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THE SEDIMENTOLOGY AND GEOTECTONIC SIGNIFICANCE OF UPPER ORDOVICIAN AND LOWER SILURIAN SAND-BODIES IN THE RHINNS OF GALLOWAY AND ADJACENT AREAS, SOUTHWEST SCOTLAND.

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ABSTRACT

The study reported here involved detailed mapping, logging, stratigraphical, structural, sedimentological and petrographical analyses of sequences exposed in two areas: the Rhinns of Galloway, between Killantringan Bay (NW 9820 5700) and Clanyard Bay (NX 1010 3800) and the strike-wise equivalent sector on the east side of Luce Bay.

The upper Ordovician and lower Silurian sediments exposed within these areas represent an aggregate thickness in excess of 10km of greywackes, conglomerates and shales displaying the typical Southern Uplands structural style of broad steeply inclined northwest-younging belts abruptly terminated by steep strike-faults. Ten of these tectono-stratigraphical tracts have been recognized within the study areas.

Sedimentological, petrographical and biostratigraphical data have enabled 16 stratigraphical units (formations and members) to be defined in the Rhinns tracts and 8 units in the Glenluce area. Recognition of the diachronous development of some of these units in the two areas (both along- and across-strike) provides important evidence bearing on palaeoenvironmental and geotectonic evolution of this part of the Southern

Uplands.

Sedimentological data from these sequences confirm their exclusively deep-water nature, while lithofacies analysis permits the recognition of a variety of depositional systems, the evolutionary trends of which have been determined.

Two phases of tectono-sedimentary development are recognized: (1) During the Caradoc-Ashgill interval north- and northwest-prograding clastic slope aprons and axially diverted, immature sand-rich fans were formed on the northern flanks of a contemporaneously active volcanic terrain. Petrographical and stratigraphical data suggest that this may have been a sinistrally displaced, tectonically migrating continental margin arc, briefly juxtaposed within a fore-arc and trench region; (2) During the Llandovery the depositional systems evolved from an axial wedge, to axially diverted sand-rich fans and, eventually, to mud-rich fans. Small local debris cones were also formed. These systems were probably also deposited in a fore-arc and were derived from sources to the north and northeast which initially included remnants of the arc terrain. The evolutionary trends displayed by the early Silurian systems indicate a general increase in sediment supply and/or a decrease in convergence rate during the Llandovery.

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"...we've tried making movies from a volume of stills..."   Peter Gabriel, "Slowburn"

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CHAPTER 1

INTRODUCTION

1.1 EXTENT OF STUDY

This thesis is directly concerned with the stratigraphy, sedimentology, petrography and structure of the Llandeilo to late Llandovery sediments, exposed within two 0.25 to 1.5km wide 'corridors' in the extreme southwestern Southern Uplands of Scotland:

(1) West of Luce Bay (Fig. 1.1). This corridor extends between two east-northeast trending lines passing through Killantringan Bay (NW 9820 5700) and Clanyard Bay (NX 1010 3800). The corridor has an average width of between 0.25km and 1.0km and includes:

(a) An almost completely exposed, approximately 25km long, across-strike section which extends between Killantringan Bay (NW 9820 5700) and Clanyard Bay (NX 1010 3800), on the west coast of the Rhinns peninsula.

(b) A few, almost completely exposed sections on the east coast of the

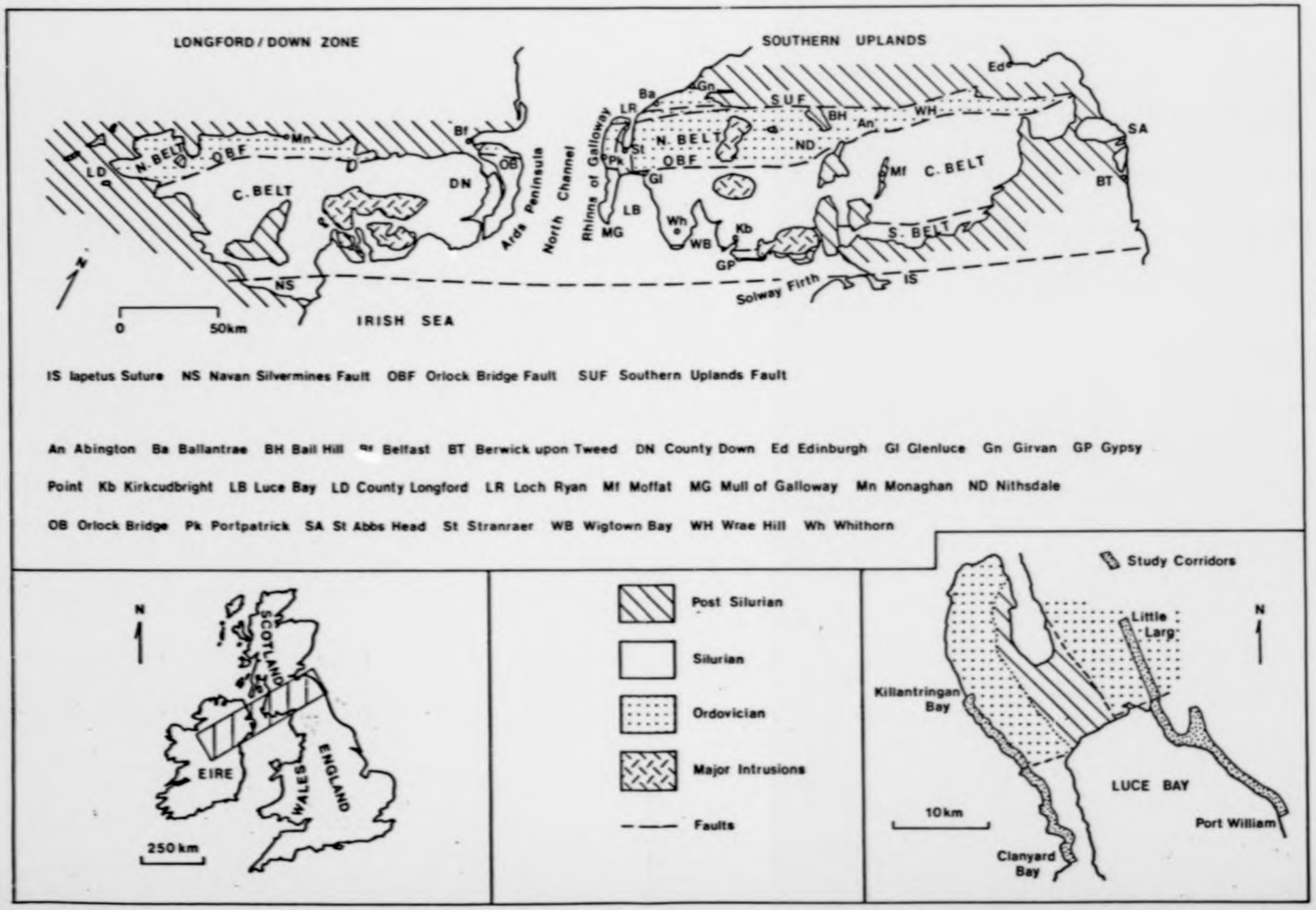

LONGFORD / DOWN ZONE
SOUTHERN UPLANDS
N. BELT
OBF
C. BELT
Mn
LD
Bf
OB
DN
Ards Peninsula
North Channel
Rhinns of Galloway
Ba
Gn
LR
Pk
St
Gl
LB
MG
N. BELT
OBF
SUF
BH
An
WH
ND
Ed
Mf
C. BELT
S. BELT
SA
BT
Wh
WB
Kb
GP
Solway Firth
IS
NS
IRISH SEA
N
0
50km
IS Iapetus Suture NS Navan Silvermines Fault OBF Orlock Bridge Fault SUF Southern Uplands Fault
An Abington Ba Ballantrae BH Ball Hill Bf Belfast BT Berwick upon Tweed DN County Down Ed Edinburgh Gl Glenluce Gn Girvan GP Gypsy Point Kb Kirkcudbright LB Luce Bay LD County Longford LR Loch Ryan Mf Moffat MG Mull of Galloway Mn Monaghan ND Nithsdale
OB Orlock Bridge Pk Portpatrick SA St Abbs Head St Stranraer WB Wigtown Bay WH Wrae Hill Wh Whithorn
N
SCOTLAND
EIRE
WALES
ENGLAND
250 km
Post Silurian
Silurian
Ordovician
Major Intrusions
Faults
Study Corridors
N
Little Larg
Killantringan Bay
LUCE BAY
10km
Port William
Clanyard Bay

Figure 1.1: Map showing the regional geological setting of the study area and the locations of the study corridors and the other regions which are referred to in the text.

Rhinns peninsula. These attain a maximum across-strike length and are partially hidden by sand and shingle.

(c) Poorly exposed inland sections and localities.

(2) East of Luce Bay (Fig. 1.1). This corridor has an average width of between 0.75km and 1.5km and extends between two imaginary east-northeast trending lines passing through Little Larg (NX 1612 6615), in the north, and Port William (NX 3370 4355), in the south. The corridor includes:

(a) Two, almost completely exposed, across-strike sections extending between: (i) Fish House (NX 1984 5543) and the Mull of Sinniness (NX 2276 5150) and (ii) Craignarget (NX 2452 5140) and Garheugh Port (Nx 2690 5000), on the eastern shores of Luce Bay.

(b) Moderately to well exposed inland areas; crags and stream sections.

The sediments exposed within these corridors are included within the southern part of the Northern

Belt and the northern part of the Central Belt (Peach and Horne 1899), in southwestern Scotland (Fig. 1.1).

Stratigraphical, sedimentological, petrographical and structural comparisons are made, throughout this study, with other areas within the Southern Uplands/Longford-Down zone, for example, West Nithsdale (Floyd 1982) and the western end of the Longford-Down Inlier (Morris 1983).

1.2 APPROACHES, AIMS AND OBJECTIVES

The ultimate aims of this study were to:

(1) Determine the types of depositional system responsible for the formation of the sedimentary sequences included within the various stratigraphical units exposed within the study area.

(2) Assess how these depositional systems evolved through time.

(3) Assess the nature of the geotectonic controls which influenced the development and evolution of these depositional systems.

Before any of these aims could be achieved it was necessary to:

(1) Determine the detailed stratigraphical, structural, sedimentological and petrographical characteristics of the sediments exposed within the two study corridors.

(2) Correlate between the two study corridors.

(3) Compare and contrast the sedimentological and petrographical features displayed by correlated stratigraphical units.

Parts of the corridors have formed the subject matter of previous studies (Kelling 1961; Gordon 1962; Welsh 1964; see below). Where necessary the conclusions of these studies have been modified and revised in the light of new data.

The nature and distribution of the stratigraphical units and the major and minor structural features within each of the study corridors has been determined through 1:10,000 scale mapping. Mapping has shown that the corridors are each cut by a series of major, steeply inclined strike-faults, which form the boundaries to structurally defined tracts, otherwise referred to a tectonostratigraphical units. The tracts all contain at least one lithostratigraphical unit. Lithostratigraphical subdivision has been undertaken according to the procedure proposed by Holland et al. (1978). The lithostratigraphical units are described in terms of their component sedimentology, petrography and biostratigraphical status.

In order to fully describe the sedimentology of each of the stratigraphical units the deep-water facies classification scheme proposed by Pickering et al. (1986) has been used and a facies association classification scheme has been erected (Chapter 5). This scheme identifies thirteen facies associations subsumed within four facies association groups. A total number of 73 graphic logs have been measured, each log illustrating a particular facies association or facies association group. Two log scales have been employed: (1) 1:40 and (2) 1:80. A total of 66 logs have been measured at scale (1), while 7 have been measured at scale (2). The logs range in thickness between 5m and 75m and have an average thickness of between 15m and 23m. In addition to the logs, detailed 'plane table' sketches have been drawn at 17 localities where particularly interesting sedimentological features are exposed. These sketches were drawn on a scale of 2.5mm = 10cm. The sedimentological information presented in the form of logs and sketches is supplemented by extensive and detailed fieldnotes. In order to ascertain the derivation and transport directions of the sediments exposed within the study corridors, a A total number of 389 current direction indicators (e.g. flute casts, grooves, longitudinal ridges and furrows) were measured (Appendix 3).

The petrographical characteristics of the sediments included within each of the stratigraphical units have been subjectively assessed by visual analysis of 200 thin sections and objectively assessed by point count analysis of 148 of these (Appendix 2). A total of 1000 points was counted for each analysed sample (a full description of the methodology is given in Chapter 4).

Biostratigraphical information has been derived from three main sources:

(1) Previous publications and Ph.D. theses (e.g. Peach and Horne 1899; Kelling 1958).

(2) The collections and reports of the Palaeontology Division of the British Geological Survey (Appendix 1).

(3) Collections made by the author during the course of the present study (Appendix 1).

Bedding, fold and fault orientations have been measured throughout the study corridors. Detailed sketches have been made of structures at important localities. The measurements and sketches are supplemented by detailed fieldnotes.

Correlation of tectonic and stratigraphical units between the study corridors has been possible by comparing the structural positions they occupy within their respective profiles, and by using distinctive petrographical and lithological associations as marker horizons. Biostratigraphical data have been used to identify coeval tectonic and stratigraphical units. In certain cases distinctive structures and structural styles provide a useful tool for correlating tectonostratigraphical units (e.g. Barnes et al. 1987).

Correlation has allowed sedimentological and petrographical comparisons to be made between along-strike equivalent stratigraphical units thus providing information on lateral large scale facies changes and regional palaeoflow patterns. Combined with a knowledge of the vertical ordering of facies, within correlated sequences, this information has been used to determine the types of environmental setting and depositional system in which the sediments within the study area were deposited. Biostratigraphical data has subsequently enabled an evolutionary sequence of depositional systems to be elucidiated. Petrographical data has been used to determine the nature of source areas.

An impression of the geotectonic environments in which the depositional systems were formed has been gained from combined analyses of palaeocurrent, petrographical and structural data.

1.3 PREVIOUS STUDIES

1.3.1 Regional Geology and General Structural/ Stratigraphical Models

Lapworth (1889) provided one of the first attempts to reconcile the structure and stratigraphy of the Southern Uplands into a single model. Lapworth's (1889) model, subsequently revised and extended by Peach and Horne (1899), suggested that the Southern Uplands is composed of an intensely folded, relatively thin succession of cherts, black shales (forming the Moffat Shales) and 'grits'. The many inliers of Moffat Shale were interpreted as the cores of elongate periclines.

