks, occurring in the form of agmatitic blocks in a leucogranitic matrix. The only extensive body of relatively unmigmatised rock is the Diorite de Portsall, which resembles the Diorite de Lannilis in mineralogy and structure. Elsewhere, the original material appears to have undergone a much more severe reconstitution than seen for example in the L'Aber-Benoît sector. Even in the case of the Diorite de Portsall, there appears to have been migmatisation and local replacement of hornblende by biotite.

Some observed assemblages are listed in table 8-7.

It is likely that the chlorite observed in certain assemblages listed in table 8-7 represents a disequilibrium assemblage, due to post M2 alteration of biotite to chlorite plus opaque mineral.

Some noteworthy features of the high-grade assemblages observed in the Complexe Mētamorphique de Lannilis and the Complexe Migmatitique de Plouguerneau are the following:

(a) the abundance of sillimanite in metapelites and the melanosomes of metasedimentary migmatites
(b) the abundance of garnet in leucosomes of migmatites, in psammites, and locally with sillimanite in melanosomes of metasedimentary migmatites; garnet being however rare in metaigneous material
(c) the scarcity or absence of cordierite
(d) the relatively small, though widespread, quantity of muscovite
(e) the abundance of myrmekitic int rgrowths
(f) the replacement of biotite by chlorite and opaque mineral, particularly in the more quartzofeldspathic rocks, such as leucosomes of migmatites

E. METAMORPHISM ATTRIBUTABLE TO THE M2 EPISODE IN AREAS ADJACENT TO THE WESTERN PAYS DE LĒON

E.1. THE EASTERN PAYS DE LĒON

Only the Western Pays de Lēon has so far been discussed in this chapter, the writer having had little opportunity to study adjacent areas, at first hand. However, the Pays de Lēon has generally been regarded as a single lithological and structural complex, and the writer concurs with this view. The metamorphism of the Eastern Pays de Léon has been described by Cabanis (1975) who recognised a succession of isograds and metamorphic zones in the area between St Thégonnec, Morlaix and St. Pol de Léon. There is a general increase in metamorphic grade in a westerly and north-westerly direction as the high-grade rocks of the central and NW Pays de Léon are approached. (It should be noted that Cabanis has argued that the main metamorphism in the Morlaix area is post-Viséan, i.e. significantly later than 'M2'), while Roach and Griffiths (pers comm) consider that the distribution of metamorphic zones in the eastern Pays de Léon may be more complex than suggested by Cabanis, possibly including some pre-Hercynian assemblages and structures.)

A zone characterised by the presence of chloritoid and chlorite occurs between Morlaix and St Thégonnec. This is succeeded to the N.W. in the valley of the Penzé by a zone where chlorite gives way to biotite and, at slightly higher grade, chloritoid is lost and garnet appears. A third zone in the area of Plouvorn is characterised by the occurrence of staurolite. An andalusite isograd and zone are also shown in this sector by Cabanis (op.cit). However Cabanis and Fabriès (1972) had earlier suggested that the occurrences of andalusite in the Morlaix area may have been associated with a granite intruded during a relatively late episode in the evolution of the area; they considered that the growth of andalusite (and possibly certain other minerals) was possibly contemporaneous with their Phase II fold episode, which, if the classification used by the present writer in the Western Pays de Léon is applicable, would be equivalent to D3/M3 rather than D2/M2. In view of this it seems possible that the presence of an andalusite zone in the Eastern Pays de Léon, only a short distance to the N.W. of Morlaix, may likewise be related to a post-M2 episode and/or the well established late Hercynian granites in the area such as that of Ste Catherine (Leutwein et al, 1969a).

The widespread occurrence of chloritoid in the chlorite zone and the lowest part of the biotite zone is a noteworthy feature of the Eastern Pays de Léon.

E.2. THE AREA IMMEDIATELY SOUTH OF THE PAYS DE LÉON

Although there has been disagreement as to the stratigraphic status (Brioverian or Palaeozoic) of certain of the sedimentary formations in Central Finistère, there is no doubt that the whole succession has undergone low-grade metamorphism.

Le Corre (1975) used XRD methods to compare the crystallinity of phyllosilicates in the Brioverian and Palaeozoic rocks of West Finistère. He concluded that the Brioverian had undergone higher-grade conditions than the Palaeozoic and that the metamorphism of the two groups was therefore not contemporaneous. However in the present writer's view the variation in crystallinity could have been caused by a somewhat greater depth of burial and resulting higher temperatures in the Brioverian during the same episode which caused the metamorphism of the Palaeozoic. (It should nevertheless be emphasised that the Brioverian in this sector had undoubtedly undergone the D1/M1 orogenic episode prior to the deposition of the Palaeozoic rocks.)(See section C above.)

Porphyroblasts of the characteristic low-grade regional metamorphic mineral chloritoid have been reported in a number of localities in central Finistère (Chauris, 1971c, p.2045; Darboux and Garreau, 1976, p.1008). In the latter case the chloritoid occurs in what are generally agreed to be Devonian rocks, and is stated to be approximately contemporaneous with the earliest phase of folding, while andalusite at the same locality is associated with a later episode. This evidence can be taken to suggest that in the area to the south of the Pays de Leon chloritoid was produced during a low-grade regional metamorphism, possibly equivalent to the D2/M2 episode in the Pays de Léon itself, while andalusite was produced during a later pepisode, which may have been either D3/M3 or the intrusion of the granite of Huelgoat and Commana. (The structural and textural evidence for these conclusions has been questioned by some workers (Roach, pers.comm).)

F. METAMORPHIC REACTIONS AND PHYSICAL CONDITIONS DURING THE M2 EPISODE

F.1. INTRODUCTION

This chapter has so far been mainly concerned with description of the mineral assemblages attributable to the M2 episode in the western Pays de Léon and adjacent areas. An attempt will now be made to suggest some of the processes and physical conditions which may have given rise to the assemblages observed.

F.2. LOW-GRADE ASSEMBLAGES

It should perhaps be re-emphasised that notably in the Quartzophyllades de L'Élorn, but also to some extent in the schists of Le Conquet and

L'Aber-Wrac'h, one is dealing with rocks which have undergone both of the regional metamorphic episodes M1 and M2. As a result some uncertainty exists as to whether the mineral assemblages and metamorphic fabrics observed are to be attributed to M1 or M2. Some earlier authors (e.g. Renouf 1965) have attributed virtually all the metamorphic minerals and fabrics in the Quartzophyllades de L'Élorn to the Cadomian (i.e. M1) episode. However, the present writer considers that the deformational features and low-grade metamorphic fabrics are of comparable intensity and apparently concordant in the Quartzophyllades and in the adjacent Palaeozoic rocks. This observation suggests that the most prominent metamorphic features in both groups of rocks may have been produced in the same episode, presumably M2. Any relict M1 assemblages in the Quartzophyllades de L'Élorn are likely to be subordinate to or have been obliterated by the M2 assemblages.

Low-grade metamorphic assemblages characterised by the presence of chlorite, chloritoid, albite, and sericite/muscovite are found at the southern margin of the Pays de Léon and adjacent areas to the south. In general little textural evidence is available to indicate what reactions were responsible for the observed assemblages.

In the pelitic portions of the Quartzophyllades de L'Élorn the association of muscovite and albite may have arisen by the reaction suggested by Hemley and Jones (1964) (quoted in Winkler, 1974, p.201):

$$KAlSi_3O_8 + NaAl_3Si_3O_{10}(OH)_2 = NaALSi_3O8 + KAL_3Si_3O_{10}(OH)_2$$

Alkali-feldspar Paragonite Albite Muscovite

Where the Granodiorite de Brest has been affected by low-grade M2 metamorphism the pair biotite + oligoclase has given way to chlorite + albite. An isochemical reaction cannot be constructed involving these minerals alone, as any such reaction must account for the potassium in the biotite; this may have gone to form muscovite, or been in part lost from the system.

Possible prograde reactions leading to the formation of chloritoid have been suggested by Frey (1972) and Thompson and Norton (1968)(quoted in Winkler, 1974 p.205-6)

Pyrophyllite + Fe-rich chlorite = Chloritoid + Quartz + H_2O

Hematite + Fe-rich chlorite = Chloritoid + Magnetite + Quartz + H_2O

The sporadic distribution of chloritoid in this and other metamorphic terrains may be due to particular chemical parameters such as to Fe/Mg ratio and Al/K,Na,Ca ratio of the rock which are thought to control the formation of chloritoid.

The assemblage albite-actinolite-chlorite-epidote-sphene-apatite observed in the margin of a basic dyke at Le Minou appears to result from the hydration and retrogression of a dolerite. A relict higher grade assemblage is seen in the centre of this dyke.

Little is known about the PT conditions controlling any of the possible reactions mentioned above. Comparison with what is known about the stability fields of such minerals as staurolite which occur in the adjacent medium-grade terrain indicates that the low-grade assemblages were formed for the most part at temperatures less than about 400°C.