The model was generally accepted until the mid-1950s and early 1960s when, through the recognition and use of sedimentary younging criteria and as a result of detailed structural, stratigraphical and petrographical studies, it was recognised that the rock sequences of the Southern Uplands are cut by a number of, apparently major, steeply inclined strike-faults (Craig and Walton 1959; Kelling 1961; Gordon 1962; Welsh 1964). These form the boundaries to a number of discrete 'tracts'. In each tract cherts and black shales (often intensely folded) are overlain by thick greywacke sequences, which may be folded but young predominantly towards the northwest. However, in aggregate, the greywacke sequences become progressively younger from tract to tract, proceeding from northwest to southeast.

This stratigraphical paradox was eventually satisfactorily resolved by McKerrow et al. (1977). They suggested that the structural, stratigraphical and sedimentological characteristics of the Southern Uplands and the Longford-Down zone indicate that this terrain developed as an imbricate thrust stack and probably as an accretionary complex. The geological characteristics of the Southern Uplands were considered to be closely comparable to those inferred, at that time, for modern accretion complexes in which progressively younger sedimentary sequences were considered to be transported to the accretion front on the subducting oceanic plate and consequently 'accreted'. Progressive accretion at the toe of the thrust-stack was considered to lead to the back-rotation and steepening of thrusts within the accretionary complex (Seely et al. 1974; Karig and Sharman 1975). This model for the Southern Uplands was supported and expanded upon in several subsequent publications: Leggett (1980), Leggett et al. (1979).

Although it is still generally accepted that the Southern Uplands/Longford-Down zone represents an imbricate thurst stack, the accretionary prism origin and, therefore, the original geotectonic setting of the thrust stack has been challenged by various workers. Stone et al. (1987) and Morris (1987) favour a back-arc basin geotectonic setting, at lest for the Northern Belt sediments. Their evidence is derived mainly from generalised sedimentological and petrographical studies.

A number of studies have shown that the Southern Uplands/Longford-Down zone is probably underlain by continental crust: Strogen (1974) and Upton et al. (1984) discovered gneissose xenoliths in Carboniferous vents, while Hall et al. (1983, 1984) found evidence from seismic experiments for crust with continental affinities at 1-5km depth. Bluck (1985) states that this crust is indistinguishable seismologically from that beneath the Midland Valley. These lines of evidence have led various authors to suggest that the Southern Uplands have been thrust northwestwards over the southeastern extension of the Midland Valley (Bluck and Halliday 1982; Hall et al. 1983, 1984; Bluck 1983). Furthermore, Bluck (1983) has provided convincing sedimentological data suggesting that a considerable spatial gap (>60km) lay between the Midland Valley and the Southern Uplands terrains during the Ordovician and lower Silurian, subsequently reduced by overthrusting of the Southern Uplands to the northwest.

1.3.2 Local Geology

Several previous geological studies have been made in areas overlapping with parts of the study area, the most important of these are listed below:

(1) Peach and Horne (1899) collected graptolites from many of the Moffat Shale inliers exposed within the study area, thus providing invaluable information with regard to the biostratigraphical status of many of the sedimentary sequences.

(2) Kelling (1958, 1961, 1962) described the stratigraphy, structure, sedimentology and petrography of the rocks exposed in the Northern Belt of the Rhinns of Galloway.

(3) Welsh (1964) described the stratigraphy, structure sedimentology and petrography of the Northern Belt sediments exposed to the east of Loch Ryan, and correlated the stratigraphical units exposed here with those described by

Kelling (1958, 1961, 1962).

(4) Gordon (1962) described the stratigraphy, structure, sedimentology and petrography of the rocks exposed within the Central Belt to the east of Luce Bay.

Together these studies have provided a valuable stratigraphical and structural framework for a substantial part of this study. The rocks of the Central Belt on the Rhinns of Galloway have, however, not been studied in detail since the area was mapped by Irvine (1872). The study provided information regarding the distribution of geological units. The Cairngarroch Fault has recently been studied in detail at outcrop by Anderson and Oliver (1986) and is presently considered to represent the Northern/Central Belt boundary.

During the course of the present study the British Geological Survey have, as part of their Southern Uplands remapping programme, mapped and collected graptolites from various parts of the study areas (Jackson 1985; Barnes et al. 1987; Appendix 1).

1.3.3 Determination of Deep-Water Depositional Environments and Systems

A large number of previous studies, reviewed in

Nelson and Nilsen (1984) and Stow (1985), have shown that the nature and types of deep-water depositional environment and system can be determined from analyses of vertical stratigraphical sequences, lateral facies relationships, bed-geometry and palaeocurrent data.

A number of deep-water depositional environments have been identified by numerous authors. In a review work Nilsen (1984) lists the following environments: (1) upper and lower slope, (2) canyon, (3) channel, (4) levee, (5) interchannel, (6) lobe, and (7) basin plain. In addition to these Mutti (1977) has identified the following more specific environments: (1) channel margin, (2) channel mouth, and (3) lobe fringe. Identification of these environments has been shown to rely on a detailed analyses of vertical sections and bed-geometry. Thinning-up and thickening-up sequences rucognized in many ancient successions are commonly regarded as being diagnostic of lobe and channel environments, respectively (Ricci-Lucchi 1975; Walker 1978; Nilsen 1984).

The depositional environments, briefly identified above, form elements of larger depositional systems. Three 'main' types of deep-water depositional system exist, and may be recognized by the 'facies' they contain and by their lateral and vertical arrangement.

Fan systems often display radial or sub-radial palaeoflow patterns and display upward progradational trends, commencing with basin floor deposits and passing up through lobe eventually into channel and channel related deposits (e.g. Walker 1978, 1979). Axial wedge systems display linear palaeoflow patterns and, in ancient sequences, they are dominated by channel, channel-related and basin floor deposits (see Schweller and Kulm 1978).

Debris wedges and slope aprons consist of turbidites, hemipelagic and debris flow deposits. The degree of internal organization is minimal. Slope aprons may include significant thicknesses of 'proximal' turbidites (clastic slope aprons) (Stow 1985).

1.3.4 Depositional Systems within the Southern Uplands

Several previous studies in the Southern Uplands/Longford-Down zone have been able to determine the types of depositional systems which were operative at various times during the Ordovician-Silurian interval. Kelling (1964) and Walton (1965) speculated on the submarine canyon or fan-channel origin of conglomerate bodies in the Ordovician sequences exposed in the Rhinns of Galloway - Glenn App areas. Kelling and Holroyd

(1978) and Holroyd (1978) studied similar Ordovician sequences in the Glen Afton, Carsphairn and Scaur-Shinnel areas, similarly ascribing them to fan-channel complexes. Leggett (1980) described a prograding submarine fan-sequence from the Stobo area and suggested that late Ordovician sedimentation in the Southern Uplands may have been analogous to the Quaternary of the Eastern Aleutians, and characterised by small fans extending from a (northwestern) lower slope across a mud-rich trench wedge. Hepworth *et al*. (1982) have suggested that the late Ordovician sequences in the Abington-Sanquhar area represent axially deflected fans.

1.3.5 The Use of Petrography

Petrographical variation, which is particularly common and well developed in the Northern Belt of the Southern Uplands/Longford-Down zone, has been commonly used as a stratigraphical tool, enabling both distinction and correlation of stratigraphical units (Walton 1955; Kelling 1961, 1962; Welsh 1964; Floyd 1982; Craig 1984). Petrography has also been used as a provenance indicator either subjectively (e.g. Kelling 1962), or objectively by comparing the compositional characteristics of greywacke suites with provenance discrimination diagrams, such as those constructed by Dickinson and Suczek (1979) (e.g. Morris 1987).

1.3.6 The Geotectonic Setting of the Southern Uplands

The accretionary prism model proposed by McKerrow *et al*. (1977) and developed further by Leggett *et al*. (1979), Leggett (1980) has recently been questioned by many workers. In February 1986, a discussion meeting of the Geological Society of London, entitled 'The Southern Uplands Controversy' was held in order to let these workers present their own models and interpretations (McKerrow 1987). Many of the papers presented have since been published (Anderson 1987; Barnes *et al.* 1987; Kelling *et al.* 1987; Kemp 1987; Morris 1987; Stone *et al.* 1987).

Numerous workers have cited sedimentological and petrographical evidence which suggests that certain Northern Belt sequences were derived from a volcanic terrain situated to the south (the apparent derivation of upper Ordovician volcanilithic-rich sands from the south and southwest) (Morris 1987; Stone *et al*. 1987; Kelling *et al*. 1987). This evidence has given rise to reinterpretations which consider that the Southern Uplands/Longford Down zone represents a deformed back-arc basin (Morris 1987; Stone *et al*. 1987). Leggett (1987) suggested, by analogy with modern fore-arcs, that such sedimentological and petrographical 'anomalies' can easily be accommodated for in a complex fore-arc system. Fore-arc complications are envisaged, by Kelling et al. (1987) to be responsible for major anomalies observed within the Southern Uplands (e.g. the southerly derivation of volcanilithic detritus). Kelling et al. recognize the need for an arc terrain to the south of the Northern Belt in late Ordovician times, but also accept the convincing stratigraphical, structural and sedimentological evidence for the development of the Southern Uplands as an accretionary prism.

The back-arc basin models form the main alternative to the fore-arc accretionary prism model (McKerrow et al. 1977). Morris (1987) has suggested that the basin was filled by 'distal' continental derived turbidites, from the northwest and 'proximal' arc-derived greywackes, from the southwest. He envisaged the basin to have closed by the late Ordovician. Morris (1987) considered the rocks of the Central and Southern belts to have been deposited in a fore-arc setting, these were supposedly, subsequently overthrust to the northwest. Stone et al. (1987) suggest that back-arc basin sedimentation continued through until the upper Llandovery. Collision during the upper Llandovery is considered to have been responsible for the initiation of a southeast propogating thrust-stack. They have suggested that the Hawick and Wenlock sequences may have been deposited in a foreland basin related to the advance of this rising thrust-stack.

1.4 NOTES ON THE ORGANIZATION OF, AND TERMINOLOGY USED WITHIN THIS THESIS

The stratigraphical, structural and petrographical characteristics of the rocks exposed within the study area are described in Chapters 2, 3 and 4 respectively. Chapter 5 describes the facies associations encountered within the study area and offers interpretations as to the environmental settings in which they were probably deposited. The distributions of the various facies associations throughout the study area are described in Chapter 6. This Chapter is, however, mainly devoted to interpreting the types of depositional system which are represented by the sedimentary sequences exposed within the study area. Chapter 7 describes the evolution of these systems through the late Ordovician to early Silurian time interval.

The term ′sand-body′ is used to describe a body of sediment which displays distinctive sedimentological features. The scale of the discrete sand-bodies referred to in this thesis are usually equivalent to single stratigraphical units (and their correlatives) and are thus often referred to simply by a stratigraphical name.

When referring to sediment grain size the Wentworth grain size scale is used. Bed thicknesses are defined according to Ingram (1954) (see section 5.2).

CHAPTER 2

STRATIGRAPHY

2.1 GENERAL

The stratigraphical terminology used in studies of the Southern Uplands can appear both over complicated and confusing. Basically the region comprises structurally deformed Llandeilo to Wenlock greywackes and occasional linear belts of Llandeilo to Llandovery black shales. The black shales are often very fossiliferous while the greywackes are most commonly barren.

Lapworth (1889) succeeded in stratigraphically subdividing the black shales which he termed the Moffat Shale Series. Four lithostratigraphically and biostratigraphically distinctive subdivisions were defined these are listed below (Table 2.1):

(1) The Glenkiln Shales; Llandeilo to Caradoc graptolitic black shales, mudstones radiolarian cherts and fine volcanic tuffs.

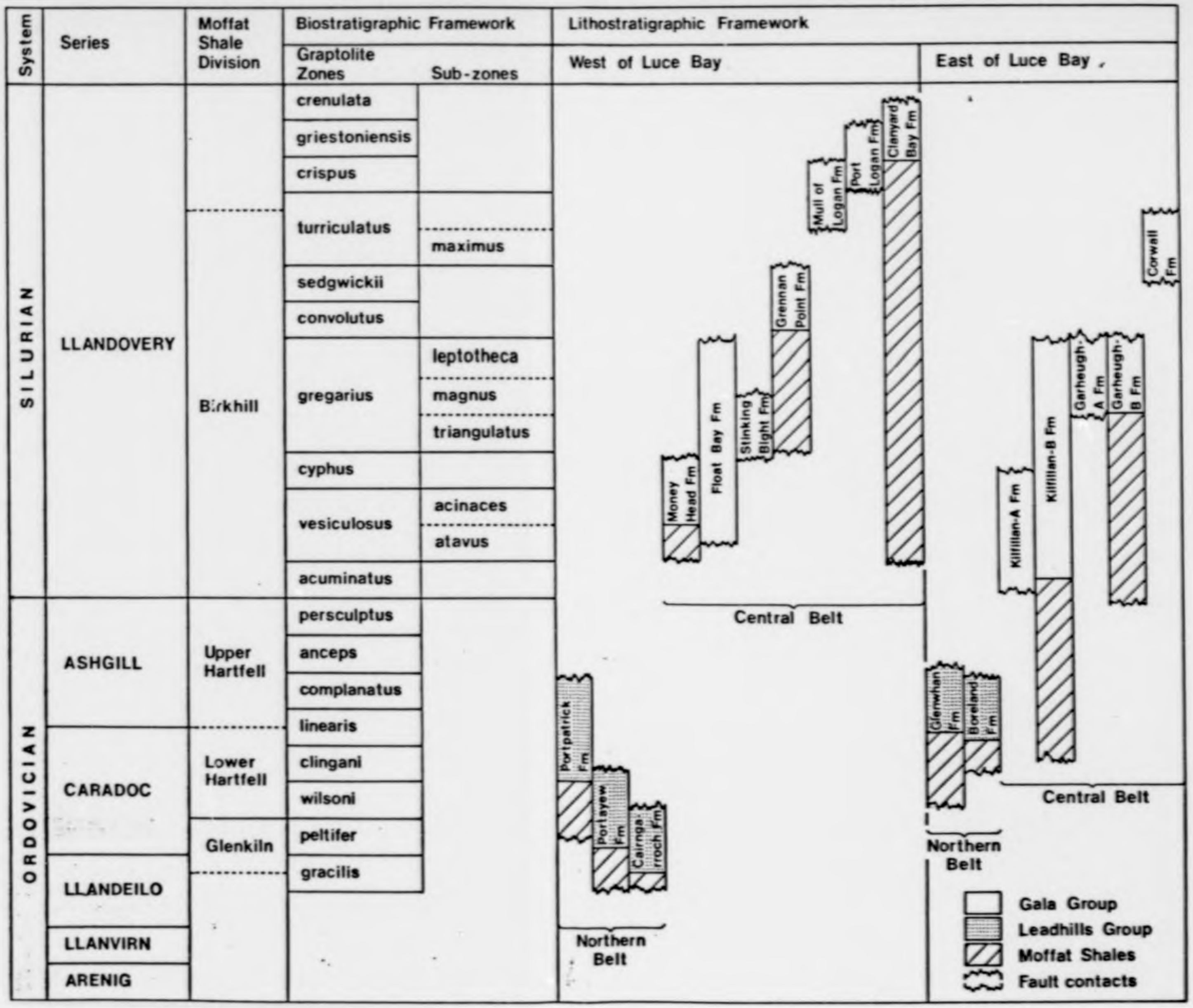

System
Series
Moffat Shale Division
Biostratigraphic Framework
Graptolite Zones
Sub-zones
Lithostratigraphic Framework
West of Luce Bay
East of Luce Bay
SILURIAN
ORDOVICIAN
LLANDOVERY
ASHGILL
CARADOC
LLANDEILO
LLANVIRN
ARENIG
Birkhill
Upper Hartfell
Lower Hartfell
Glenkiln
crenulata
griestoniensis
crispus
turriculatus
maximus
sedgwickii
convolutus
gregarius
leptotheca
magnus
triangulatus
cyphus
vesiculosus
acinaces
atavus
acuminatus
persculptus
anceps
complanatus
linearis
clingani
wilsoni
peltifer
gracilis
Mull of Logan Fm
Port Logan Fm
Clanyard Bay Fm
Grennan Point Fm
Stinking Bight Fm
Float Bay Fm
Money Head Fm
Central Belt
Portpatrick Fm
Portayew Fm
Cairngarroch Fm
Northern Belt
Corwall Fm
Garheugh-A Fm
Garheugh-B Fm
Kilfillan-B Fm
Kilfillan-A Fm
Glenwhan Fm
Boreland Fm
Central Belt
Northern Belt
Gala Group
Leadhills Group
Moffat Shales
Fault contacts