F.3. MEDIUM AND HIGH-GRADE ASSEMBLAGES

F.3.a. Plagioclase

Plagioclase (usually oligoclase/andesine) is a characteristic mineral of metaigneous (granodioritic to mafic) rocks of the western Pays de Lēon, and the failure of this mineral to undergo retrogression to albite coincides with the lower limit of medium-grade conditions during the M2 metamorphism. Once medium-grade conditions are attained the composition of plagioclase is probably controlled more by bulk composition than by physical conditions and variation within the range oligoclase/andesine are probably of little use in themselves in indicating grade or the PT conditions responsible.

F.3.b. Incoming of biotite

Biotite becomes stable in the S.W. Pays de Lēon at about the same grade as oligoclase. However the reactions leading to the formation of biotite in prograde metamorphism of pelitic rocks do not seem to be well known. Winkler (1974, p.209) has suggested the reaction

Phengite + Chlorite = Biotite + Al-rich chlorite + Quartz

but indicates that direct evidence for its occurrence is lacking.

Biotite may also be formed in mafic rocks at the expense of other mafic minerals (particularly amphiboles). This represents a retrograde (hydration) reaction in which both K_2O and H_2O must be supplied.

It is a widely held opinion that the chlorite-biotite transition takes place at c. 350°- 400°C, but the present writer is not aware of the experimental backing for this opinion.

F.3.(c) Incoming of garnet

Garnet (generally assumed to be rich in the almandine component, but with little direct evidence apart from its pink colour) is abundant in the Western Pays de Lēon, particularly in the metasedimentary schists and some metabasic rocks.

In the S.W. Pays de Lēon it appears in pelites at slightly higher grade than biotite; this absence of garnet from other biotite-bearing rocks at lower grades may be due to their bulk composition (granodioritic to metabasic). Garnet does not appear to have been observed in the muscovite-biotite pelites of the L'Aber-Wrac'h medium-grade area.

A number of reactions leading to the formation of garnet in pelites, usually inferred from petrographic observations, have been reported in the literature. Perhaps the suggestions most relevant to the S.W. Pays de Lēon are those of Thompson and Norton (1968) (quoted in Winkler, 1974, p.210):

Chlorite + Muscovite + Quartz = Almandine + Biotite + H_2O

Chloritoid + Chlorite + Quartz = Almandine + H_2O

The grade at which garnet first appears in pelitic rocks is known to vary significantly with the composition of the garnet, particularly in spessartine content, and thus may be controlled by the content of Mn and other components in the whole rock system. In view of this, the mere observation of the presence of garnet cannot, without further information, give any precise indication of parameters such as temperature, and all that can be concluded is that the appearance of garnet in the S.W. Pays de Lēon probably represents a temperature approaching 400°C.

F.3.(d) Garnet and cordierite

A distinctive feature of the M2 metamorphism in the Pays de Lēon is the abundance of garnet relative to cordierite. Cordierite ($(Mg,Fe)_2Al\ Si_5O_{18}$) is often regarded as an approximate chemical equivalent of almandine-pyrope garnet ($(Fe,Mg)_3\ Al_2Si_3O_{12}$) but stable at rather lower ranges of pressure than the latter.

Garnet (probably almandine-rich in most cases) is widespread and abundant in the medium and high-grade metamorphic and migmatitic rocks of the Western Pays de Lēon. There are on the other hand few reports of cordierite from the area; although it has been recorded by Barrois

(1:80,000 Brest sheet, notice explicative). The scarcity of records of cordierite may be due in part to such factors as difficulties of identification and the proneness of the mineral to secondary alteration. Nonetheless the scarcity of cordierite associated with the M2 episode in Lēon appears to be real, and must have petrogenetic significance.

Various workers have studied the phase relations between cordierite and other minerals, particularly garnet. Richardson (1968) using pure Fe end-members of the cordierite and almandine solid solution series obtained a curve for the reaction

Fe cordierite + sillimanite = Fe almandine + sillimanite + quartz

His curve has a small negative slope in the range $700^{\circ}/3.5$ kb to $800^{\circ}/2.5$ kb; combining this curve with that obtained for the reaction

Fe staurolite + quartz = Fe cordierite + sillimanite

which intersects the former curve near $700^{\circ}/3.5$ kb he concluded that the absence of cordierite from rocks of appropriate composition and temperature indicates total $P > 3.5$ kb.

Subsequent work by other authors (Hensen and Green, 1973, Currie, 1971) (discussed by Winkler, 1974, p.224) has drawn attention to the importance of the divariant field in PT space in which garnet and cordierite co-exist. The position and extent of this divariant field is itself controlled by the bulk composition, particularly the FeO/FeO + MgO value (see Winkler, 1974, fig 14-12).

More recently Holdaway and Lee (1977) have obtained a series of PT curves (reproduced here as Fig 8-3) which indicate that cordierite of any given composition is confined to rather lower pressures than had been suggested by Currie (op.cit) or Hensen and Green (op.cit), particularly if $PH_2O < P$ total. The general form and approximate position in PT space of the Fe cordierite stability field as obtained by both Richardson (1968) and Holdaway and Lee (op.cit) are similar, a fact which permits one to place some confidence in both sets of results. Holdaway and Lee's curves for the stability field of Fe cordierite ($PH_2O = P$ total) are included in Fig 8-6.

It is clear that the abundance of garnet and scarcity of cordierite in the metamorphic rocks of the Western Pays de Lēon may be related to compositional control and PH_2O as well as to PT conditions. It may nonetheless be concluded that the mean geothermal gradient was significantly lower during the M2 metamorphism in this area than in regional metamorphic terrains where cordierite is abundant and almandine absent, such as the Ryoke-Abukuma belt in Japan (andalusite-sillimanite type; Miyashiro, 1961).

F.3.(e) Incoming of staurolite

The appearance of staurolite occurs at a significantly higher grade in the S.W. Pays de Lēon that the other minerals (oligoclase, biotite, garnet) characterising the medium-grade M2 metamorphism.

Although chloritoid has been observed in areas of low-grade M2 metamorphism adjacent to the Pays de Lēon it has not been established that it has been involved in reactions producing staurolite, although the occurrence of such reactions has been suggested in other metamorphic belts.

Winkler (1974, p.76 and p.212-3) has mentioned a number of possible reactions to produce staurolite. These include:

Chlorite + Muscovite = Staurolite + Biotite + Quartz + Water (Hoschek, 1969). In a system where the Mg/Mg+Fe ratio was 0.4 reversals for this reaction were obtained at 540 ± 15°C, 4 kb H_2O
565 ± 15°C, 7 kb H_2O

Reactions producing staurolite may also involve garnet:

Chlorite + Muscovite + Almandine = Staurolite + Biotite + Quartz + Water (Carmichael, 1970)

Ganguly (1969) concluded that in the absence of an Al_2SiO_5 mineral, chloritoid and quartz could react to form staurolite, almandine and H_2O at about 545 - 560°C, 4 kb. Ganguly also considered that the formation of staurolite was a temperature sensitive reaction, whether it forms from chloritoid or from chorite and muscovite, and that its appearance indicated temperatures of 540 - 560°C at a wide range of pressures.

A line corresponding to the incoming of staurolite at temperatures indicated by the above studies has been included in fig 8-6 (H-H).

F.3.(f) Upper limit of staurolite

The upper limit of the medium-grade zone in the S.W. Pays de Lēon is marked by the non-appearance of staurolite in pelitic rocks to the north of Le Conquet. Sillimanite has already made an appearance in the higher grade part of the staurolite zone. A number of reactions have been suggested involving the production of an Al_2SiO_5 mineral and either biotite or garnet from staurolite in the presence of quartz and muscovite:

staurolite + muscovite + quartz = Al_2SiO_5 + biotite + H_2O
(Winkler, 1974, p.217)

staurolite + muscovite + quartz = Al_2SiO_5 + almandine + H_2O
(Thompson and Norton, 1969, quoted in Winkler, 1974, p.217)

staurolite + Na-rich muscovite + quartz = Al_2SiO_5 + K-rich muscovite + albite + almandine + H_2O
(Guidotti, 1970, quoted in Winkler, 1974, p.217)

Although no textural evidence is available to indicate whether any of the above reactions actually occurred in the S.W. Pays de Lēon, the fact that in this area staurolite always occurs with muscovite and quartz, while sillimanite, biotite and garnet are all abundant in the adjacent higher-grade zone, suggests that some reaction such as those mentioned above was responsible for the disappearance of staurolite.

Richardson (1968) investigated the reaction:

Fe-staurolite + quartz = almandine + sillimanite + quartz

However common staurolites normally contain a significant cont nt of Mg and so for practical purposes the results obtained by Hoschek (1969) are more relevant.

Hoschek (op.cit) investigated the reaction:

staurolite + muscovite + quartz = Al_2SiO_5 + biotite + H_2O

with staurolite of MgO/FeO + MgO = 0.4, 0.2. The breakdown of staurolite took place at $575 \pm 15^\circ$, 2 kb H_2O
$675 \pm 15^\circ$, 5.5 kb H_2O. A curve through these two points has been included in Fig 8-6 (J-J).

Winkler (1974, p.218) has pointed out that the above reaction is not valid at $PH_2O > 5$ kb if anatexis in gneisses takes place and muscovite in the presence of quartz and plagioclase breaks down to give a granitic melt. Since the field evidence from the S.W. Pays de Lēon indicates that staurolite becomes absent from pelitic assemblages at lower grade than the disappearance of muscovite or the onset of metatexis, one may conclude that prevailing pressures at the level represented by the disappearance of staurolite were less than about 5 kb. This argument has been taken into account in drawing line $O-Q^2$ on Fig 8-6.

F.3.(g) Distribution of Al_2SiO_5 polymorphs

The only Al_2SiO_5 polymorph which is common in the western Pays de Léon is sillimanite. It occurs in fibrolitic and prismatic habits, both commonly observed in a single thin section. Andalusite has not been reported as a regional metamorphic mineral from this area, although it occurs in the contact aureole of the Granodiorite de Brest. Kyanite has only been reported from a single locality, in the staurolite zone. The early appearance and relative abundance of sillimanite, which appears in the S.W. Pays de Léon well within the zones where staurolite and muscovite are still stable, would be consistent with a regional mean geothermal gradient passing somewhere near the 'triple point' of the Al_2SiO_5 polymorphs; for it is at this point that the stability field of sillimanite has its greatest extent in the direction of lower temperature.

Although the general form of the distribution of the stability fields of the three polymorphs in PT space is agreed by most workers, the position and orientation of the boundaries have been a matter of controversy, and attempts to plot the position of the triple point have led to a great deal of confusion and apparently contradictory results in the literature.

At present at least three significantly different versions of the Al_2SiO_5 equilibrium diagram are current, namely those of Althaus (1967, 1969); Richardson, et al.(1968, 1969) and Holdaway (1971) (Fig 8-4).Some of the arguments for and against the various versions are summarised by Anderson et al. (1977), who prefer the Holdaway version on the grounds of its greater compatibility with thermodynamic data on the polymorphs. However it is felt by the present writer that the demonstration by Althaus (1969) that the kyanite-sillimanite reaction is at least bivariant has not received the attention it warrants by subsequent workers.

Althaus (1969) subjected his own (1967) starting materials and those of Richardson et al (1968) (both being a mixture of kyanite and sillimanite) to identical conditions. He found that the reaction moved in the kyanite direction for the material supplied by Richardson et al, and in the sillimanite direction for his own material and that this relation held good for material of various grain sizes (thus apparently meeting the objection of Newton (1969) that Althaus' (1967) results had been influenced by his use of finely ground starting materials); and with varying admixtures of quartz. Althaus concluded that both determinations of the equilibrium were valid, and that the significant difference between them (c. 2 kb at 700°C) must be accounted for by some other control. One possible variable which has been suggested to account for the variation in extent of the stability field of sillimanite is the incidence of Al-Si disorder. However Althaus (1969) argued that another significant variable is due to the incorporation of impurities in the structure. He argued that the volume and entropy changes of reactions between the polymorphs were so small that even small quantities of constituents other than Al_2O_3 and SiO_2 could markedly affect the differences between the physical properties of the polymorphs, and thus also significantly affect the equilibrium conditions of reactions between them.

According to Deer et al (1966, p 35-43) the chief impurity in the Al_2SiO_5 minerals is Fe_2O_3 (or $FeAlSiO_5$), with MnO_3 also entering into the andalusite structure. Althaus (op.cit) found that the Fe_2O_3 content of his own sillimanite was 15 times as great as that used by Richardson et al., while the Fe contents of the kyanites were approximately equal, or showed a small inverse relationship. He concluded that the difference between the two equilibria obtained by himself and by Richardson et al was due at least in part to the Fe_2O_3 content of the sillimanite, the increase in Fe_2O_3 content causing a significant (although undefined) enlargement of the field of sillimanite at the expense of that of kyanite. It should further be emphasised that neither of the two positions for the kyanite-sillimanite equilibrium can be regarded as limits to a field of bivariant equilibrium, involving the two phases, as one may assume that more extreme contents of Fe_2O_3 would expand the field even further. In view of this problem both lines have been incorporated in Figure 8-6 (lines $D^2 - E^2$, $D^3 - E^3$) but with the addition of further undefined fields (barred) representing sillimanite of more extreme composition.

Althaus (op.cit.) further pointed out that the difference in thermodynamic properties between andalusite and sillimanite was even less than in the case of kyanite and sillimanite (the entropy change being almost an order of magnitude less) and that as a result the potential influence of impurities on the equilibrium conditions between these two polymorphs was likely to be even greater, with a potentially even larger field of bivariant equilibrium separating fields where only one phase is stable.

In view of this problem the present writer has incorporated in Figure 8-6 the curves indicating the position of the andalusite-sillimanite equilibrium obtained by both Holdaway (1971) (D^1 - F^1) and Richardson et al (1969)(D^2 - F^2). It will be noted that the separation of the two curves is even greater than the separation of the kyanite-sillimanite curves. It is not however known which chemical, structural or other controls influence the position of the andalusite-sillimanite curves. Holdaway (1971) attributed the difference to the presence of faster-reacting but less stable fibrolite in the samples used by Richardson et al, but also implied that variation in Al-Si disorder could have a significant effect.

It is clear from the above that until more information on the bivariant or multivariant nature of reactions between the Al_2SiO_5 polymorphs is available, mere observation of the distribution of the polymorphs in a regional metamorphic terrain such as the Pays de Lēon can only give a very imprecise indication of PT conditions or geothermal gradients. In the case of the Pays de Lēon the abundance of sillimanite relative to kyanite and andalusite may be related to bulk compositional and other controls superimposed on the controls provided by the range of PT conditions.

It may nonetheless be concluded that whatever the equilibrium conditions between Al_2SiO_5 polymorphs were which prevailed during the M2 metamorphism in the Pays de Lēon, the relative abundance of sillimanite suggests that the mean path of prograde M2 metamorphism passed close to the 'triple point' (or 'triple field') (X-Y-Z on fig 8-6) and that temperatures at any given pressure were rather higher than in terrains where kyanite is abundant, and lower than in those where regional metamorphic andalusite is abundant (see arrows marked 1,2,3 on figure 8-6).

F.3.(h) Formation of sillimanite

Reactions which may have given rise to the abundant sillimanite in the Western Pays de Lēon include those suggested above (sub-section (f)) for the breakdown of staurolite in the presence of muscovite and quartz; these reactions may well have been active in the SW Pays de Leon where the staurolite zone passes into a zone without staurolite but with both sillimanite and muscovite. However staurolite has not been reported from the Complexe Metamorphique de Lannilis and the transition from the muscovite-rich Mica-schistes de l'Aber-Wrac'h to the muscovite-poor sillimanite-bearing Gneiss de l'Aber Benoit indicates that some such reaction as the often-quoted (and possibly oversimplified):

$$\underset{\text{Muscovite}}{KAl_3Si_3O_{10}(OH)_2} + \underset{\text{Quartz}}{SiO_2} = \underset{\text{Alkali-feldspar}}{KAlSi_3O_8} + \underset{\text{Sillimanite}}{Al_2SiO_5} + \underset{\text{Vapour}}{H_2O}$$

may have taken place. Data for this reaction are summarised by Winkler (1974, Table 7-1, p.86).

kb	°C
1	580
2	620
3	655
4	680

A curve connecting these points is included in Figure 8-6 (K-K). In the presence of plagioclase the reaction takes place at temperatures about 20° less than the above.

F.3.(j) The assemblage Ksp-sill-bi-corundum

This rare assemblage occurs locally in the Migmatites de Plouguerneau (Chapter 3). A reaction which may produce corundum in pelitic rocks in a regional metamorphic terrain is the breakdown of muscovite in the absence of quartz:

$$\underset{\text{Muscovite}}{KAl_2(AlSi_3O_{10})(OH)_2} = \underset{\text{K-feldspar}}{KAlSi_3O_8} + \underset{\text{Corundum}}{Al_2O_3} + \underset{\text{Water}}{H_2O}$$

This reaction has been investigated experimentally by Evans (1965), quoted in Turner (1968, p.120). A curve representing the reaction has been incorporated in figure 8-6 (line L-L).

It may be noted that if this reaction is responsible for the presence of corundum in the Migmatites de Plouguerneau, then the prevailing temperature at the peak of metamorphism at this structural level must have been in excess of 750°C at 4-6 kb H_2O.

Corundum may however appear at much lower grade in such rocks as metabauxites, where it is produced by the breakdown of such minerals as diaspore (Jansen and Schuiling, 1976).

F.3.(k) Metamorphic pyroxenes

Clinopyroxene, sometimes in association with garnet, but more usually with hornblende, is found in a number of rocks,mostly mafic, in the medium and high-grade metamorphic terrains of the Western Pays de Léon (Chapters 2 and 6). No pyroxenes have however been observed in what may be regarded as the highest grade metamorphic terrain in the area, that of the Migmatites de Plouguerneau, where the place of pyroxene appears to be taken by amphibole. This feature may simply indicate greater mobility of H_2O during migmatisation than during medium/high-grade metamorphism in this case.