Table 2.1: Summary of the stratigraphical terminology used in this thesis. The Moffat Shale subdivision was devised by Lapworth (1878). The biostratigraphical framework used is after Elles and Wood (1922) and Rickards (1976). The lithostratigraphical framework is based on a review of previous studies and original fieldwork (see text).

(2) The Lower Hartfell Shales; Caradoc mudstones with thin seams of black shale and volcanic tuffs.

(3) The Upper Hartfell Shales; Ashgill, black flaggy graptolitic shales.

(4) The Birkhill Shales; Llandovery black graptolitic shales.

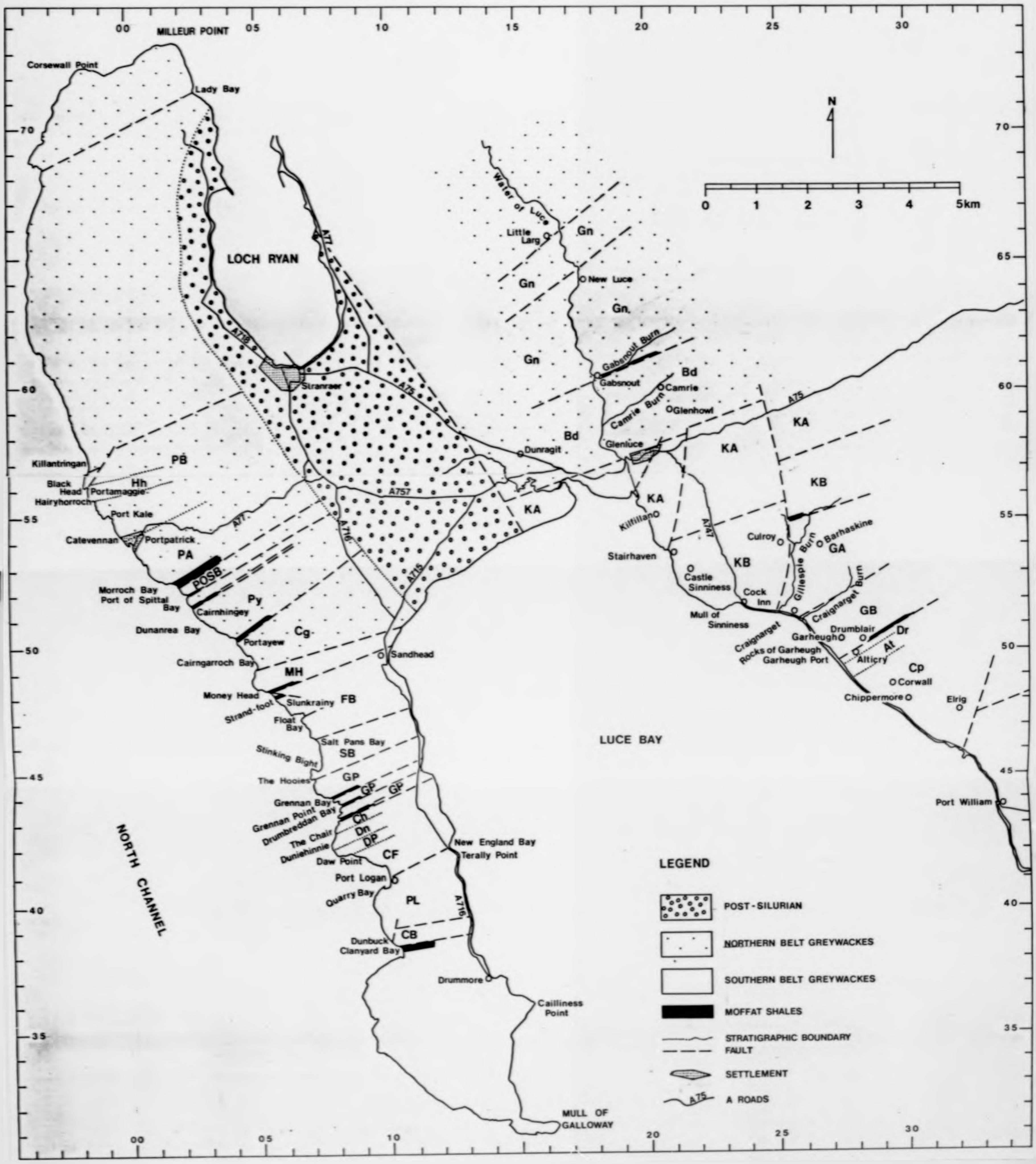
Peach and Horne (1899) subdivided the Southern Uplands into three strike-parallel belts, the Northern, Central and Southern Belts. The Northern Belt comprises a number of Ordovician greywacke sequences, which collectively make up the Leadhills Group, and which conformably overlie Glenkiln and Hartfell Shales (Figs. 1.1, 2.1 and Table 2.1). The Central Belt comprises a number of Llandovery greywacke sequences which collectively make up the Gala Group, and which conformably overlie Birkhill Shales (Figs. 1.1, 2.1 and Table 2.1). The Southern Belt (Fig. 1.1) is composed mainly of Wenlock greywackes which form the Hawick Group. The Moffat Shales are absent from the Southern Belt.

The present study is directly concerned with the rocks which comprise the southern part of the

Figure 2.1: Geological map of the study area showing the main localities referred to in the text and the distribution of stratigraphical units. The table below explains the stratigraphical abbreviations and illustrates the correlations which have been made.

Abbreviations and correlations

NORTHERN BELT				
PB Basic-clast Division	Hh Hakyhorroch Mbr. POSB Port of Spittal Bay Mbr.	Portpatrick Fm.	Gn Glenwhan Fm.	
PA Acid-clast Division				
Py Portayew Fm.			Bd Boreland Fm.	
Cg Cawngarroch Fm.				
CENTRAL BELT				
MH Money Head Fm.				
FB Float Bay Fm.			KA Kilfillan-A Fm. KB Kilfillan-B Fm.	
SB Stinking Bight Fm.			GA Garheugh-A Fm.	
GP Grennan Point Fm.			GB Garheugh-B Fm.	
Ch Chair Mbr.		Mull of Logan Fm.	Dr Drumblair Mbr.	Corwall Fm.
Dn Dunniehinnie Mbr.			At Alticry Mbr.	
DP Daw Point Mbr.				
CF Cairnie Finnart Mbr.			Cp Chippermore Mbr.	
PL Port Logan Fm.				
CB Clanyard Bay Fm.				
WEST OF LUCE BAY			EAST OF LUCE BAY	


MILLEUR POINT
Corsewall Point
Lady Bay
LOCH RYAN
Stranraer
Killantringan
Black Head
Portamaggie
Hairyhorroch
Port Kale
Catevennan
Portpatrick
PB
Hh
PA
POSB
Py
Cg
MH
FB
SB
GP
Cn
Dn
DP
CF
PL
CB
Morroch Bay
Port of Spittal Bay
Cairnhingey
Dunanrea Bay
Portayew
Cairngarroch Bay
Money Head
Strand-foot
Slunkrainy
Float Bay
Salt Pans Bay
Stinking Bight
The Hooies
Grennan Bay
Grennan Point
Drumbreddan Bay
The Chair
Duniehinnie
Daw Point
Port Logan
Quarry Bay
Dunbuck
Clanyard Bay
Drummore
Cailliness Point
MULL OF GALLOWAY
New England Bay
Terally Point
Sandhead
NORTH CHANNEL
LUCE BAY
Water of Luce
Little Larg
New Luce
Gabsnout Burn
Gabsnout
Camrie
Camrie Burn
Glenhowl
Dunragit
Glenluce
Gn
Bd
KA
KB
GA
GB
Dr
At
Cp
Kilfillan
Stairhaven
Castle Sinniness
Cock Inn
Mull of Sinniness
Culroy
Barhaskine
Gillespie Burn
Craignarget Burn
Craignarget
Rocks of Garheugh
Garheugh Port
Garheugh
Drumblair
Alticry
Corwall
Chippermore
Elrig
Port William
A77
A718
A75
A757
A716
A747
N
0
1
2
3
4
5km
00
05
10
15
20
25
30
35
40
45
50
55
60
65
70
LEGEND
POST-SILURIAN
NORTHERN BELT GREYWACKES
SOUTHERN BELT GREYWACKES
MOFFAT SHALES
STRATIGRAPHIC BOUNDARY
FAULT
SETTLEMENT
A ROADS

delineated and broadly defined in a co-operative manner by the author and J.A. McCurry who carried out a contemporary Ph.D. study, with a structural bias, on the Rhinns of Galloway (Figs. 1.1 and 2.1, and Table 2.1). It should be noted that the descriptions of the stratigraphical presented in this study are those of the author. Formal stratigraphical descriptions of these units and others present within the study area have been avoided since:

(1) Structural deformation has in most places made it difficult to determine true broad scale sedimentological sequences and accurate stratigraphical thicknesses.

(2) The biostratigraphical ages and age ranges of the majority of the stratigraphical units remain unknown.

(3) The stratigraphical units are rarely recognizable throughout the Southern Uplands/Longford-Down region.

Table 2.2 lists each of the stratigrphical units studied along with 'locally' suitable but informal 'type-sections' and lists of previous studies in which the stratigraphical units have been described

Northern Belt and the northern part of the Central Belt (Figs. 1.1 and 2.1). The stratigraphical units present within these units are described and local and regional correlations are presented.

2.2 STRATIGRAPHICAL FRAMEWORK AND CORRELATION

The lithostratigraphical hierarchy summarized in Holland *et al.* (1978) is employed within this study. Stratigraphical ´groups´ are subdivided into ´formations´ and then into ´members´. A further stratigraphical term ´division´ is used to denote units defined exclusively on the basis of petrography. These are not usually immediately recognizable in the field. Divisions may form parts of formations or members.

In this study the zonal distribution of graptolites for Ordovician sequences is taken from Elles and Wood (1922), while the zonal distribution for Silurian sequences is taken from Rickards (1976) (Table 2.1). All the lithostratigraphical units described and discussed in this Chapter have been described in previous studies (see Sections 2.3.1, 2.3.2, 2.4.1 and 2.4.2) with the exception of the Silurian sequences exposed on the Rhinns of Galloway. The stratigraphical units which form these sequences were in detail. The ´type-sections´ which are listed are intended as a guide to the better exposed areas for those wishing to pursue field studies in this area. It can not be proven that the ´type-sections´ are typical of the stratigraphical units in the more poorly exposed areas.

Broad scale correlation between the study corridors (Figs. 1.1 and 2.1) has been achieved by comparing the relative structural positions of the individual formations within their respective profiles and by using distinctive petrographical and lithological associations as marker horizons. Biostratigraphical data have been used to identify coeval tectonostratigraphical blocks.

2.3 THE STRATIGRAPHY OF THE SOUTHERN PART OF THE NORTHERN BELT

This section is directly concerned with the stratigraphy of the rocks contained within the following parts of the study corridor:

(1) Killantringan Bay (NW 9820 5700) to Cairngarroch Bay (NX 0464 4905), on the Rhinns of Galloway (Figs. 1.1 and 2.1).

(2) Little Larg (NX 1612 6615) to the vicinity

of Glenluce (NX 2000 5755), to the east of Loch Ryan (Figs. 1.1 and 2.1).

The stratigraphical units exposed within each of these areas are described and tentative correlations between them are presented (Fig. 2.1).

2.3.1 Killantringan Bay (NW 9820 5700) to Cairngarroch Bay (NX 0464 4905)

Kelling (1961) studied the rocks of the Northern Belt on the Rhinns of Galloway and subdivided them into a number of stratigraphical units. The Portpatrick Group formed the southernmost of these and was defined as a lithologically and petrographically distinctive stratigraphical unit, bounded to the north by the Killantringan Fault Zone, and to the south by the Portayew Fault Zone. The Portayew Fault Zone (Thrust) was interpreted as the Northern/Central Belt boundary (Kelling 1961) (Figs. 1.1, 2.1 and 3.1).

Variations in the relative proportions of quartz and of acid- and basic-igneous lithic detritus, within the distinctively volcanilithic and ferromagnesian mineral-rich Portpatrick Group, enabled Kelling (1961) to subdivide it into the Acid- and Basic-clast Divisions. The contact between the two Divisions was considered to be a stratigraphical boundary. This boundary was thought to meet the coast just to the north of Portpatrick (NW 9990 5410), its inland continuation affected by the inferred dextral Portpatrick Wrench Fault which supposedly displaced the boundary by approximately 1.25km to the south on its eastern side (Kelling 1961) (Fig. 2.1).

Kelling (1961) recognized the structurally repeated basal stratigraphical contact of the Portpatrick Group, Acid-clast Division, with the underlying Moffat Shales at three localities; Morroch Bay (NX 0150 5250), Port of Spittal Bay (NX 0200 5212) and Portayew (NX 0385 5030). The Moffat Shales exposed at these localities contain Glenkiln and Hartfell graptolite faunas (Peach and Horne 1899; Kelling 1961), providing a maximum, though imprecise, biostratigraphical age of Hartfell for the Portpatrick Group (Kelling 1961)(Fig. 2.1 and Table 2.1)

Greig (1971) suggested that graptolites representative of the wilsoni Zone occur within the shales interbedded with the greywackes at the base of the Portpatrick Group in Morroch Bay (NX 0150 5250), providing a more precise maximum biostratigraphical age for the Group(Figs. 2.1 and 2.2).

Floyd (1982) suggested, on the basis of a detailed examination of Kelling's (1958) sample localities and modal analyses, that two major, petrographically distinctive, stratigraphical units occur between the

Killantringan and Portayew Fault Zones and that these are separated by faulting in Morroch Bay (NX 0150 5250). Floyd (1982) suggested that the volcanilithic and ferromagnesian mineral-rich rocks to the north of Morroch Bay (NX 0150 5250) should retain their original name, the Portpatrick Group, while the more siliceous rocks to the south should be designated the 'Portayew Rocks' (Floyd 1982).

The present study has recognized the Portpatrick Group, Acid- and Basic-clast divisions and the 'Portayew Rocks'. More detailed mapping and sampling has, however, made it necessary to modify certain aspects of the stratigraphy. Several new stratigraphical units are proposed, namely the Hairyhorroch Member, the Port of Spittal Bay Member (both of which occur within the Basic-clast Division) and the Cairngarroch Formation, which is exposed between the Portayew and Cairngarroch Faults. It is suggested that the Portpatrick Group should be termed the Portpatrick Formation, and that the 'Portayew Rocks' should be termed the Portayew Formation, in order to conform with current stratigraphical procedure (Holland et al. 1978). The terms Acid- and Basic-clast Division are retained for the reasons given in Kelling (1961) that the subdivision of these units is based exclusively on petrographical criteria.

The Portpatrick, Portayew and Cairngarroch Formations are all included within the Leadhills Group (Table 2.1).

2.3.1.1 The Portpatrick Formation

The Portpatrick Formation is best exposed within a 1.25km long coastal section which extends between Killantringan Bay (NW 9820 5700) and Cairnhingey (NX 0200 5189) on the west coast of the Rhinns of Galloway. Across-strike exposure is almost complete. The Formation is bounded to the north by the Killantringan Fault Zone and to the south by an imbricated stratigraphical contact with the Moffat Shales exposed within the Morroch Bay Fault Zone (Figs. 2.1 and 3.1).

The Portpatrick Formation is subdivided into the Acid- and Basic-clast Divisions, the boundary between these is probably stratigraphical, occurring in the vicinity of Catevennan (NW 9947 5429) (Kelling 1961). There is little evidence to support Kelling's (1961) suggestion that a large dextral wrench fault cuts the coastline just to the north of Catevennan (NW 9947 5429) displacing the Acid- Basic-clast Division boundary.

(a) The Acid-clast Division

The Acid-clast Division is bounded to the south by a

Table 2.2: ´Suggested type-sections´ for the stratigraphical units exposed within the study area. The locations of the sections are often dictated by the quality of exposure rather than their being definitely typical of a particular stratigraphical unit. They are therefore not type-sections in the true sense of the word.

		LITHOSTRATIGRAPHICAL UNITS		SUGGESTED ´TYPE-SECTIONS´		IMPORTANT STUDIES
				From (south)	To (north)	
WEST OF LUCE BAY	NORTHERN BELT	Portpatrick Formation	Basic-clast Division	Catevennan (NW 9947 5429)	Killantringan Bay (NW 9820 5700)	Kelling (1958, 1961 & 1962); Kelling et al. (1987)
			Hairyhorroch Member	Hairyhorroch (NW 9812 5590)	Portamaggie (NW 9835 5665)	
			Port of Spittal Member	Port of Spittal Bay (NX 0200 5215)	Morroch Bay (south) (NX 0177 5235)	
			Acid-clast Division	Morroch Bay (north) (NX 0159 5205)	Catevennan (NX 9947 5429)	Kelling (1958, 1961 & 1962); Kelling et al. (1987)
		Portayew Formation		Portayew (NX 0385 5030)	Cairnhingey (NX 0200 5189)	Floyd (1982)
		Cairngarroch Formation		Cairngarroch Bay (NX 0464 4905)	--	
	CENTRAL BELT	Money Head Formation		Strand-foot (NX 0515 4815)	Cairngarroch Bay (NX 0464 4905)	Barnes et al. (1987); Kelling et al. (1987); McCurry (1989)
		Float Bay Formation		Salt Pans Bay (NX 0700 4620)	Strand-foot (NX 0515 4815)	
		The Stinking Bight Formation		The Hooies (NX 0680 4455)	Salt Pans Bay (NX 0700 4620)	
		The Grennan Point Formation		Drumbreddan Bay (NX 0780 4350)	The Hooies (NX 0680 4455)	
		Mull of Logan Formation	The Chair Member	Duniehinnie (NX 0760 4262)	Back Port (NX 0773 4289)	
			The Duniehinnie Member	Lurgie Point (NX 0741 4197)	Duniehinnie (NX 0760 4262)	
			The Dew Point Member	Yellnowte Isle (NX 0815 4165)	Lurgie Point (NX 0741 4197)	
			The Cairnie Finnart Member	Port Logan Bay (NX 0963 4091)	Yellnowte Isle (NX 0815 4165)	
		Port Logan Formation		Dunbuck (NX 0957 3857)	Port Logan Bay (NX 0963 4091)	
		Clanyard Bay Formation		Clanyard Bay (NX 1010 3800)	Dunbuck (NX 0957 3857)	
EAST OF LUCE BAY	NORTHERN BELT	The Glenwhan Formation		Gabenout Burn (NX 1840 6060) Scattered inland exposures only	Little Larg (NX 1612 6615)	Jackson (1985); Welsh (1964)
		The Boreland Formation		Glenluce (NX 2000 5760) Section poorly exposed	Gabenout Burn (NX 1840 6060)	
	CENTRAL BELT	Kilfillan-A Formation		Stairhaven (NX 2070 5374)	Fish House (NX 1981 5538)	Barnes et al. (1987); Gordon (1962); Kelling et al. (1987)
		Kilfillan-B Formation		Mull of Sinniness (NX 2277 5150)	Stairhaven (NX 2070 5374)	
		Garheugh-A Formation		Craignarget (NX 2562 5140) Scattered inland exposures	Culroy (NX 2530 5399)	
		Garheugh-B Formation		Garheugh Port (NX 2700 5000)	Craignarget (NX 2562 5140)	
		Corwall Formation	The Drumblair Member	0.5km west of Culshabbin at (NX 2980 5100), poor inland exposures		
			The Alticry Member	Corwall (NX 2884 4939) Scattered inland exposures	Alticry (NX 2800 4990)	
			The Chippermore	Chippermore (NX 2955 4855) Scattered inland exposures	Corwall (NX 2884 4939)	

stratigraphical contact with the Moffat Shales in Morroch Bay (NX 0159 5250) (Kelling 1961; Grieg 1971) and to the north by a probable stratigraphical contact with the Basic-clast Division at Catevennan (NW 9947 5429) (Kelling 1961)(Fig. 2.1 and Table 2.2).

The Acid-clast Division is dominated by medium- to very thick-bedded (15 to 200cm thick) greywackes (Kelling _et al._ 1987; Table 2.3, (a) and (b)). The Division is petrographically distinctive, being rich in volcanilithic clasts (Type A greywackes, Chapter 4).

The sediments which form the Acid-clast Division are intensely folded. It is thus tentatively suggested that the Acid-clast Division has a stratigraphical thickness of between 200m and 300m.

Previous studies (Peach and Horne 1899; Kelling 1961; Greig 1971) indicate that the Acid-clast Division has a maximum Hartfell, and more precisely, _wilsoni_ Zone age (Fig. 2.2).

(b) The Basic-clast Division

Representatives of the Basic-clast Division are present in two geographically separate sections:

(1) Killantringan Bay (NW 9820 5700) to

LITHOSTRATIGRAPHICAL UNITS EAST OF LUCE BAY

APPROXIMATE PROPORTION OF SEQUENCE	LITHOSTRATIGRAPHICAL UNITS	FACIES ASSOCIATION GROUPING	INCLUDED FACIES ASSOCIATIONS & THEIR PROPORTIONS	DOMINANT GRAIN-SIZE RANGE	AVERAGE BED-THICKNESS	GROUPING/ PACKET THICKNESS	DOMINANT BOUMA SEQUENCES	BED-GEOMETRY	CYCLIC CHARACTER	APPROXIMATE PROPORTION OF SEQUENCE
65% 35%	Glenwhan Formation	a b	2c-70%; 3a-30% 2c-30%; 2e-70%	Md-CSd St-FSd	>1m <10-50cm	2-16m 50cm-10m	Ta/Tab/Tabc Tab/Tbcd(e)	Lent-Tabr Tabr-Lent	Some TKU (5-15m) & TNU (4-10m) Some TKU (3-8m)	65% 35%
65% 30% 5% 60% 40%	Lithostratigraphical equivalents of the Acid-clast Division and Hairyhorroch and Port of Spittal Bay Members not present									
55% 45%	Boreland Formation	a b	2c-30%; 3a-70% 3a-80%; 3b-20%	CSd-GSd MSd-CSd	50cm-2m <10-60cm	5-30m 2-20m	Ta/Tab Tab/Tbcd	Tabr-Lent Tabr	Some TKU (3-10m) & TNU (2-10m) Acyclic	55% 45%
45% 55%	Lithostratigraphical equivalent of the Cairngarroch Fm. not present									
45% 35% 20%	Lithostratigraphical equivalent of the Money Head Fm. not present									
75% 15% 10%	Kilfillan-A & -B Formations	a b c	2c-65%; 2e-35% 2b-100% 2f-50%; 4b-50%	MSd-CSd CSd Md-FSd	10cm-2m 1-4m 1-10cm	Dominant 10-100m 1-5m	Tab/Tbcd Tab Tcde/Tde	Lent-Tabr Lent Tabr	Some TKU (4-12m) Some poor TNU (4-15m) Acyclic	75% 15% 10%
80% 20%	Garheugh-A Formation	a b	2a-10%; 2b-90% 2d-80%; 2e-20%	CSd-GSd Md-FSd	1-5m 1-10cm	Dominant 40-60cm	Ta/Tab Tbc/Tcd	Lent Tabr	Acyclic Acyclic	85% 15%
100%	Garheugh-B Formation	a b	2c-10%; 3a-90% 3a-75%; 3b-25%	MSd-CSd Md-FSd	10cm-2m 1-5cm	Dominant 1-7m	Tab/Tbcd Tcd/Td	Tabr Tabr	Some TKU (3-30m) TKU into (a) over 4-7m	90% 10%
85% 15%	Corwall Formation Drumblair Member	a b c	2b-100% 3a-100% 3b-25%; 4b-75%	CSd MSd-CSd Md-FSd	1-5m 15-55cm 1-10cm	10-20m Dominant 1-10m	Tab Tabc/Tbcd Tde	Lent Tabr Tabr	Acyclic Common TKU (1-3m) Acyclic	35% 60% 5%
100%	Alticry Member	a b	1b-80%; 3a-10% 2b-50%; 3a-50%	10cm clasts CSd-GSd	1-8m 1-4m	Dominant 8-16m	-- Ta/Tb	Irreg Lent	Acyclic Acyclic	60% 40%
60% 10% 30%	Lithostratigraphical equivalent of the Daw Point Mbr. not present									
100%	Chippermore Member	a b	2c-40%; 3a-60% 2a-100%	MSd Cong	5-80cm --	Dominant 5-20m	Tab --	Tabr Lent	Poor TNU (1-7m) Acyclic	95% 5%
20% 30% 50%	Lithostratigraphical equivalents of the Port Logan and Clanyard Bay Formations present but very poorly exposed.									