Two occurrences of the mineral pair clinopyroxene + garnet have been recorded from the NW Pays de Lēon (Chapter 2). In one case the rock is a calc-psammite interbanded with muscovite-biotite schists (Micaschistes de L'Aber-Wrac'h). In the other case the rock is of mafic composition and is interbanded with non-garnetiferous mafic rocks usually containing hornblende. The latter feature presumably indicates small-scale variation in P (H_2O).

The stability field of the assemblage garnet + clinopyroxene + plagioclase (or 'garnet-granulite') has mainly been investigated at high T ($>1000^\circ C$) and P; extrapolation to the much lower temperatures likely to have prevailed during the M2 metamorphism in the Pays de Lēon is rather uncertain. Green and Ringwood (1972) have suggested that, at least for rocks of basaltic composition, the 'garnet-granulite' field may lie in the region shown in Fig 8-6 (between lines R-R and T-T).

However the observation (Winkler, 1974, p.265) that the pressure required to stabilise garnet in rocks containing pyroxene and plagioclase varies considerably with slight variation in bulk composition, entails that the 'garnet-granulite' field is not to be regarded as very closely defined, particularly for rocks which diverge widely from a basaltic composition such as the L'Aber-Wrac'h calc-psammite.

The occurrences of co-existing garnet and clinopyroxene in the Lannilis Metamorphic Complex nonetheless offer scope for geothermometry using the Fe:Mg partition co-efficient as described by Råheim and Green (1974), Saxena (1979) and others. It is hoped to obtain microprobe analyses for this purpose.

Another possible reaction relevant to co-existing clinopyroxene and garnet is:

clinopyroxene + 2 garnet + 2 quartz = 3 orthopyroxene + 2 anorthite

These five phases have been found by Green and Ringwood (1967) (quoted in Winkler, 1967, p.256) to co-exist at $700^\circ C$, 8 to 10 kb.

F.3.(1) Anatexis and formation of migmatites

The abundance of migmatites associated with the high-grade metamorphic rocks of the Western Pays de Lēon leads one to consider the possible processes and conditions that may have caused the formation of these migmatites.

A number of different processes have been invoked to account for the occurrence of migmatites elsewhere (see comprehensive account in Mehnert, 1968); these include:

- (i) injection of extraneous quartzo-feldspathic material in a molten state
- (ii) hydrothermal emplacement
- (iii) partial metasomatism
- (iv) partial melting of the country rock, with reconsolidation in situ, or nearly so.

It is outside the scope of the present work to consider all the arguments for and against the operation of the above processes, except to observe that persuasive arguments have been proposed to indicate the importance of each of the processes in individual cases.

All that will be attempted here is to consider whether probable physical conditions during the M2 episode in the Western Pays de Léon were likely to have given rise to the fourth of the above processes, namely partial melting with reconsolidation in situ or nearly so.

Tuttle and Bowen (1958) investigated equilibrium among crystals, melt and H_2O in a simplified or artificial granitic system:

SiO_2 - $NaAlSi_3O_8$ - $KAlSi_3O_8$ - H_2O.

Their results can be summarised in the often-quoted 'minimum-melting curve for H_2O - saturated granite', which is commonly incorporated in petrogenetic diagrams. The usefulness, though not the validity, of the work of Tuttle and Bowen has been questioned by Winkler (1967, 1974) and his co-workers, who recognised the importance of making a closer approximation to the actual composition of real rocks. According to Winkler the two main drawbacks of the model of Tuttle and Bowen were

- (i) failure to allow for the anorthite ($CaAl_2Si_2O_8$) component
- (ii) assumption that the system is saturated with respect to H_2O.

The relevant arguments are summarised by Winkler (1974, p.271-311). Von Platen (1965), quoted in Winkler (1974, p.283) found that the Ab/An ratio of any rock containing plagioclase, alkali-feldspar and quartz determines both the composition of the first anatectic melt produced by heating the rock and the position in PT space of the minimum melting curve itself. So there exists, not just a single 'minimum melting curve' but a minimum melting 'band'.

Brown and Fyfe (1970) have pointed out that rocks undergoing anatectic melting may not be saturated with respect to H_2O, but may have only a limited amount of free H_2O available, or none at all, the H_2O being supplied by breakdown of hydrated minerals such as micas and amphiboles. The effect of such non-H_2O-saturated conditions is that the minimum melting curve (or 'band') for such rocks is shifted towards regions of higher temperature, and takes up a positive slope (Fig 8-5). Such considerations clearly complicate the inclusion of minimum melting curves curves on petrogenetic diagrams, there being a wide range of possible positions and slopes for such a curve, depending on the An and H_2O content, and hydrated mineral species present in the rock undergoing anatexis.

However it is clear from Figure 8-5 (reproduced from Winkler (1974, Fig 18-8, p.293) that melting may be expected to commence in biotite gneisses, with pressures of 4 to 6 kb, at temperatures from 650° to 750° . Temperatures in this range are likely to have been achieved in the Western Pays de Lēon at just slightly higher grade than that of the disappearance of staurolite in the presence of muscovite. Thus the occurrence of banded migmatites in the sillimanite-bearing high-grade zone of the S.W. Pays de Lēon can quite easily be accounted for by invoking the incipient partial melting of muscovite - and biotite-bearing schists and gneisses, whether or not additional free H_2O was available.

Winkler and Von Platen (1961) (quoted in Winkler, 1974, p.303) describe experimental anatexis of 4 naturally occurring greywackes at 2 kb H_2O. These began to melt at 685°-715°C and at 770°C were between 60% and 70% molten. Melting on this scale and in this temperature range could easily account for the development of abundant migmatitic leucosomes and leucogranite such as are observed in the Migmatites de Plouguerneau. It may further be argued that more nearly complete melting of supra-crustal rocks at depths somewhat greater than that represented by the Migmatites de Plouguerneau could account for the associated occurrence of large quantities of nebulitic granite such as the Granite de Landunvez.

F.3.(m) Conclusion

It is concluded that the sector of the crust which is now the Western Pays de Lēon underwent during the M2 episode (broadly identifiable with the 'Bretonic' phase of the Hercynian orogeny) conditions which produced results ranging from very low grade metamorphism to widespread anatexis. The particular sequence of metamorphic assemblages, together with what is known about the physical conditions under which the inferred metamorphic reactions could have taken place, indicates that at medium and high-grades of metamorphism conditions corresponded to a mean geothermal gradient of about 130°C per kb. This represents conditions intermediate between those of the Abukuma or andalusite-sillimanite type of metamorphism and those of the Barrovian or kyanite-sillimanite type (Miyashiro, 1961).

G. REGIONAL CONTEXT AND GEOTECTONIC SIGNIFICANCE OF THE M2 METAMORPHISM IN THE WESTERN PAYS DE LÉON

G.1. INTRODUCTION AND PREVIOUS MODELS

It has been argued in the present chapter that the distribution of metamorphic mineral assemblages attributable to the M2 or 'Bretonic' orogenic episode in the Western Pays de Léon represents a range of PT conditions corresponding to a mean geothermal gradient intermediate between that of the low-pressure Abukuma (or andalusite-sillimanite) type and that of the rather higher-pressure Barrovian (or kyanite-sillimanite) type. An attempt will now be made to compare this Bretonic metamorphic episode as seen in the Pays de Léon with possibly contemporaneous genetically related phenomena elsewhere in the Massif Armoricain, using information available in the literature.

A number of previous authors have attempted to integrate geological observations derived from the whole, or large sectors of the Massif Armoricain; these include approaches from the point of view of stratigraphy (e.g. Pruvost, 1949; Roach et al, 1972; Roach, 1977, Renouf, 1974); geochronology (e.g. Leutwein et al 1968, etc; Leutwein, 1968; Adams, 1967a, 1976; Vidal, 1976 (Thèse d'Etat, Rennes)); and broadscale regional studies (e.g. Cogné 1960, 1972, 1974). Work such as the above has enabled a progressively more coherent picture of the geology of the massif to emerge. With the advent of the new global tectonics an opportunity has arisen to reinterpret geological features of the massif in terms of plate movements and related processes; and global tectonics theories have been used in particular to interpret the relations between the Ile de Groix blueschists and the South Armoricain metamorphic belt, e.g. by Carpenter and Civetta (1976) and Hanmer (1977b). This approach has been expanded by

Chauris (1977), who has outlined a basically tripartite model for the development of the Massif Armoricain during the Hercynian orogeny. His model comprises:

(a) a trench, being the surface expression of a NE-dipping subduction zone in which the eclogites, glaucophanic rocks and serpentinites of Groix and Vendée were produced.

(b) a cordilleran zone, with a thermal dome, Upper Palaeozoic volcanism, low-pressure high-temperature metamorphism, and formation of granites; this zone comprises most of Western and Central Brittany and the Vendée.

(c) a zone of little or no metamorphism, with an older basement of folded Brioverian sediments intruded by Cadomian granites and overlain by relatively undeformed Cambrian and Ordovician ssediments; this zone, or 'domaine normano-breton' is located in NE Brittany, Lower Normandy and the Channel Islands, and corresponds to 'Mancellia' and the eastern part of 'Domnonea' (Fig 1-4).

Chauris further subdivided the cordilleran zone (b) into two divisions according to the distribution of different granitic types with :

(i) in the south: a belt characterised by abundant 'subconcordant' or lobate leucogranites closely associated with intensely metamorphosed Brioverian

(ii) in the north: a belt characterised by biotite granites and granodiorites of well-defined sub-circular outcrop whose distribution is not closely related to that of the regional metamorphic rocks, and whose emplacement was preceded by the extrusion of Devonian and Dinantian volcanics.

Chauris attributed the glaucophanic rocks and eclogites to high pressure conditions associated with a descending slab, while the lower pressure metamorphism and magmatism in the cordilleran zone are attributed to the anomalously high temperature associated with a thermal dome overlying a sub-duction zone.

The leucogranites were attributed to anatexis of crustal material while the more northerly biotite granites and granodiorites are attributed to anatexis at deeper levels than the leucogranites (Chauris, op.cit. p.897).

Chauris also argued that the parallelism between the (postulated) Groix subduction zone and the two major (transcurrent) faults of the

Armorican Massif (zone broyée sudarmoricaine and lineament Molène-Moncontour) suggested that the latter structures are very deep-rooted (profondement enracines).

While Chauris' interpretation is felt by the present writer to be acceptable in most respects some comments and modifications are suggested below.

G.2. SUGGESTED MODEL

G.2.(a) The Ile de Groix-Vendée high-pressure belt

Although there has been disagreement concerning the geochronology of the Ile de Groix (Maluski, 1976; Peucat and Cogné, 1977; Carpenter and Civetta, 1976), there is general agreement that the regional metamorphic assemblages found there, which include glaucophane, jadeitic pyroxene and lawsonite, belong to the blueschist facies, Glaucophane is also of widespread occurrence in the Vendée. (Guiges and Devismes, 1969, quoted in Chauris, 1977) as is the rock type eclogite (Velde, 1970). Serpentinites and eclogitic assemblages have been reported from the Ile de Groix (Chauris et al, 1970a) and from the Baie d'Audierne (Velde, 1972).

There is also a notable absence of granites in close association with the glaucophanic and eclogitic assemblages.

Such features are characteristic of well-preserved blueschist belts such as the Sanbagawa belt of Japan (Miyashiro, 1961). However in the case of the Ile de Groix-Vendée 'belt' marine geological studies have shown that granitic rocks intervene between and perhaps surround the various outcrops of blueschist type, so that even if the outcrops originated as a single belt, it has been subsequently fragmented by granite emplacement in the later stages of the Hercynian orogeny. Another objection to the application of a simple subduction-type blueschist model to the Groix and Vendée rocks is posed by the fact that most of the eclogites of the Nantes area (Velde, 1970) occur to the <u>north</u> of the main branch of the zone broyee sudarmoricaine and also to the north of the main Hercynian migmatite belt. In addition the age of the high-pressure metamorphism has only been independently dated as early Hercynian in the case of the Ile de Groix blueschists (Carpenter and Civetta, 1976) and even this date is disputed by Peucat and Cogné (1977) who consider the blueschist metamorphism was rather earlier; the eclogites of the Nantes area and the serpentinites of Baie d'Audierne have not been dated and are thought by some workers to be pre-Hercynian.

Estimates of PT conditions represented by eclogitic assemblages on Groix have been made by Carpenter and Civetta (1976) at c.400°C at 8 kb, giving a rather low mean geothermal gradient of about 17°C/km, and for the area to the north of Nantes by Velde (1970) at ≥ 10 kb at 600°C. Carpenter and Civetta (op.cit) suggest on the basis of Rb-Sr and K-Ar dating of glaucophanes and muscovites that these conditions were realised in the Groix rocks at about 340 my ago, i.e. soon after the climax of the Bretonic phase.

The suggested PT conditions could be expected to be realised at a destructive plate margin. However there does not seem to be sufficient evidence from the rocks themselves to conclude that the destructive plate margin represented convergence between an oceanic and a continental plate as suggested by Chauris (1977, p.897) rather than the convergence of two continental plates (continental collision).

G.2.(b) The 'Cordilleran' zone

G.2.(b)(i) Introduction

The fragmentary outcrops of the Ile de Groix 'belt' are flanked to the north by the 'Cordilleran' zone of Chauris (1977). As indicated above (section G.1.) Chauris (op.cit.) has divided the cordilleran zone into two parallel belts characterised by different types of granites. The distribution of the two main types of granites (alkaline two-mica leucogranites and calc-alkaline granites/granodiorites) is shown on Fig 1-3. While this subdivision is felt by the writer to be significant and to represent a real difference between the northern and southern zones of the Cordilleran belt, some of the granites are post-Visēan and therefore significantly later than the Bretonic phase and the postulated climax of the M2 metamorphic episode in the Pays de Lēon; while the distribution of the granites may be ultimately under the same control as the distribution of the regional metamorphic zones and isograds an alternative subdivision based on the latter is proposed here.

G.2.(b)(ii) South Armorican Metamorphic Belt

The geology of the South Armorican Metamorphic Belt has been described by Cognē (1960). Its axis coincides with the Zone Broyēe Sudarmoricaine.

Post metamorphic strike-slip movements parallel with the Zone Broyēe may have been large; it has not known what effects the latter movements have had on the relative positions of the metamorphic zones on either side. Cognē (op.cit) considered that the migmatites in the South Armorican Belt were produced during the Bretonic phase. There is also evidence that the main deformation and metamorphism in the western part of the belt post-dated the emplacement of the Granite de Pors-Poulhan, whose Rb-Sr whole rock isochron age is c. 346 my (Cognē and Peucat, 1973).

South of the Zone Broyee Sudarmoricaine, Barrois (1934b) has described a belt of 'morbihanites' extending from the coast SE of Quimper to the area between Nantes and Angers (Fig 1-1). Morbihanites are described (op.cit.p.43) as "mica-schistes riches en mica noir; mica blanc, sillimanite, quarz, zircon, tourmaline, avec parfois chloritoïde, grenat, cordierite ... (chlorophyllite), ... rutile ...". It seems unlikely that all these minerals form a single paragenesis. Some of the minerals may be of contact metamorphic origin. The present writer is uncertain how to classify the 'morbihanite terrain' in terms of the petrogenetic grid of Fig 8-6; however the reportedly common association of chloritoid and sillimanite in this terrain may indicate that sillimanite has formed at rather low grade, and that the path of prograde metamorphism may have passed rather near the Al_2SiO_5 triple field (Fig 8-6).

In that part of the South Armorican Belt which lies north of the Zone Broyee Sudarmoricaine rather different metamorphic assemblages are characteristic of pelitic schists. Staurolite and garnet are wide-spread (Barrois, 1934b), while a number of kyanite occurrences are known. Nodules or pods, approximately concordant with the enclosing schists, of kyanite, often showing secondary alteration to andalusite have been reported at several localities by Barrière et al (1973). These occurrences are indicated on Fig 8-7. They are stated to be in both Devonian and Brioverian schists. The authors remark that at Scaër (Fig 1-1) staurolite and kyanite appear to have crystallised simultaneously. The metamorphism in this northern zone of the South Armorican belt is thus similar in some respects to that of the 'Barrovian' metamorphism of the classical terrain, and is thus contrasted with the apparently rather lower-pressure metamorphism seen in the 'morbihanite' terrain.

G.2.(b)(iii) North Armorican Metamorphic and Granitic Belt

As in the case of the South Armorican Metamorphic and Granitic belt, the corresponding North Armorican belt is characterised by an array of granitic plutons (some of which are post-Viséan and therefore later than the Bretonic or M2 metamorphism).

The Lineament Molène-Moncontour lies in an axial position with respect to these granites, and may have influenced or controlled their location (Chauris, 1977, p.896). For much of the length of the lineament (> 200 km) the granites are intruded into Brioverian and Palaeozoic sedimentary formations which are highly deformed but of generally low metamorphic grade. The metamorphism in the Morlaix area, where staurolite and garnet are locally developed, has been described by Barrois (1934b) and Cabanis and Fabriēs (1972). Further west the lineament passes into the medium and high-grade regional metamorphic terrain of the Pays de Lēon which has been described earlier in this chapter. In the writer's opinion the Pays de Lēon can perhaps be regarded as merely a sector of the North Armoricain Metamorphic and Granitic Belt where the amount of post-M2 erosion has been greater; higher-grade metamorphic and migmatitic rocks may well be present at depth beneath the more easterly sectors of the belt.