LITHOSTRATIGRAPHICAL UNITS WEST OF LUCE BAY

LITHOSTRATIGRAPHICAL UNITS		FACIES ASSOCIATION GROUPING	INCLUDED FACIES ASSOCIATIONS & THEIR PROPORTION	DOMINANT GRAIN-SIZE RANGE	AVERAGE BED-THICKNESS	GROUPING/ PACKET THICKNESS	DOMINANT BOUMA SEQUENCES	BED-GEOMETRY	CYCLIC CHARACTER	APPROXIMATE PROPORTION OF SEQUENCE
Portpatrick Formation	Basic-clast Division	a	2c-70%; 3a-30%	Md-CSd	>1m	2-16m	Ta/Tab/Tabc	Lent-Tabr	Some TKU (5-15m) & TNU (4-10m)	65%
		b	2c-30%; 2e-70%	St-FSd	<10-50cm	50cm-10m	Tab/Tbcd(e)	Tabr-Lent	Some TKU (3-8m)	35%
	Hairyhorroch & Port of Spittal Bay Members	a	2c-70%; 3a-30%	Md-CSd	>1m	2-16m	Ta/Tab/Tabc	Lent-Tabr	Some TKU (5-15m) & TNU (4-10m)	65%
		b	2c-30%; 2e-70%	St-FSd	<10-50cm	50cm-10m	Tab/Tbcd(e)	Tabr-Lent	Some TKU (3-8m)	30%
		c	Individual units of Facies Group B1-C2	FSd-CSd	50cm-2m	up to 2m	Tbc,Tc	Tabr	Acyclic	5%
	Acid-clast Division	a	2c-30%; 3a-70%	CSd-GSd	50cm-2m	5-30m	Ta/Tab	Tabr-Lent	Some TKU (3-8m)	60%
		b	3a-80%; 3b-20%	MSd-CSd	10-60cm	2-20m	Tab/Tbcd	Tabr	Some TKU (2-12m)	40%
Portayew Formation		a	2c-15%; 3a-85%	CSd-GSd	50cm-2m	5-30m	Ta/Tab	Tabr-Lent	Some TKU (3-10m) & TNU (2-10m)	55%
		b	3a-45%; 3b-55%	MSd-CSd	<10-70cm	2-20m	Tab/Tbcd	Tabr	Acyclic	45%
Cairngarroch Formation		a	2c-15%; 3a-85%	CSd	50cm-2m	5-30m	Ta/Tab	Tabr-Lent	Some TKU (3-10m) & TNU (3-10m)	45%
		b	3a-45%; 3b-55%	MSd-CSd	<10-70cm	5-10m	Tabc/Tbcd	Tabr	Acyclic	55%
Money Head Formation		a	2b-100%	CSd-GSd	1-5m	5-30m	Ta/Tab/Tb	Lent	Acyclic	45%
		b	2b-10%; 3a-90%	CSd-GSd	1-2m	5-35m	Tab/Tbcd	Tabr	Acyclic	35%
		c	2d-85%; 2e-15%	FSd-CSd	2-35m	5-25m	Tab/Tabc	Tabr-Lent	TKU (5-7m) into (a) or (b)	20%
Float Bay Formation		a	2c-60%; 3a-40%	MSd-CSd	25cm-1m	Dominant	Tab/Tbcd	Tabr	Acyclic	75%
		b	3b-100%	FSd-MSd	4-5cm	4-5m	Tbcd/Tcd	Tabr	Acyclic	15%
		c	3b-40%; 4b-60%	Md-FSd	<5cm	50cm-5m	Tde	Tabr	Acyclic	10%
Stinking Bight Formation		a	2c-80%; 2e-20%	MSd-CSd	50cm-4m	Dominant	Tab/Tabc	Lent-Tabr	Acyclic	80%
		b	2d-50%; 2e-50%	FSd-MSd	10-50cm	1-12m	Tbc/Tbcd	Tabr	Acyclic	20%
Grennan Point Formation		a	2c-10%; 3a-90%	MSd-CSd	10cm-1.5m	Dominant	Tab/Tabc Tcd	Tabr	Rare TKU (5-15m)	100%
Mull of Logan Formation	The Chair Member	a	2c-20%; 2e-20%; 3a-60%	MSd	50cm-4m	Dominant	Tab/Tbc	Tabr	Rare TKU (3-10m)	85%
		b	3b-50%; 4b-50%	Md-St	<2cm	3m	Tcde/Tde	Tabr	Acyclic	15%
	Duniehinnie Member	a	1a-70%; 1b-20% 1c-10	10m Clasts, CSd Matrix	Bedding not clear	--	--	Irreg	Acyclic	100%
	Daw Point Member	a	2b-75%; 2c-25%	CSd-GSd	70cm-2m	Dominant	Tab	Lent	Common TKU (1-4m)	60%
		b	2d-45%; 2e-55%	FSd-MSd	5-35cm	1-5m	Tbcd/Tcd	Tabr	Acyclic	10%
		c	2b-100%	CSd-GSd	1-8m	10-30m	Ta/Tab	Lent	Acyclic	30%
	Cairnie Finnart Member	a	2c-15%; 3a-80%; 4b-5%	St & FSd-CSd	25-60cm	Dominant	Tabc/Tbc/ Tcd	Tabr	Rare TKU (1-5m)	100%
Port Logan & Clanyard Bay Formations		a	2b-40%; 2c-50%; 2d-10%	CSd	1-3m	10-15m	Tab/Tabc	Lent	Acyclic	20%
		b	2d-15%; 2e-75%; 2f-10%	St-MSd	<5-20cm	5-20m	Tabcd/Tbcd	Lent	Rare TKU (1-5m)	30%
		c	3b-80%; 4b-20%	Md-FSd	<5cm	80-100m	Tcde/Tde	Tabr	Acyclic	50%

Table 2.3: Summary of the sedimentological characteristics of each of the stratigraphical units exposed within the study area. It should be noted that a 'facies association grouping' is an actual commonly recurring group of facies associations, the term is not synonymous with 'facies association group' which refers to theoretically, genetically related facies associations (eg. all channel/channel-related facies associations.

Abbreviations:

Md-mud; St-silt; FSd-fine sand; MSd-medium sand; CSd-coarse sand; GSd-granular sand; Cong-conglomerate.

Tabcde-Bouma Divisions.

Lent-lenticular; Tabr-tabular; Irreg-irregular.

TNU-thinning-up; TKU-thickening-up.

Catevennan (NW 9947 5429). Within this section the Basic-clast Division is bounded to the south by a stratigraphical contact with the Acid-clast Division at Catevennan and to the north by the Killantringan Fault Zone (Figs. 2.1 and 3.1).

(2) Morroch Bay (NX 0177 5235) to Cairnhingey (NX 0200 5189). This section occurs within the Morroch Bay Fault Zone and includes several structural elements. Between Cairnhingey and Port of Spittal Bay (NX 0200 5215) there is a small sequence of highly deformed Basic-clast Division sediments which appear to be faulted against Moffat Shales occurring to the northwest. On the north side of Port of Spittal Bay (NX 0200 5215) a sequence of Moffat Shales pass stratigraphically upwards into Basic-clast Division sediments, bounded to the north by a fault situated at the south side of Morroch Bay (NX 0177 5235)(Figs. 2.1 and 3.1).

The Basic-clast Division is dominated by medium- to very thick-bedded (15cm to 250cm thick) greywackes (Kelling et al. 1987; Table 2.3 (a) and (b)). The Division is petrographically distinctive being rich in detrital ferromagnesian minerals and volcanilithic clasts (Type B greywackes, Chapter 4).

The Hairyhorroch and Port of Spittal Bay Members are included within sections (1) and (2) respectively.

(i) The Hairyhorroch Member lies centrally within section (1) of the Basic-clast Division. Its boundaries, which occur just to the south of Hairyhorroch (NW 9812 5590) and in the vicinity of Portamaggie (NW 9835 5665), are of a stratigraphical nature. The unit is marked by the occurrence of thin- to thick-bedded siliceous units (5-100cm thick) (Type C greywackes, Chapter 4) which are interbedded with units exhibiting a petrography more typical of the Basic-clast Division (volcanilithic and ferromagnesian mineral rich) (Type B greywackes, Chapter 4). The siliceous units are easily identifiable in the field, weathering to a steel-grey and containing well defined sedimentary structures. The sedimentological characteristics of these units are summarised in Table 2.3.

(ii) The Port of Spittal Bay Member lies at the base of section (2) in stratigraphical contact with the underlying Moffat Shales and the overlying Basic-clast Division

Figure 2.2: Time-stratigraphical diagram for the Killantringan Bay (NW 9820 5700) to Clanyard Bay (NX 3800 1010) study corridor, showing generalized lithological successions.

Figure 2.3: Time-stratigraphical diagram for the Little Larg (NX 1612 6615) to Port William (NX 3370 4355) study corridor, showing generalized lithological successions.

Abbreviations: g-gregarius Zone, v-vesiculosus Zone. The above diagrams show the sub-zones which are included within these zones (Table 2.1).

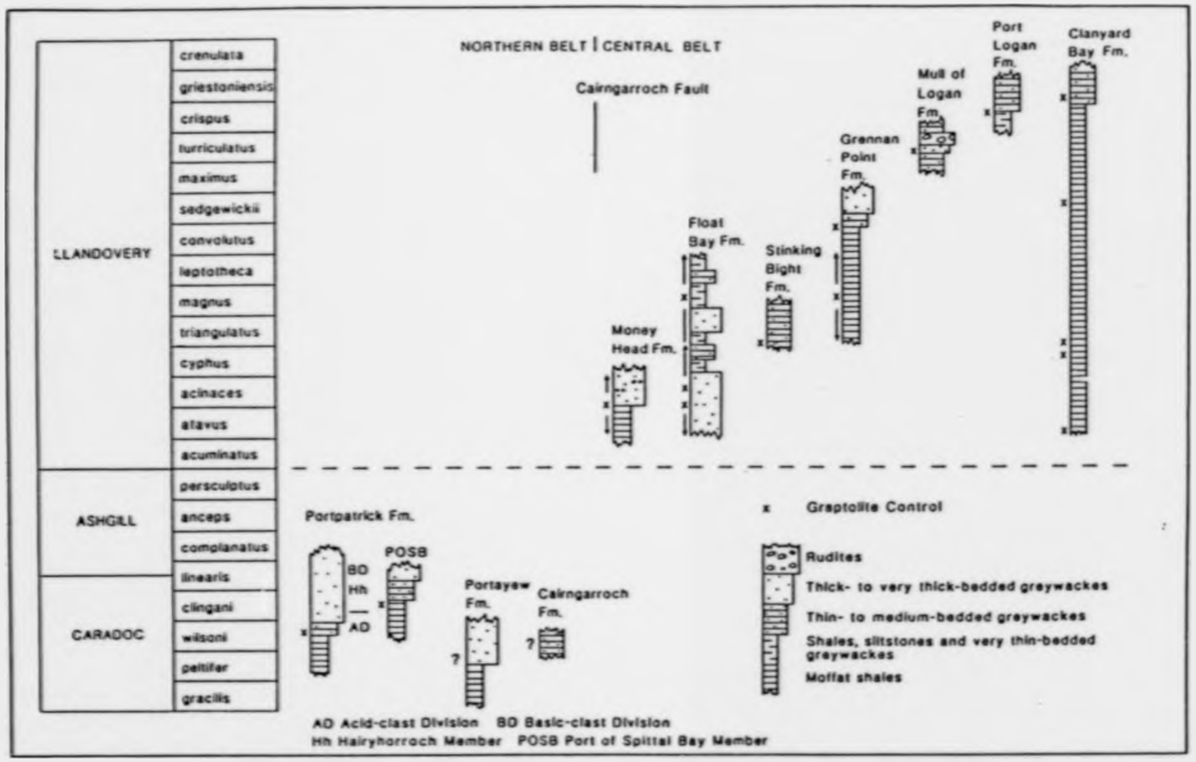


Figure 2.2: Time-stratigraphical diagram for the Killantringan Bay (NW 9820 5700) to Clanyard Bay (NX 1010 3800) study corridor, showing generalized lithological successions.

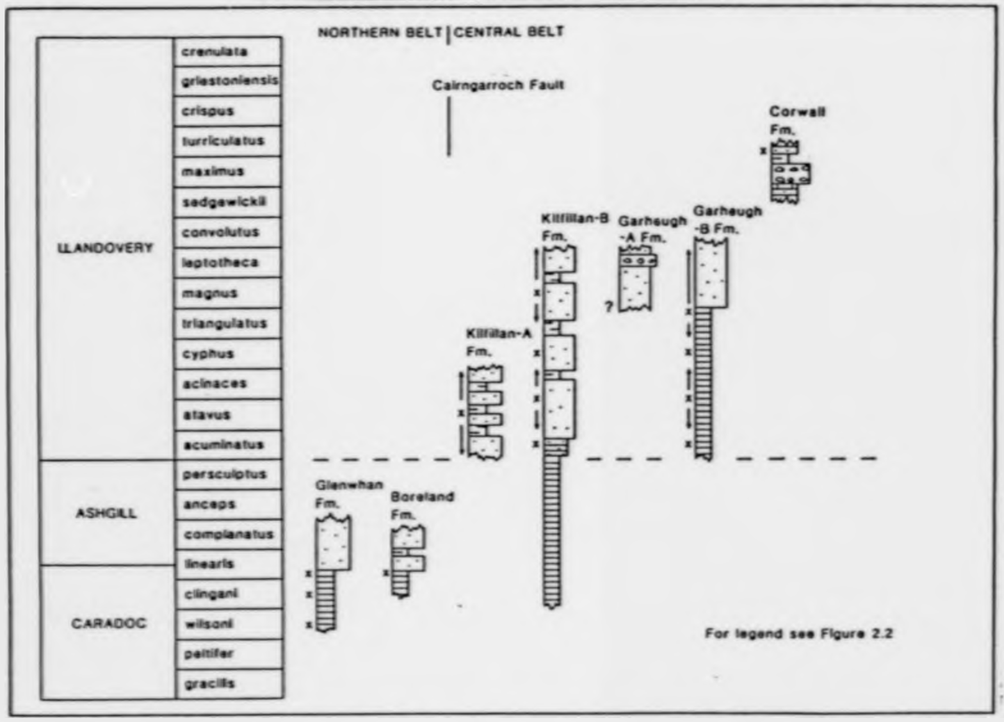


Figure 2.3: Time-stratigraphical diagram for the Little Larg (NX 1612 6615) to Port William (NX 3370 4355) study corridor, showing generalized lithological successions.

greywackes. The Member is marked by the occurrence of thin- to medium-bedded (5cm to 25cm thick) siliceous units (Type C greywackes, Chapter 4), identical to those contained within the Hairyhorroch Member. Trace fossils, particularly Palaeodictyon are extremely common on the bases of the Port of Spittal Bay siliceous units (Plate 5.16). Table 2.3(c) summarizes the sedimentological characteristics of the siliceous units.

Estimates of the stratigraphical thickness of the Basic-clast Division in sections (1) and (2) have been made, along with estimations of the thicknesses of the Hairyhorroch and Port of Spittal Bay Members. The stratigraphical thickness of the very rarely folded Basic-clast Division in section (1) is estimated to be in the region of between 2.5 and 3.5km. The Hairyhorroch Member, which occupies the upper half of this section is estimated to be between 850 and 1250m thick. Within section (2) only the thickness of the succession to the north of Port of Spittal Bay has been estimated, the rocks to the south being much too intensely deformed to permit any worthwhile estimation. To the north of Port of Spittal Bay, the rocks young almost continuously towards the north. The Basic-clast Division here is considered to be between 160m and 200m thick, the

Port of Spittal Bay Member occupies the lowermost 60m to 80m of this section (Fig. 2.1 and Appendix 4).

Graptolites have not been collected directly from section (1) of the Basic-clast Division and consequently the precise biostratigraphical ages of the Basic-clast Division and the included Hairyhorroch Member remain unknown. Since the Basic-clast Division in section (1) stratigraphically overlies the Acid-clast Division, it cannot be older than *wilsoni* Zone age (Fig. 2.2).

Graptolites have been recovered from the Moffat Shales on the north side of Port of Spittal Bay (NX 0200 5215) within section (2) by Kelling (1961) and more recently by the Palaeontology Division of the B.G.S. (Rushton and White 1986; Rushton 1987a). Kelling (1961) identified both Glenkiln and Hartfell faunas. The B.G.S. reports (Rushton and White 1986; Rushton 1987) suggest that the Moffat Shales here may be of either *clingani* or *linearis* Zone age. It is consequently suggested that the Basic-clast Division and the Port of Spittal Bay Member at this locality have a maximum biostratigraphical age represented by either the *clingani* or the *linearis* Zones (Fig. 2.2).

If sedimentation of the Basic-clast Division commenced at approximately the same time in sections (1) and (2) then it may be concluded that these sections share the same maximum biostratigraphical age of clingani or linearis. Alternatively, the similarities displayed by the Hairyhorroch and Port of Spittal Bay Members suggest that these might be equivalent units, implying that the maximum age of the Hairyhorroch Member might be represented by either the clingani or linearis Zone. The maximum age of the Basic-clast Division could then be represented by either the wilsoni, clingani or linearis Zone (Fig. 2.2).