An important distinction between the medium and high-grade sector of the North Armoricain Belt (as seen in the Pays de Lēon) and that part of the South Armoricain belt which lies north of the Zone Broyēe is shown by the distribution of the Al_2SiO_5 polymorph kyanite. This mineral is scarce or absent in the Pays de Lēon, where garnet and staurolite bearing assemblages pass laterally into extensive sillimanite sillimanite-bearing and migmatitic zones, while in that part of the South Armoricain belt which lies north of the Zone Broyēe kyanite is widespread, sometimes in association with staurolite (Chauris et al 1970a; Barrière et al 1973). This distinction may perhaps be attributed to a difference in the geothermal gradient at the peak of metamorphism be between the two areas; the gradient having been somewhat higher in the Pays de Lēon. There may be a transition between the two areas at depth below the intervening cover of lower grade rocks.

It should be emphasised that that part of the South Armoricain Metamorphic and Granitic Belt which lies <u>south</u> of the Zone Broyēe is also characterised by the scarcity or absence of kyanite; in this respect it resembles the Pays de Lēon sector of the North Armoricain Belt.

G.2.(c) Zone Normano-breton

The northern boundary of the North Armorican Metamorphic and Granitic Belt may be traced from the vicinity of Lannion to that of Dinan. North and N.E. of this line, and extending throughout most of the area occupied by the Channel Islands and Lower Normandy as far east as the sub-Mesozoic unconformity is a zone which appears to have largely escaped the effects of the Hercynian orogeny. Sensitive indicators of thermal or tectonic disturbance such as K-Ar and Rb-Sr mica dates are predominantly in the range 500-600 m.y.(Adams 1967b), with a few as low as c. 400 m.y. (Leutwein and Sonet, 1965). Except in the vicinity of Cherbourg Hercynian granites are absent.

A number of distinct subdivisions can be recognised within this zone; notably 'Mancellia' (Pruvost, 1949) which lies east of a line between Dinan and Granville and consists of Brioverian sediments intruded and underlain by a composite Cadomian batholith (Jonin and Vidal, 1975).

Near the northern extremity of the zone, in the vicinity of Cherbourg, a relatively narrow belt of Hercynian activity intersects the Zone normano-breton, with deformed Cambrian to Devonian sediments intruded by the Hercynian granites of Flamanville and Barfleur. Chauris (1977) has suggested these granites may represent part of a belt of late Hercynian granites including petrographically similar granites of NW Brittany (Ploumanac'h, L'Aber-Ildut). They may well represent a post-Bretonic 'mobile' belt.

Apart from the Flamanville-Barfleur belt of deformation and granite intrusion, the Zone normano-breton seems to have acted as a stable or cratonic block during the Hercynian orogeny. It is bounded to the south by the 'cordilleran zone' of the Massif Armoricain; it may well be bounded to the north under the English Channel by further belts of intense Hercynian orogenic activity, forming the easterly prolongation of the Hercynides of S.W. England.

G.2.(d) Possible correlations with S.W. England

The Hercynian granites of S.W. England are of late Hercynian (post-Visēan) date and some metamorphic mineral dates reflect this post-Bretonic activity, notably the c.300 m.y. K-Ar dates from the Start Point schists (Dodson and Rex, 1971).

However earlier work (Dodson, 1961) had resulted in Rb-Sr and K-Ar mica ages of 350-360 m.y. from the Lizard Gneisses in South Cornwall, and K-Ar whole rock ages ranging from 286 m.y. to 365 m.y. (with a concentration at 350-365 m.y.) from the Mylor, Gramscatho and Dodman slates and phyllites, also in South Cornwall. Hornblende dates from the Lizard area range up to 492 ± 26 (Miller and Green, 1961) but are more commonly in the same range as the mica dates (Adams, 1967a).

There is thus enough geochronological evidence to suggest the occurrence of orogenic activity, at any rate in South Cornwall, broadly contemporaneous with the Bretonic phase in Brittany. However the Bretonic phase does not appear to be represented in S.W. England by a distinct fold phase or unconformity separating the deposition of the Devonian and Carboniferous sedimentary sequences; it may none the less be noted that a prominent volcanic horizon occurs near the Devonian-Carboniferous boundary in the Boscastle area of North Cornwall. The latter may perhaps be regarded as an expression of the Bretonic phase in this sector of the Hercynian orogenic belt.

CHAPTER 9 CONCLUSIONS

A. SUMMARY OF PRESENT WORK

B. GEOLOGICAL EVOLUTION OF THE WESTERN PAYS DE LÊON

C. POSSIBLE FURTHER WORK

1. Petrology and geochemistry.
2. Structural geology.
3. Geochronology.
4. Lithological mapping.

CHAPTER 9 CONCLUSIONS

A. SUMMARY OF PRESENT WORK

An introduction to the Western Pays de Léon from a geological point of view is given in Chapter 1, where attention is drawn to the considerable amount of previous geological literature on the area.

In Chapter 2 a primary distinction is made between metasedimentary and metaigneous lithologies in the Lannilis Metamorphic Complex. The former are classified and described according to their metamorphic grade, the latter according to their bulk composition. It is concluded that the metasedimentary lithologies in the Lannilis Complex have been produced by the medium to high grade regional metamorphism of what were originally Brioverian sediments; while the metaigneous rocks are for the most part derived from post-Brioverian intrusions, rather than representing a basement on which the sediments were deposited, as has been suggested by earlier workers.

Four main phases of deformation are recognised, the effects of the earliest (D1/M1) being only definitely recognisable in the metasedimentary Mica-schistes de L'Aber-Wrac'h. Most of the existing metamorphic assemblages and fabrics are attributed to the second (D2/M2) phase. The emplacement of certain of the post-D2/M2 granitic intrusions of the area appears to be related to post-D2 (D3) folding in the metamorphic rocks.

In Chapter 3 a totally new classification of the migmatitic and granitic rocks of the area north of the Porspoder Lineament is presented. The Diorite de Portsall is recognised as the only extensive lithology to survive without major modification the episode of migmatisation which has given rise to the Migmatites de Plouguerneau. It is emphasised that if any lithology north of the Porspoder Lineament is to be considered as an equivalent to the Diorite de Lannilis on the south side, then it should be the Diorite de Portsall, rather than, as suggested by Cogné and Shelley (1966), the 'granite sombre' (the lithology described here as Adamellite de Ste Marguerite).

The petrography of the Migmatites de Plouguerneau is described in detail for the first time, a distinction being drawn between migmatites with metasedimentary and metaigneous parentage (as indicated by the palaeosomes or melanosomes). A metasedimentary melanosome of particular interest has the assemblage biotite-sillimanite-alkali-feldspar-corundum. It is concluded that the migmatitic features are due to anatexis and reconsolidation at the the structural level now exposed of pelitic metasediments and other low-melting-point lithologies.

The Granite de Landunvez is distinguished from the Migmatites de Plouguerneau, being regarded as a later allochthonous intrusive phase. Field relations indicate that the granite was emplaced at the end of the migmatitic episode, but before the migmatites had cooled. A number of different facies of the Granite de Landunvez have been recognised and mapped according to the variation in content of possibly xenocrystic garnets and to the abundance of nebulitic patches and schlieren. A possible structural control of this variation is suggested.

The distinct group of late granitic intrusions which includes the Adamellite de Ste Marguerite is recognised, classified and described. Particular attention is drawn to the field relations, which suggest that this group of granitic rocks was emplaced during a post-Granite de Landunvez phase of folding.

A correlation is suggested between the sequence of geological events recognised south and north of the Porspoder Lineament and described in

Chapters 2 and 3 respectively.

In Chapter 4 attention is drawn to the polyphase nature of movements along the Porspoder Lineament. Support is given to the suggestions of Chauris (1966b) that the lineament, which separates the areas described in Chapters 2 and 3, has acted as a locus for a number of major granitic intrusions. The deformational features which were produced during the later (D4) movements along the lineament are described more fully than by previous workers. Attention is drawn to the lack of secondary chloritisation in the zone most severely affected by D4; this feature may indicate that the temperature was higher in this zone than for instance in the zone to the north where secondary chloritisation is common. It is suggested that the net displacement across the lineament was sinistral, and that the displacement was parallel to the subhorizontal or ENE-plunging lineations, rather than parallel to the subvertical quartz c-axis lineation as suggested by Cogné and Shelley (1966). It is concluded that the Porspoder Lineament in common with other similar transcurrent structures in western Brittany may have been originally a deep-seated continental fault of transform type produced during the latter stages of a continental collision.

In Chapter 5 all the available geochronological literature on the NW Pays de Léon (the areas described in Chapters 2-4) is reviewed and reinterpreted. Some new K-Ar dates for hornblendes and sphenes which are thought to have crystallised during the M2 metamorphism are presented. The importance of the Hercynian orogeny, particularly the latter stages, is demonstrated, most mineral dates being post-300 my. The D2/M2 episode is considered to be bracketed between the $\leq$ c380 my whole rock Rb-Sr date of the Gneiss de Tréglonou and related granitic gneisses and the c345 my U-Pb zircon date of the Granite de St Renan. Apart from these two dates there is a scarcity of adequate U-Pb or

Rb-Sr whole-rock dates from either the pre-D2 (eg Diorite de Lannilis) or post-D2 (eg Granite de Landunvez, Complexe Granitique de L'Aber-Ildut) intrusions, and an attempt is made to combine single whole-rock Rb-Sr analyses from different authors to obtain an estimate of the date of emplacement of the Complexe Granitique de L'Aber-Ildut.