2.3.1.2 The Portayew Formation

The Portayew Formation is best exposed within a 2.5km long coastal section which extends between Cairnhingey (NX 0200 5189) and Portayew (NX 0385 5030) on the west coast of the Rhinns of Galloway. Across-strike exposure is almost complete. The Formation is bounded to the north by the Morroch Bay Fault Zone and to the south by an imbricated stratigraphical contact with Moffat Shales in the Portayew Fault Zone (Figs. 1.1, 2.1 and 3.1).

Sedimentologically the Formation is dominated by a characteristic alternation of 5m to 30m thick packets of thick- to very thick-bedded (50cm to 200cm thick) greywackes (Table 2.3 (a)), with 2m to 7m thick packets of shales, siltstones and very thin- to thick-bedded (2cm to 70cm thick) greywackes (Kelling et al. 1987; Table 2.3 (b)).

The sediments which form the Portayew Formation are commonly intensely folded and faulted (Fig. 3.1) and furthermore, the section is not completely accessible, thus a reliable estimate of the stratigraphical thickness represented by the Formation cannot be made. It is, however, clear from the across-strike width of the Formation that its stratigraphical thickness cannot exceed 2.5km and is probably much less.

Graptolites have been collected from the Moffat Shales which crop out in the vicinity of Portayew (NX 0385 5030) by Peach and Horne (1899) and by Kelling (1961). The collections made by Peach and Horne (1899) have been reviewed by the Palaeontology Division of the B.G.S. (Rushton 1987c). These collections have yielded nothing more precise than a Glenkiln to Hartfell age (Table 2.1). Thus the maximum biostratigraphical age of the Portayew Formation can only be confined to the Hartfell (Fig. 2.2).

2.3.1.3 The Cairngarroch Formation

The Cairngarroch Formation is best exposed within a 1.25km long coastal section extending between Portayew (NX 0385 5030) and the south side of Cairngarroch Bay (NX 0464 4905) on the west coast of the Rhinns of Galloway. Across-strike exposure is almost complete but much of the section is obscured by the occurrence of intrusive igneous bodies and inaccessibility. The Cairngarroch Formation is bounded to the north by the Portayew Fault Zone and to the south by the Cairngarroch Fault (Figs. 1.1, 2.1 and 3.1, and Table 2.2).

Sedimentologically the Cairngarroch Formation is characteristically dominated by thin- to medium-bedded (5cm to 30cm thick) 'classical' turbidites. Occasionally, 10m to 20m thick packets of thick- to very thick-bedded (50cm to 150cm thick) greywackes are associated with these sediments (Table 2.3).

The sediments forming the Cairngarroch Formation are folded. A complete section through the Formation is not seen due to: (1) the masking of the succession by intrusive igneous bodies, and (2) the partial inaccessibility of the Formation. Consequently, the stratigraphical thickness of the Cairngarroch Formation has not been estimated.

Graptolites have not been recovered from the Cairngarroch Formation and thus its biostratigraphical status remains unclear.

2.3.2 Little Larg (NX 1612 6615) to Glenluce (NX 2000 5755)

The rocks exposed within this section were studied by Welsh (1964). The section is bounded to the north by the Little Larg Fault, the along-strike equivalent of the Killantringan Fault Zone and to the south by the Northern/Central Belt boundary, the Cairngarroch Fault. Welsh (1964) recognized two distinctive stratigraphical units, within this section, which he termed the Glenwhan and Boreland 'Rocks'. In this study these units are re-termed the Glenwhan and Boreland Formations. Jackson (1985) has contributed some new information concerning the stratigraphy of the rocks exposed within this section (Figs. 1.1 and 2.1).

The Glenwhan and Boreland Formations are both included within the Leadhills Group (Table 2.1).

2.3.2.1 The Glenwhan Formation

The Glenwhan Formation is patchily exposed within a 5km long section, extending between just south of Little Larg (NX 1612 6615) and Gabsnout Burn (NX 1840 6060), in the vicinity of New Luce (NX 1750 6450). The Formation is bounded to the north by the Little Larg Fault and to the south by a stratigraphical contact with Moffat Shales associated with the Gabsnout Burn Fault (Jackson 1985; Fig. 2.1 and Table 2.2).

Sedimentologically the Glenwhan Formation is dominated by thick- to very thick-bedded (50cm to 300cm thick) greywackes, 5m to 10m thick packets of shale, siltstone and medium- to thick-bedded (25cm to 80cm thick) greywackes. Petrographically the Glenwhan Formation is very distinctive, being rich in volcanilithic detritus and ferromagnesian minerals (Type B greywackes, Chapter 4).

The stratigraphical thickness of the Glenwhan Formation has not been accurately determined since the component sediments are not completely exposed and thus the structure not fully understood. Jackson (1985) records a 1.5km long section within the northern part of the section through the Glenwhan Formation in which the rocks young continuously towards the north. This section provides a minimum estimate for the thickness of the Glenwhan Formation, while the length of the section which the Formation occupies provides a maximum thickness. It is, therefore, concluded that the Glenwhan Formation has a stratigraphical thickness of between 1.5km and 5km.

According to Peach and Horne (1899) the Moffat Shales of Gabsnout Burn, which stratigraphically underlie the Glenwhan Formation, contain a Lower Hartfell fauna. More recently, Jackson (1985) has reported that the wilsoni to linearis Zones are represented in the shales of Gabsnout Burn. Thus it is concluded that the Glenwhan Formation exhibits a maximum linearis Zone age (Fig. 2.3).

2.3.2.2 The Boreland Formation

The Boreland Formation is patchily exposed within a 3km section which extends between Gabsnout Burn (NX 1840 6060) in the north, to the Glenluce (NX 2000 5760) area, in the south. The Formation is bounded to the north by the Gabsnout Burn Fault and to the south by the Northern/Central Belt boundary which passes in the vicinity of Glenluce (Barnes et al. 1987, their Fig. 4; Fig. 2.1 and Table 2.2).

Sedimentologically the Boreland Formation comprises thin- to thick-bedded (50cm to 75cm thick) greywackes, thick (1m to 5m thick) packets of siltstone and shale characteristically form a substantial part of the Boreland Formation succession (Welsh 1964)(Table 2.3).

The poorly exposed nature of the Boreland Formation makes it impossible to determine its stratigraphical thickness with any accuracy. Graptolites have been collected from the Moffat Shales cropping out in the Camrie (NX 2085 6065) area and underlying the Boreland Formation. These are indicative of the linearis Zone, suggesting that the Boreland Formation has a maximum linearis Zone age.

2.3.3 Local Correlation

Welsh (1964) correlated the Glenwhan 'Rocks' with the Portpatrick Group, Basic-clast Division and the Boreland 'Rocks' with the Acid-clast Division (as defined by Kelling 1961). Floyd (1982) also correlated the Portpatrick Group and the Glenwhan 'Rocks'. These conclusions are broadly accepted by the present study. The Portpatrick and Glenwhan Formations are correlated, as are the Portayew and Boreland Formations. The Cairngarroch Formation, which is exposed to the south of the Portayew Formation on the west coast of the Rhinns of Galloway, has not been recognized in the Little Larg (NX 1612 6615) to Glenluce (NX 2000 5755) section (Figs. 1.1 and 2.1, and Table 2.4).

2.3.3.1 The Portpatrick and Glenwhan Formations

In general, the petrographical and lithological characteristics exhibited by the Portpatrick and Glenwhan Formations are very similar. However, whereas the Portpatrick Formation is subdivided into two petrographically distinctive sub-units, the Acid- and Basic-clast Divisions, the Glenwhan Formation, appears to form a single petrographically homogeneous, stratigraphical unit. The Glenwhan Formation most closely resembles the Portpatrick Formation, Basic-clast Division in terms of its petrography (both are composed of Type B greywackes, Chapter 4). It is thus concluded that an equivalent of the Acid-clast Division (composed of Type A greywackes) is absent from the Glenwhan Formation. Equivalents of the Hairyhorroch and Port of Spittal Bay Members have not been positively identified, as yet, within the Glenwhan Formation (Fig. 2.1).

The Acid-clast Division is considered to have a maximum _wilsoni_ Zone age (Greig 1971). The Basic-clast Division exposed on the north side of Port of Spittal Bay (NX 0200 5215) has a maximum _clingani_ or _linearis_ Zone age (Rushton and White 1986; Rushton 1987a), this is closely comparable with the maximum _linearis_ Zone age deduced for the Glenwhan Formation (Jackson 1985). Since the Basic-clast Division stratigraphically overlies the Acid-clast Division in the vicinity of Portpatrick (NW 9947 5429) it must, here, be of _wilsoni_ Zone age or younger. If the correlated sections of the the Basic-clast Division exposed to the north of Portpatrick (NW 9947 5429) and in Port of Spittal Bay (NX 0200 5215) and the Glenwhan Formation, are age equivalent, then the _clingani_ or _linearis_ Zone provides a minimum age for the Acid-clast Division and a maximum age for the Basic-clast Division at Portpatrick. Alternatively, the similarities displayed by the Hairyhorroch and Port of Spittal Bay Members suggest that these might be laterally equivalent units, implying that the maximum age of the Hairyhorroch Member might be represented by either the clingani or linearis Zone. The age of the underlying Acid-clast to Basic-clast transition could then be represented by either the wilsoni, clingani or linearis Zone. Thus, there may be some local along-strike diachronism towards the northeast, in the base of the Basic-clast Division and the correlated Glenwhan Formation (Fig. 2.4).

2.3.3.2 The Portayew and Boreland Formations

The petrographical and lithological characteristics displayed by the Portayew and Boreland Formations are closely comparable (Floyd 1982). Both Formations are relatively quartzose containing minor amounts of ferromagnesian mineral detritus (Floyd 1982) (Type D greywackes, Chapter 4).

The biostratigraphical age of the Portayew Formation has only been confined to a maximum Hartfell age (Kelling 1961; Rushton 1987c) (Table 2.1). The biostratigraphical age of the Boreland Formation is probably equivalent to that of the Portayew Formation (Kelling 1961; Rushton 1987).

2.3.3.3 The Cairngarroch Formation

The Cairngarroch Formation, which is exposed on the west coast of the Rhinns of Galloway, does not appear to be represented within the Little Larg (NX 1612 6615) to Glenluce (NX 2000 5755) section (Fig. 2.1).

2.3.3.4 Summary

The Portpatrick and Glenwhan Formations have been correlated with each other as have the Portayew and Boreland Formations (Figs. 2.1, 2.2 and 2.3).

The Acid-clast Division which forms the stratigraphically lowermost part of the Portpatrick Formation to the north of Morroch Bay (NX 0159 5250), has no equivalent either to the north of Port of Spittal Bay (NX 0200 5215) or within the Glenwhan Formation. It is thus concluded that the Acid-clast Division, locally at least, was deposited within a limited area. The Hairyhorroch and Port of Spittal Bay Members may have originally been, laterally equivalent stratigraphical units. These have not been positively identified within the Glenwhan Formation. Biostratigraphical information suggests that the base of the Portpatrick Formation, Basic-clast Division/Glenwhan Formation may be locally diachronous towards the northwest (Fig. 2.4).

The absence of an equivalent of the Cairngarroch Formation within the Little Larg (NX 1612 6615) to Glenluce (NX 0200 5755) (Fig. 2.1) section could suggest that either:

(1) The Cairngarroch Formation was only deposited locally within the Rhinns of Galloway area (Fig. 1.1).

(2) The Cairngarroch Formation is cut out laterally by strike-faulting.

It is, however, important to note that exposure is extremely poor just to the north of Glenluce and consequently, an equivalent of the Cairngarroch Formation may simply just not have been recognized.

It is here suggested that the onset of greywacke sedimentation within the southern part of the Northern Belt in the study area becomes progressively younger towards the northwest. Biostratigraphical control is generally poor and allows this interpretation although it most certainly does not prove it. The evidence for this across-strike diachronism derives mainly from a consideration of palaeocurrent data and the distribution of stratigraphical units exposed within the southern part of the Northern Belt. The sediments contained within these stratigraphical units appear to have been derived from sources to the south and southwest (Fig. 6.5, Appendix 3). Taking this factor into consideration it is clear that if the Portpatrick Formation sequences were the oldest in the southern part of the Northern Belt their petrographically distinctive stratigraphical equvalents should be seen underlying the the greywackes of the Portayew and Cairngarroch Formations, particularly where these directly overlie the Moffat Shales for example in Portayew (NX 0385 5030) (Figs. 2.1 and 2.2). This is not the case and in the absence of good structural evidence for major strike-slip movements it seems reasonable to suggest that the greywacke sequences become progressively younger from tract to tract from the southeast to the northwest (Figs. 2.2 and 2.3). Thus the Cairngarroch Formation is probably the oldest in the area while the Portpatrick Formation is the youngest. It is accepted that this interpretation is by no means proven but it is the best alternative at present. Only further biostratigraphical investigations will provide an incontrovertible answer to this crucially important problem.

Most of the stratigraphical units exposed in the Killantringan Bay (NW 9820 5700) to Cairngarroch Bay

(NX 0464 4905) section are represented within the Little Larg (NX 1612 6615) to Glenluce (NX 2000 5755) section (Fig. 2.1). Those units which are not were probably only deposited over a limited area.

Sedimentation of the greywacke sequences exposed in the southern part of the Northern Belt appears to have been diachronous in both across-strike, to the northwest, and along-strike, to the northeast, directions (Figs. 2.2, 2.3 and 2.4).

2.4 THE STRATIGRAPHY OF THE NORTHERN PART OF THE CENTRAL BELT

This section is directly concerned with the stratigraphy of the rocks exposed within the following parts of the study corridors:

(1) Cairngarroch Bay (NX 0464 4950) to Clanyard Bay (NX 1010 3800) on the Rhinns of Galloway (Figs. 1.1 and 2.1).

(2) Glenluce (NX 2000 5755) to Port William (NX 3380 4350) to the east of Luce Bay (Figs. 1.1 and 2.1).

The stratigraphical units exposed within each area are described and tentative correlations between them are presented below.

2.4.1 Cairngarroch Bay (NX 0464 4905) to Clanyard Bay (NX 1010 3800)

The stratigraphy of the rocks exposed in this area has recently been briefly described in Kelling *et al*. (1987) and Barnes *et al*. (1987). This stratigraphy has been erected during the course of the present study and is the result of work undertaken by the author and J.A. McCurry (see Barnes *et al*. 1987). A number of new stratigraphical units are proposed including: the Money Head Formation, the Float Bay Formation, the Stinking Bight Formation, the Grennan Point Formation, the Mull of Logan Formation, the Port Logan Formation and the Clanyard Bay Formation (Figs. 2.1 and 2.2). Each of these Formations is included within the Gala Group (Table 2.1).

2.4.1.1 The Money Head Formation

The Money Head Formation is best exposed within a 1.25km long coastal section, which extends between Cairngarroch Bay (NX 0464 4905) and Strand-foot (NX 0515 4815). Across-strike exposure is virtually complete. The Formation is bounded to the north by the Cairngarroch Fault, which forms the Northern/Central Belt boundary (Anderson and Oliver 1986) and to the south by an imbricated stratigraphical contact with the Moffat Shales, exposed within the Strand-foot Fault Zone (Fig. 2.1 and Table 2.2).

Sedimentologically the Money Head Formation is dominated by thick- to very thick-bedded (0.8m to 10m thick), often massive and amalgamated greywackes. Intraclast rudites are associated with these sediments (Table 2.3, (a) and (b)). Very thick packets (5m to 25m thick) of very thin- to medium-bedded (2cm to 35cm thick) greywackes occur at regular intervals within the succession (Tables 2.3 (c)). Petrographically the Money Head Formation is quite distinctive within the Cairngarroch Bay (NX 0464 4905) to Clanyard Bay (NX 1010 3800) profile, being relatively rich in detrital pyroxenes (Type E greywackes, Chapter 4).

The sediments forming the Money Head Formation are almost completely unfolded, younging continuously towards the northwest. The stratigrahical thickness of the Formation is estimated at approximately 800m to 900m (Fig. 3.1).

Graptolites have been collected from the Moffat Shales which stratigraphically underlie the Money Head Formation, within the Strand-foot Fault Zone, by the Palaeontology Division of the B.G.S (Rushton 1987a). These are indicative of an atavus or acinaces or cyphus Zone age. Rushton (1987) states that the lithology of the sediment from which the collections were made is that of the 'Vesiculosus

Flags' and suggests that the horizon may be restricted to the atavus or acinaces Zone. It is thus suggested that the Money Head Formation has a maximum atavus or acinaces Zone biostratigraphical age (Fig. 2.2).

2.4.1.2 The Float Bay Formation

The Float Bay Formation is best exposed within a 2.5km long section extending between Strand-foot (NX0515 4815) and Salt Pans Bay (NX 0700 4620) on the west coast of the Rhinns of Galloway. Across-strike exposure is almost complete. The Formation is bounded to the north by the Strand-foot Fault Zone and to the south by the Salt Pans Bay Fault Zone (Fig. 2.1 and Table 2.2).

Sedimentologically the Formation is dominated by thick-to thin-bedded greywackes (25cm to 100cm thick) (Table 2.3, (a)). Thick packets (0.5m to 5m thick) of laminated mudstones, siltstones and very thinly-bedded greywackes (1cm-3cm thick) are characteristically associated with these sediments. Some packets contain just homogeneous, often graptolitic, black shales (Table 2.3, (b)).

Petrographically the sediments are quartzose (Type F greywackes, Chapter 4).

The sediments which make up the Formation are folded and are also internally cut by strike-faults, interpreted as early thrusts, with unknown throws. If these throws are minimal then the stratigraphical thickness of the Formation may be as much as 1200m to 1500m. Otherwise, the Formation may comprise several blocks containing laterally equivalent sedimentary successions, reaching a maximum thickness of between 400m and 500m (Appendix 4, Map 3).

Graptolites have been collected from within the Float Bay Formation by Peach and Horne (1899), the Palaeontology Division of the B.G.S. and by the author. Collections, made by the author, during the course of the present study from Dun Stone (NX 0640 4696), south of Float Bay (NX 0651 4722), have been assigned to the atavus to cyphus Zone interval (Appendix 1). Collections made by the Palaeontology Division of the B.G.S. from this area, have been assigned to the acinaces to cyphus Zone interval (Rushton 1987a)(Fig. 2.2).

North of Float Bay (NX 0651 4722) Peach and Horne (1899) collected from Dove Cave (NX 0587 4735), while the Palaeontology Division have collected from the Strand-foot area (NX 0526 4805) (Rushton 1987a). These collections have all yielded gregarius Zone ages. Thus it is concluded that the Float Bay Formation in total has an acinaces to gregarius Zone age (Fig. 2.2).

2.4.1.3 The Stinking Bight Formation

The Stinking Bight Formation is best exposed with a 1.6km long section which extends between Salt Pans Bay (NX 0700 4620) and the Roc1es (NX 0680 4455), on the west coast of the Rhinns of Galloway. The across-strike exposure, which is almost complete, is broken by Ardwell Bay (NX 0700 4500), a 300m wide sandy beach. The Formation is bounded to the north by the Salt Pans Bay Fault Zone and to the south by the Rocles Fault Zone (Fig. 2.1 and Table 2.2).

Sedimentologically the Formation is dominated by medium- to very thick-bedded greywackes (0.5m to 4.0m thick). Parts of the succession include 1m to 12m thick packets of very thin- to medium-bedded (10cm to 50cm thick) greywackes (Table 2.3, (a) and (b)).

Petrographically the sediments are quartzose (Type F greywackes, Chapter 4).

The sediments included within the Stinking Bight Formation are folded, however, they do young predominantly towards the northwest. It is estimated that the sediments exposed to the south of Ardwell Bay (NX 0700 4500) have a stratigraphical thickness age (Fig. 2.2).

2.4.1.3 The Stinking Bight Formation

The Stinking Bight Formation is best exposed with a 1.6km long section which extends between Salt Pans Bay (NX 0700 4620) and the Hooies (NX 0680 4455), on the west coast of the Rhinns of Galloway. The across-strike exposure, which is almost complete, is broken by Ardwell Bay (NX 0700 4500), a 300m wide sandy beach. The Formation is bounded to the north by the Salt Pans Bay Fault Zone and to the south by the Hooies Fault Zone (Fig. 2.1 and Table 2.2).

Sedimentologically the Formation is dominated by medium- to very thick-bedded greywackes (0.5m to 4.0m thick). Parts of the succession include 1m to 12m thick packets of very thin- to medium-bedded (10cm to 50cm thick) greywackes (Table 2.3, (a) and (b)).

Petrographically the sediments are quartzose (Type F greywackes, Chapter 4).

The sediments included within the Stinking Bight Formation are folded, however, they do young predominantly towards the northwest. It is estimated that the sediments exposed to the south of Ardwell Bay (NX 0700 4500) have a stratigraphical thickness of between 125m and 175m, while those to the north have a thickness of between 625m and 725m. Thus the Formation may have a total stratigraphical thickness of between 750m and 900m.

Graptolites have been collected from near the base of the Stinking Bight Formation by the Palaeontology Division of B.G.S. (Rushton 1987a). The collections, made from Castle Point (NX 0683 4455) are indicative of the *cyphus*/*triangulatus* Zone boundary (Rushton 1987a). Thus it is concluded that the Stinking Bight Formation has a maximum *cyphus* or *triangulatus* Zone age (Fig.2.2).

2.4.1.4 The Grennan Point Formation

The Grennan Point Formation is best exposed within a 1.5km long section which extends between the Hooies (NX 0680 4455) and Drumbreddan Bay (NX 0780 4350). Across-strike exposure is almost complete. The Formation is bounded by the Hooies Fault Zone to the north and by an imbricated stratigraphical contact with the Moffat Shales in the Drumbreddan Bay Fault Zone, to the south (Fig. 1.1, 2.1 and 3.1, and Table 2.2).

Sedimentologically the Grennan Point Formation is dominated by thin- to very thick-bedded (10cm to 150cm thick), tabular, greywackes (Tables 2.3 and 2.4).

Petrographically the sediments are quartzose (Type F greywackes, Chapter 4).

The sediments which make up the Grennan Point Formation are folded. However, they do young predominantly towards the northwest. Two small imbricate blocks of the Grennan Point Formation occur within the Drumbreddan Bay Fault Zone. These blocks exhibit approximate stratigraphical thicknesses of between 75m and 125m, and 150m and 200m. The main development of the Formation, which occurs to the north of Grennan Bay (NX 0750 4380) has an estimated stratigraphical thickness of between 650m and 750m.

Graptolites have been collected from the Moffat Shales which stratigraphically underlie the Grennan Point Formation in Grennan Bay (NX 0750 4380) and in Drumbreddan Bay (NX 0770 4360). Collections have been made by Peach and Horne (1899), by the Palaeontology Division of the B.G.S. and by the author during the course of the present study (Appendix 1). The collections made by Peach and Horne (1899) have been re-examined by Rushton (1987c) and it appears that they are partly indicative of the Ordovician Period. The highest zone which is represented is the convolutus Zone. The collections made by the author have been identified by Rushton (1986) and loosely assigned to the atavus, acinaces, cyphus and gregarius Zones. The Palaeontology Division collections are indicative of the gregarius Zone (Rushton 1987a). Since the Grennan Point Formation stratigraphically overlies the Moffat Shales in Drumbreddan Bay (NX 0770 4360) and Grennan Bay (NX 0750 4380) it probably has a maximum convolutus Zone age (Fig. 2.2).

2.4.1.5 The Mull of Logan Formation

The Mull of Logan Formation is best exposed within a 3.75km long coastal section extending between Drumbreddan Bay (NX 0780 4350) and Port Logan Bay (NX 0963 4091) on the west coast of the Rhinns of Galloway. Across-strike exposure is virtually complete. The Formation is bounded to the north by the Drumbreddan Bay Fault Zone and to the south by the unexposed Port Logan Fault (Fig. 2.1). The Formation comprises four members: (a) the Cairnie Finnart Member; (b) the Daw Point Member; (c) the Duniehinnie Member; (d) the Chair Member (Fig. 2.1). The sediments comprising the Mull of Logan Formation are distinctive, being rich in acid-volcanilithic detritus (Type G greywackes, Chapter 4).

(a) The Cairnie Finnart Member

The Cairnie Finnart Member is best exposed within a 1.4km long coastal section which extends between Port

Logan Bay (NX 0963 4091) and Yellnowte Isle (NX 0815 4165). The Member is bounded to the south by the unexposed Port Logan Fault and to the north by a sharp stratigraphical contact with the overlying Daw Point Member (Figs. 2.1 and 3.1, and Table 2.2).

Sedimentologically the Cairnie Finnart Member is dominated by medium- to thick-bedded (25cm to 60cm thick) (Table 2.3), well graded, tabular greywackes. The sediments which make up the Cairnie Finnart Member are intensely folded, making it impossible to estimate its original stratigraphical thickness with any accuracy. However, it is estimated that the Member has a stratigraphical thickness of between 200 and 350m.

Graptolites have recently been collected from the Cairnie Finnart Member by the Palaeontology Division of the B.G.S. (Rushton 1987b). These are indicative of a _turriculatus_ Zone age (Fig. 2.2).

(a) The Daw Point Member

The Daw Point Member is best exposed within a 900km long coastal section which extends between Yellnowte Isle (NX 0815 4165) and Lurghie Point (NX 4197 0741). The Member is bounded to the south by a sharp stratigraphical contact with underlying Cairnie Finnart Member, and to the north by a transitional stratigraphical contact with the overlying Duniehinnie Member (Fig. 2.1). This contact is marked by a zone of soft-sediment deformation.

Sedimentologically the Daw Point Member is dominated by thick- to very thick-bedded (0.7m to 8m thick) lenticular and often amalgamated greywacke units (Table 2.3, (a) and (c)). Packets, usually less than 5m thick, of thin- to medium-bedded (5cm to 35cm thick) tabular, greywackes are associated with the above (Table 2.3, (b)). The sediments within the Member young predominantly northwestwards and it is estimated that they have a 500m to 700m stratigraphical thickness.

Graptolites have not been collected from the Daw Point Member, but its relationship with the Cairnie Finnart Member suggests that it cannot be older than turriculatus Zone age (Fig. 2.2).

(c) The Duniehinnie Member

The Duniehinnie Member is best exposed within a 700m long coastal section extending between Lurghie Point (NX 0741 4197) and Duniehinnie (NX 0760 4262). The Member is bounded to the south by a transitional stratigraphical contact with the Daw Point Member and to the north by a sharp stratigraphical contact with the Chair Member (Fig. 2.1 and Table 2.2).

Sedimentologically the Member is dominated by very coarse conglomerates which contain clasts of up to at least 15m x 10m in size (Table 2.3). Thick- to very thick-bedded 'blocky' units are interbedded with the conglomerates at various levels through the Member, becoming more common in its stratigraphically central parts. Packets (up to 35m thick) of thin- to medium-bedded (5cm to 30cm thick), lenticular to tabular greywackes have been noted from parts of this stratigraphical unit.

The sediments within the Duniehinnie Member appear to young continuously towards the north. A stratigraphical thickness of between 400m and 500m is estimated for the Duniehinnie Member.

Graptolites have not been collected from the Duniehinnie Member and consequently its precise biostratigraphical age remains unknown. Since, however, the Duniehinnie Member occupies a higher stratigraphical position than the Cairnie Finnart Member, it cannot be older than turriculatus Zone age (Fig. 2.2).

(d) The Chair Member

The Chair Member is best exposed within a 250m long coastal section extending between Duniehinnie (NX

0760 4262) and Back Port (NX 0773 4289). The rocks enclosed within this section are bounded to the south by a sharp stratigraphical contact with the Duniehinnie Member and to the north by the southernmost fault of the Drumbreddan Bay Fault Zone (Fig. 2.1). Three fault bounded blocks containing sediments included within the Chair Member are enclosed with the Fault Zone.

The Chair Member is dominated by thick- to very thick-bedded (0.5m to 4m thick) tabular greywackes (Table 2.3, (a)), which are occasionally interbedded with 3m thick packets of laminated siltstones and shales (Table 2.3, (b)).

The sediments included within the Chair Member, which stratigraphically overlie the Duniehinnie Member, young continuously towards the north and probably have a stratigraphical thickness in the region of 200m to 250m.

Graptolites have not been collected from the Chair Member. Since, however, the Chair Member occupies a higher stratigraphical position than the Cairnie Finnart Member it cannot be older than turriculatus Zone age (Fig. 2.2).

2.4.1.6 The Port Logan Formation

The Port Logan Formation is best exposed within a 1.5km long coastal section which extends between Port Logan Bay (NX 0963 4091) and Dunbuck (NX 0957 3857). The Formation is bounded to the north by the unexposed Port Logan Fault and to the south by an unexposed major strike-fault, which is affected by a north-northwest trending sinistral wrench fault (Appendix 4, Map E) (Fig. 2.1 and Table 2.2).