No geochronological evidence of any Precambrian events in the NW Pays de Lēon has been obtained, although as mentioned above no appropriate study of the Diorite de Lannilis has yet been made. The zircons in the Gneiss de Plounevez-Lochrist appear to be $\gtrsim$ 450 my old.

In Chapter 6 attention is switched to the metamorphic rocks of the SW Pays de Lēon, particularly the field relations in the coastal sector between Pointe de Corsen and Pointe de St Mathieu, where a completely new interpretation of the field relations within the Complexe Mētamorphique du Conquet.has been made. A single major batholithic intrusion, the'Granodiorite de Brest' is recognised, whereas previous workers had recognised an older gneissic granodiorite, the 'Gneiss de Brest' or 'Gneiss de Lesneven', which was deformed and metamorphosed during the Cadomian orogeny, and a younger post-orogenic intrusion, the'Granodiorite de la Pointe des Renards'. It is now concluded that the 'Granodiorite de la Pointe des Renards' represents the less deformed portions of a single original intrusion, which has undergone heterogeneous deformation during an orogenic episode; the more deformed portions are the lithologies which have been previously been known as 'Gneiss de Brest' and 'Gneiss de Lesneven'.

The presence in the Le Conquet area of considerable volumes of the Granodiorite de Brest which virtually escaped deformation during the episode which produced a gneissic foliation elsewhere in the batholith is attributed to the effects of the presence in this sector of unusually thick metasedimentary units (Mica-schistes du Conquet), which being of lower competence than the Granodiorite de Brest may have taken up a larger share of the bulk strain imposed on the area during the post-granodiorite deformation.

The episode which produced the foliation of the Granodiorite de Brest is identified with the metamorphic episode which gave rise to the staurolite, garnet and sillimanite bearing assemblages in the associated metasediments. The term 'D2/M2' is used to refer to this episode, and a possible correlation with the D2/M2 episode in the NW Pays de Lēon is suggested.

The hornblendic Granodiorite de Pont-Cabioc'h, which was identified with the 'Gneiss de Brest' by earlier workers, is recognised as a distinct pre-D2/M2 lithology of restricted outcrop.

The stratigraphic status of the metadoleritic Filons de Kermorvan as a post-Granodiorite de Brest, preD2/M2 dyke swarm is established, and a possible relationship with the Caradocian volcanicity of the Presqu'ile de Crozon is suggested.

In Chapter 7 all available geochronological data on the SW Pays de Lēon is reviewed. In the light of the recognition in Chapter 6 that the'Gneiss de Brest' and 'Granodiorite de la Pointe des Renards' were originally a single intrusion, the whole-rock Rb-Sr dates obtained from these lithologies by Adams (1967a) and Cabanis et al (1977) are reassessed. It is concluded that the c550±50 my 'isochron' obtained by Adams (op cit) from six samples of 'Renards Granite' is the best available estimate of the date of emplacement of the whole batholith, but that even this date should only be regarded as provisional and approximate.

A possibly better established group of dates from the pre-D2/M2 intrusions in the southern Pays de Léon is provided by the c 460 my (i.e. early Ordovician) U-Pb zircon dates of the Granodiorite de Pont-Cabioc'h and of 'Gneiss de Brest' from near Landivisiau obtained by Michot and Deutsch (1970) and Cabanis et al (pers comm).

Emphasis is laid on another important result obtained from U-Pb analyses of zircons and monazites by Michot and Deutsch (op cit). Their samples of staurolite-garnet-mica schist from near Le Conquet and of low-grade semi-pelitic Brioverian Quartzophyllades de L'Élorn from near Brest retain clear evidence of a detrital zircon component of Lower Proterozoic ('Pentevrian') age; pre-1700 my in the case of the Élorn zircons. One may conclude that material which was ultimately of Lower Proterozoic origin was abundant in the catchment area of the Brioverian of west Finistère.

The review of geochronological data in Chapter 7 together with the available information on the Palaeozoic supracrustal history of the area immediately south of the Pays de Léon (summarised in section B of Chapter 7) has enabled the writer to correlate the geological history of the SW Pays de Léon with that of the adjacent supracrustal zone (table 7-1). An important conclusion is that the main orogenic episode (D2/M2) which affected the rocks of the SW Pays de Léon is identifiable with the 'Bretonic' phase of the Hercynian orogeny; in other words it took place at around the Devonian-Carboniferous boundary. The D3 episode of folding in the SW Pays de Léon is correlated with the post-Lower Namurian pre-Stephanian folding and cleavage-formation of south-central Finistère.

In Chapter 8 the first attempt is made to treat the metamorphic rocks of the whole of the Western Pays de Léon as part of a single metamorphic belt. Using petrographic observations both from the literature and from the writer's own work an analysis is made of the distribution of metamorphic assemblages and zones attributable to the M2 episode. The metamorphism ranges in grade from the low (chlorite) grade seen in the Palaeozoic and the Quartzophyllades de l'Élorn, through the medium grade staurolite-garnet-mica schists of Le Conquet and the Mica-schistes de L'Aber-Wrac'h, to the high grade sillimanite-bearing gneisses and migmatites of the central Pays de Léon and the Plouguerneau district.

Possible reactions and physical conditions which may have given rise to the observed assemblages are discussed, with some critical assessment of the experimental literature, particularly in the case of that on the Al_2SiO_5 polymorphs. It is concluded that at medium to high grades of M2 metamorphism the mean goethermal gradient in the area corresponded to a range of conditions intermediate between those characteristic of 'Barrovian' and 'Abukuma' type terrains.

The M2 or Bretonic metamorphism in the Western Pays de Léon is compared with approximately contemporaneous phenomena elsewhere in the Massif Armoricain. It is concluded that the features observed in the whole region are consistent with the operation of a convergent or destructive plate margin during the Hercynian orogeny as suggested by Chauris (1977).

A completely new metamorphic map showing the effects of the M2 regional metamorphism of the Western Pays de Léon has been prepared (Fig 8-1)

A significant amount of new lithological and structural mapping has been carried out in the Western Pays de Léon by the writer. A completely new lithological survey of the greater part of the area north of the Porspoder Lineament has been made, and the resulting maps accompany Chapter 3 (including the larger maps at the end of the volume). Other areas in which new mapping has been carried out are the L'Aber-Benoît sector of the Lannilis Metamorphic Complex (Fig 2-2) and the coastal section of the Le Conquet Metamorphic Complex between Pointe de Corsen and Pointe de St Mathieu (Fig 6-6). A completely new lithological map of the SW Pays de Léon has been compiled from the writer's own fieldwork and from a critical reassessment of earlier maps by other workers. This is provided as Fig 6-7.

B. GEOLOGICAL EVOLUTION OF THE WESTERN PAYS DE LÉON

The earliest episode recognised in the rocks of the Western Pays de Léon is the Lower Proterozoic or Pentevrian episode ($\geq$1700 my ago) indicated by the $^{207/206}Pb$ dates of detrital zircons and monazites from the Brioverian Quartzophyllades de L'Élorn and from the Mica-schistes du Conquet. This is likely to have been an orogenic episode affecting an extensive area.

After an apparently long interval the next recognisable episode was the deposition of Brioverian turbiditic greywacke-shale sediments with occasional subaqueous volcanics. The sedimentation appears to have taken place during the uppermost Precambrian (and possibly part of the Cambrian).

Near the boundary between the Precambrian and the Palaeozoic the Brioverian sediments and volcanics were affected by an orogenic episode for which the label D1/M1 has been used in this work. This episode is probably identifiable with the Cadomian orogeny of the NE Armorican Massif. The orogeny was characterised by folding (commonly on N-S axes) and regional metamorphism. Metamorphic grade and fabrics have largely been obscured by the later (Hercynian) D2/M2 metamorphism and deformation, but conditions probably reached amphibolite facies near Le Conquet.

The emplacement of the extensive batholithic Granodiorite de Brest in the SW Pays de Léon probably took place soon after the climax of the D1/M1 episode; if Adams'(1967) Rb-Sr whole rock date of c.550 ± 40 my represents the emplacement of the granodiorite then clearly the D1/M1 episode was somewhat earlier, i.e. Lower Cambrian at the latest. However in view of the difficulty of sampling homogeneous material in the Granodiorite de Brest and in view of the size of the statistical error on the regression line, a more reliable younger age limit for the D1/M1 or Cadomian orogenic episode in the Pays de Leon may be provided by the c.460 my U-Pb zircon dates of the Granodiorite de Pont-Cabioc'h and the Gneiss de Brest near Landivisiau, and possibly also by the similar whole rock Rb-Sr date of the Trondhjemite de Douarnenez in South Finistère.

Other intrusions now represented by such metaigneous units as the Diorites of Lannilis and Portsall and the granitic Gneisses of Plounevez-Lochrist and Trēglonou were probably emplaced during the interval between D1/M1 and D2/M2. The diorites are undated and could even predate D1/M1, while the whole rock Rb-Sr date of c. 380 my for the gneisses may represent an event later than the emplacement of their granitic precursors.

By the Arenigian (c. 450 my) the Granodiorite de Brest had been partially unroofed by erosion, and a marine transgression from a southerly direction had reached the Pays de Lēon, resulting in the deposition of the orthquartzitic Grès Armoricain and Quartzite de la Roche Maurice. Mainly neritic sedimentation (with local volcanism in the Caradocian) continued without major breaks until the Upper Devonian (Famennian II).

The doleritic Filons de Kermorvan were emplaced in the rocks of the SW Pays de Léon after the emplacement of the Granodiorite de Brest, but before the D2/M2 episode. This localised dyke swarm may have been related to the Caradocian (c.430 my) volcanism of the Presqu'ile de Crozon.

By the end of the Devonian, another major orogenic episode (the Bretonic or D2/M2 episode) had commenced, possibly induced by the proximity of a converging plate margin. The Rb-Sr whole rock date of $\leq$ c.380 my for the Gneiss de Tréglonou/Plounevez-Lochrist may indicate an early (mid-Devonian) event related to this episode, although it is not clear that the date represents the emplacement of the granitic precursors of the gneisses, rather than some later event in their history.

The effect of the D2/M2 episode was to produce tight or isoclinal folds and the most prominent metamorphic fabrics and assemblages now observed in (a) The Ordovician to Devonian sedimentary succession of central Finistère; (b) the Brioverian Quartzophyllades de L'Élorn; (c) the metamorphic complexes of Le Conquet and Lannilis; and (d) the Migmatites de Plouguerneau. The range of mineral assemblages indicates that the mean geothermal gradient at the peak of this episode was intermediate between the gradients characteristic of Abukuma (andalusite-sillimanite) and Barrovian (kyanite-sillimanite) terrains.

The D2/M2 episode was at its peak at about 350 my; in the central Pays de Léon the termination of the D2/M2 episode in the metamorphic complexes of Le Conquet and Lannilis occurred before the emplacement of the St Renan Granite (U-Pb zircon date of c. 345 my; K-Ar K-feldspar date c. 340 my). In the more deep-seated terrain represented by the Migmatites de Plouguerneau high-grade conditions may have persisted rather longer; post-migmatitic cooling in the migmatites does not appear to have been completed before the emplacement of the Granite de Landunvez, whose emplacement may have been related to that of the(post-Granite de St Renan) Granite de L'Aber-Ildut.

In the Palaeozoic terrain of central Finistere the D2/M2 or Bretonic episode appears to be bracketed between Famennian II and the Upper Viséan, that is to say approximately in the interval 360 to 330 my. Here too the climax may have been at around 350 my.

After the D2/M2 episode there appears to have been a close correspondence between, on the one hand, the important post-metamorphic episode of folding which affects the regional metamorphic rocks, migmatites, and the Granite de Landunvez, as well as the Palaeozoic supracrustal rocks of central Finistère, and on the other hand, the emplacement of the later Hercynian granitic intrusions such as the Adamellite de Ste Marguerite, the Granite de Kern an Guen, the Granite de Ploudalmézeau and the Granite de Kernilis (also possibly the Granodiorite de Trégana). This postulated D3 + granite episode appears to have taken place at between approximately 315 my (Rb-Sr isochron date for the fine fractions of Ordovician and Silurian sediments in the Presqu'ile de Crozon) and around 300 my. It may be identified in part with the post-Lower Namurian pre-Stephanian episode of folding and cleavage formation observed in the supracrustal rocks of the Châteaulin Basin in central Finistère. In the NW Pays de Léon the emplacement of this later group of granites was probably completed before c.295 my (Rb-Sr whole-rock date of the 'Filons micgogranitiques' which cut the Granite de Ployudalmézeau).

Early (pre-D4) phases of movement along the Porspoder Lineament may have accompanied or influenced the emplacement of some of the post D2/M2 granites of the NW Pays de Léon (see Chapter 4). If the D4 deformation in the Porspoder Lineament and the corresponding deformation in the Molène-Moncontour Lineament were contemporaneous, then according to the observations of Chauris et al (1977), the D4 deformation must itself have been earlier than the c.295 my date of the Filons microgranitiques.

Mineral dates from the NW Pays de Léon indicate that thermal and/ or tectonic activity continued until about 275 my. Later K-Ar hornblende dates (down to 255 my) are thought to be due to the incorporation of 'initial' Ar of a composition different from that of modern atmospheric Ar.

An important feature of the geology of the central Pays de Léon which has hardly been touched upon in this study is the metasomatic greisenisation and tin-tungsten mineralisation which is mainly associated with the Granite de St Renan. These phenomena are probably attributable to a late Hercynian episode comparable with that known from SW England.

Later tectonic activity in the Pays de Léon and adjacent areas consisted mainly of strike-slip faulting accompanied by brecciation and local quartz veining; a major fault in this group is the NW-trending 'Kerforne's' fault which affects the Presqu'ile de Crozon and the Le Conquet district.

The dolerite dykes of Porsmilin and Brenterc'h were intruded into fractures parallel to the Kerforne's fault during a Triassic (c. 190 my) episode of crustal dilation, possibly connected with the initiation of the Atlantic Ocean.

C. POSSIBLE FURTHER WORK

In the light of the conclusions reached in the present study, a number of recommendations and suggestions may be made for further geological work in the Western Pays de Leon.

1. Petrology and geochemistry.

(a) The excellent exposures of undeformed migmatitic features found in the Migmatites de Plouguerneau seem to offer considerable scope for petrological study, particularly of the mineralogy and chemistry of the leucosomes and related leucogranites. Problems are likely to be caused by the fact that almost all the exposed rocks in in the Plouguerneau Complex have been affected by superficial alteration due to the action of sea water.

(b) The numerous exposures of Diorite de Lannilis along L'Aber-Wrac'h and L'Aber-Benoît offer scope for a geochemical and mineralogical study of an igneous intrusion of intermediate composition which has been deformed and metamorphosed at medium to high grades of regional metamorphism. Fresh rock can be easily obtained in this case.

(c) As suggested earlier the two occurrences of the mineral pair garnet-clinopyroxene in the Lannilis Metamorphic Complex offer scope for geothermometry using the Fe/Mg partition co-efficient.

(d)The alkali-granitic Gneiss de Trēglonou, fresh exposures of which are obtainable in the quarry at Locmajan, could be studied geochemically with a view to assessing whether, when subjected to high grade conditions such as those which produced the Migmatites de Plouguerneau,it could have given rise to large quantities of granitic melt.

(e)It is thought that the staurolite-garnet-mica schists of Le Conquet have not yet received the attention they deserve from a petrogenetic point of view.

2. Structural geology.

(a)A more detailed study of the structures associated with the emplacement of the Adamellite de Ste Marguerite and related granites could be made. Such a study might throw considerable light on the mechanisms of emplacement of igneous intrusions in an orogenic environment.

(b)The excellent exposures of the Granodiorite de Brest in the Le Conquet area offer scope for a study of the development of foliation in a major pluton undergoing inhomogeneous deformation under regional metamorphic conditions. A point of particular interest is the relationship of essentially undeformed zones in the granodiorite to the proximity of thick belts of relatively incompetent metasediment.

(c) Inspection of existing geological maps of the area indicates the possible presence of major fold interference patterns in the northern Pays de Lēon. (See Fig 1-6). There may be scope for a study of major and minor D3 folds to elucidate this feature.

(e)The polyorogenic structural and metamorphic sequence in the Mica-schistes du Conquet has not been unravelled as yet.

3. Geochronology.

There remains considerable scope for geochronological work in the Western Pays de Leon, particularly the use of Rb-Sr whole-rock isochrons and U-Pb zircon discordia-concordia intersections to date the emplacement of both pre-D2/M2 (Diorites of Lannilis and Portsall) and post-D2/M2 (Granite de Landunvez, Adamellite de Ste Marguerite, Granite de L'Aber-Ildut) intrusions.

The question of the date of the emplacement of the Granodiorite de Brest has not been satisfactorily answered, and there remains doubt about the significance of the Rb-Sr whole-rock isochron date of the Gneiss de Trēglonou/Plounevez-Lochrist.

It is suggested that in the case of Rb-Sr whole-rock isochron studies sampling should normally be confined to a single quarry or exposure, so as to minimise deviation from a common initial Sr ratio and from a common post-emplacement history; while in the case of U-Pb mineral studies sufficient material from a single site should be sampled to permit the separation of multiple size or magnetic fractions, so that a discordia line may be obtained.

4. Lithological mapping.

The central sector of the Pays de Lēon , particularly the extensive zones shown as Gneiss de Lesneven north of the main outcrop of the Complexe Granitique de St Renan/Kersaint, has not been mapped using the lithological classification introduced by this writer, and remapping of this poorly exposed sector is desirable.