Sedimentologically the Port Logan Formation is dominated by alternations of packets (10m-15m thick) of thick- to very thick-bedded (1m-3m thick) lenticular greywackes (Table 2.3, (a)), with packets (5-20m thick) of laminated siltstones and very thin- to thick-bedded (>5cm to 40cm thick) greywackes (Table 2.3, (b)). Very thick packets (80m to 100m thick) of laminated and very thin-bedded (>5cm thick) shales, siltstones and sandstones are also of substantial importance within the section (Table 2.3, (c)).

Petrographically the sediments are distinctive, being quartzose and containing substantial amounts of mica and metalithic detritus (Type H greywackes, Chapter 4).

The sediments included within the Port Logan

Formation are intensely folded and it is thus difficult to accurately estimate its stratigraphical thickness. It is, however, estimated that the Formation had an original stratigraphical thickness of between 400m and 500m.

Graptolites have been collected from the Port Logan Formation by the Palaeontology Division of the B.G.S. (Rushton 1987b). The collections are indicative of the *crispus* or *griestoniensis* Zone. The Port Logan Formation is therefore approximately of *crispus* or *griestoniensis* Zone age (Fig. 2.2).

2.4.1.7 The Clanyard Bay Formation

The Clanyard Bay Formation is best exposed within a 700m long coastal section extending between Dunbuck (NX 0957 3857) and Clanyard Bay (NX 1010 3800) (see Appendix 4, Map E and Barnes *et al*. 1987). The Formation is bounded to the north by an unexposed major strike-fault which is affected by a north-northwest trending sinistral wrench fault. The Formation continues at least as far south as the strike-faulting in Clanyard Bay (NX 1010 3800).

Sedimentologically and petrographically the rocks included within the Clanyard Bay Formation are closely similar to those included within the Port Logan Formation (see above). Uncertainty as to the original lateral relationships between these stratigraphical units, however, merits their separation (Holland et al 1978). The sediments included within the Clanyard Bay Formation are quite intensely folded. However, the Formation may have had an original stratigraphical thickness of between 175m and 225m.

Graptolites have been collected from the Clanyard Bay Formation by the Palaeontology Division of the B.G.S. (Rushton 1986b). The collection made from Dunbuck (NX 0955 3850) is indicative of the crispus Zone. The Clanyard Bay Formation exposed to the north of the Bay is in faulted contact with the Moffat Shales preserved in the Bay. Collections made from these shales are representative of a variety of zones (Rushton 1987b; Peach and Horne 1899) ranging up to the sedgwickii Zone. Thus, the Clanyard Bay Formation is known to be at least partly of crispus Zone age (Fig. 2.2).

2.4.2 Glenluce (NX 2000 5755) to Port William (NX 3380 4350)

The stratigraphy of the rocks exposed in this area has been described by Gordon (1962) and more recently, briefly by Barnes et al. (1987) and Kelling et al. (1987). The present study has modified Gordon's (1962) original stratigraphy by subdividing the Kilfillan Formation into the Kilfillan -A and -B Formations and by subdividing the Garheugh Formation into the Garheugh -A and -B Formations. These subdivisions have been made on a biostratigraphical and lithological basis. A further stratigraphical unit, the Corwall Formation, has been recognized to the south of the Garheugh Formation (Barnes et al. 1987; Kelling et al. 1987)(Figs. 1.1 and 2.1).

2.4.2.1 The Kilfillan -A Formation

The Kilfillan -A Formation is best exposed within a 2km long coastal section which extends between Fish House (NX 1981 5538) and Stairhaven (NX 2070 5374). The Formation is bounded to the north by the inferred continuation of the Cairngarroch Fault (Northern/Central Belt boundary) and to the south by a major strike-fault which passes through the bay at Stairhaven (Fig. 2.1 and Table 2.2).

Sedimentologically the Kilfillan -A Formation is dominated by thin- to very thick-bedded (10cm to 200cm thick) tabular to lenticular greywackes (Tables 2.3, (a)), which are interbedded with packets (10m to 100m thick) of very thick-bedded (1m to 4m thick) lenticular greywackes (Tables 2.3, (b)) and packets (1m to 5m thick) of laminated to homogeneous, often graptolitic siltstones and shales (Table 2.3 (c)). Petrographically the greywackes are quartzose (Type F, Chapter 4). A complete across-strike section through the Kilfillan -A Formation is not seen and furthermore the included sediments are often intensely folded and thus the stratigraphical thickness of the Formation is only roughly estimated at between 1km and 2km.

Graptolites collected from Kilfillan -A Formation by the Palaeontology Division of the B.G.S. are indicative of the acuminatus and/or acinaces zones (Tunnicliff 1983) (Fig. 2.3).

2.4.2.2 The Kilfillan -B Formation

The Kilfillan -B Formation is best exposed within a 3km long coastal section extending between Stairhaven (NX 2070 5374) and the Mull of Sinniness (NX 2277 5150). The Formation is bounded to the north by the Stairhaven Fault and to the south by a major strike-fault which is offset by a north trending sinistral wrench fault. The strike-fault crops out within the Gillespie Burn stream section to the east of Culroy (NX 2530 5399) (Fig. 2.1 and Table 2.2).

The Kilfillan -B Formation closely resembles the Kilfillan -A Formation in terms of the sedimentology and petrography of its component sediments (see above). However, the Formations are subdivided since their original lateral relationships are unknown.

The Kilfillan -B Formation is folded and it is thus only estimated that it had an original stratigraphical thickness of between 2000 and 2500m.

Graptolites have been collected from the Kilfillan -B Formation and from the Moffat Shales which underlie it in Gillespie Burn (at Culroy, NX 2530 5399), by the Palaeontology Division of the B.G.S. (Tunnicliff 1983; Rushton 1983). The collections from the Moffat Shales are indicative of a maximum acuminatus Zone age for the Formation. Graptolites indicative of a cyphus Zone age have been recovered from within the Formation. It is thus suggested that the Kilfillan -B Fomation has an acuminatus to cyphus Zone age range (Fig. 2.3).

2.4.2.3 The Garheugh -A Formation

The Garheugh -A Formation is best exposed in a craggy inland section which extends for 2.5km oblique to strike between Culroy (NX 2530 5399) and Craignarget (NX 2562 5140). The Formation is bounded to the north by the Gillespie Burn Fault and to the south by the Craignarget Fault (Fig. 2.1 and Table 2.2).

The Formation is dominated by thick to very thick-bedded (1m to 5m thick) lenticular greywackes. These often include lenticular (50cm to 15m thick) bodies of conglomerate with intraformational and extraformational clasts, the Barhaskine Conglomerate (Gordon 1962) (Table 2.3, (a)). Thin (40cm to 60cm thick) packets of thin-bedded (>10cm thick) tabular greywackes are occasionally associated with these units (Table 2.3, (b)). Petrographically the rocks included within the Garheugh -A Formation are quartzose (Type F, Chapter 4). The stratigraphical thickness of the Garheugh -B Formation is roughly estimated at between 1km and 1.5km.

Graptolites have not been collected from this Formation and consequently its biostratigraphical age remains unknown.

2.4.2.4 The Garheugh -B Formation

The Garheugh -B Formation is best exposed in a 1.5km long coastal section extending between Craignarget (NX 2562 5140) and Garheugh Port (NX 2700 5000). The Formation is bounded to the north by the Craignarget Fault and to the south by the Garheugh Fault (see Barnes et al. 1987) (Fig. 2.1 and Table 2.2).

Sedimentologically the Garheugh -B Formation is dominated by thin- to very thick-bedded (10 to 200cm thick) tabular greywackes (Table 2.3, (a)). Packets up to 7m thick of laminated siltstone and thin-bedded (<5cm) tabular greywackes are interbedded with these. Petrographically the Garheugh -B Formation is quartzose (Type F greywackes, Chapter 4). The Garheugh -B Formation is folded and across-strike exposure is not complete and it is thus only roughly estimated that the Formation has a stratigraphical thickness of between 900 and 1200m. Graptolites have been collected from the Moffat Shale, which underlie the Garheugh -B Formation near Garheugh (NX 2741 5033), by the Palaeontology Division of the B.G.S. (Rushton 1984). These are indicative of a maximum gregarius Zone age for this Formation (Fig. 2.3).

2.4.2.5 The Corwall Formation

The Corwall Formation is best exposed in a series of scattered inland outcrops in a 5km long coastal section extending between Drumblair (NX 2821 5040) and Elrig (NX 3215 4767). The Formation is bounded to the north by the Garheugh Fault. The southern boundary is not exposed and is inferred to pass through a stretch of poorly exposed land referred to here as the 'Port William Gap' (Fig. 2.1 and Table 2.2).

The Formation comprises three Members: (a) The Chippermore Member; (b) the Alticry Member; and (c) the Drumblair Member.

Petrographically the sediments included within the

Corwall Formation are distinctive, being rich in acid-volcanilithic detritus (Type G greywackes, Chapter 4).

(a) The Chippermore Member

The Chippermore Member is best seen in a series of scattered inland exposures in the vicinity of Corwall (NX 2884 4939) and Chippermore (NX 2955 4855). The Member is bounded to the north by a sharp stratigraphical contact with the overlying Alticry Member (Fig.2.1 and Table 2.2).

The Member is dominated by thin- to thick-bedded (5cm to 80cm thick) tabular greywackes (Tables 2.5 and 2.3, (a)). Packets of thick-bedded (>1m thick) amalgamated sediments occasionally occur, in addition to lenticular bodies of intraformational conglomerate (Table 2.3, (b)). The sediments included within the Chippermore Member are often intensely folded and this, in addition to its only partially exposed nature, makes any realistic estimation of original stratigraphical thickness impossible.

Graptolites have not been collected from this Member and thus its biostratigraphical status remains unknown.

(b) The Alticry Member

The Alticry Member is best seen in a series of scattered inland exposures between Corwall (NX 2884 4939) and Alticry (NX 2800 4990). The Member is bounded to the south by a sharp stratigraphical contact with the underlying Chippermore Member and to the north by a sharp stratigraphical contact with the overlying Drumblair Member (Fig. 2.1 and Table 2.2).

Sedimentologically the Alticry Member can be subdivided into three parts:

(1) The lowermost part comprises mainly very thick-bedded (1m to 3m thick), organized intraclast conglomerates. Bed-geometry is irregular to tabular (Table 2.3 (c)).

(2) The central part comprises very thick-bedded (>1m thick), occasionally 'blocky', lenticular to tabular greywackes (Table 2.3, (b)).

(3) The uppermost part comprises very thick-bedded (>1m thick) intraclast conglomerates. Bed-geometry is variable, ranging from irregular to tabular (Table 2.3, (a)).

The original stratigraphical thicknesses of these are estimated as follows: (1) 100m to 150m; (2) 400m to 500m; (3) 100m to 150m. A combined thickness of between 600m and 800m. It should be noted that these are only rough estimates as exposure is incomplete and the internal structure of the unit is thus not entirely understood.

Graptolites have not been collected from this Member and thus its biostratigraphical status remains unknown.

(c) The Drumblair Member

The Drumblair Member is best exposed in a series of scattered inland exposures in the vicinity of the junction of the B7005 road and the track to Corwall Farm, approximately 1.5km to the east-northeast of Drumblair. The Member is bounded to the south by a sharp stratigraphical contact with the underlying Alticry Member and to the north by the Garheugh Fault (Fig. 2.1 and Table 2.2).

Sedimentologically the Member is dominated by medium- to thick-bedded (15cm to 55cm thick) tabular greywackes (Table 2.3, (b)).Associated with these are packets (20m thick?) of very thick-bedded amalgamated greywackes (>1m thick) (Tables 2.3

(a)) and 1m to 10m thick packets of laminated siltstone shale and fine sandstone (Table 2.5 and 2.3, (c)). The original stratigraphical thickness of this unit, which youngs continuously northwestwards is estimated at between 200m to 250m.

Graptolites have been collected from this Member by the Palaeontology Division of the B.G.S. and these are indicative of the _turriculatus_ Zone (White 1984) (Fig. 2.3).

2.4.3 Local Correlation

2.4.3.1 The Money Head Formation

The Money Head Formation, which includes sediments with a distinctive pyroxenous petrography (Type E, Chapter 4), is not represented in the Glenluce (NX 2000 5755) to Port William (NX 3380 4350) section.

2.4.3.2 The Float Bay and Kilfillan -A and -B Formations

The Float Bay and Kilfillan -A and -B Formations are sedimentologically closely similar and display similar and at least partly coeval age ranges.

The Float Bay Formation appears to have an _acinaces_ to _gregarius_ Zone age, while the Kilfillan -A and -B

Formations have acuminatus to cyphus Zone age ranges.

2.4.3.3 The Stinking Bight and Garheugh -A Formations

The Stinking Bight and Garheugh -A Formations are correlated principally on the strength of the structural positions they occupy within their respective profiles and their positions with respect to good lithological markers, for example, the Grennan Point and Garheugh -B Formations. The Stinking Bight Formation has a maximum cyphus or triangulatus Zone age, which if the above correlation is correct, would probably also be the approximate maximum age of the Garheugh -A Formation.

2.4.3.4 The Grennan Point and Garheugh -B Formations

The Grennan Point and Garheugh -B Formations are sedimentologically almost identical. They together form a good lithological marker within the study area. In addition to their lithological similarities, the Formations also display comparable maximum biostratigraphical ages. The Grennan Point Formation has a maximum convolutus Zone age, while the Garheugh -B Formation has a maximum gregarius Zone age (Figs. 2.2 and 2.3).

2.4.3.5 The Mull of Logan and Corwall Formations

The Mull of Logan and Corwall Formations each contain several Members and are each of turriculatus Zone age. Correlations between the Members are as follows:

Mull of Logan Fm.	Corwall Fm.
Chair Mbr.	Drumblair Mbr.
Duniehinnie Mbr.	Alticry Mbr.
Daw Point Mbr.	-
Cairnie Finnart Mbr.	Chippermore Mbr.

The Daw Point Member is here considered to have had an originally limited geographical extent. The Duniehinnie and Alticry Members are both conglomeratic and provide an excellent lithological marker within the study area.

2.4.3.6 The Port Logan and Clanyard Bay Formations

Lateral equivalents of these Formations have not been observed in the Glenluce (NX 2000 5755) to Port William (NX 3380 4350) section.

2.4.3.7 Summary

Most, though not all, of the stratigraphical units identified between Cairngarroch Bay (NX 0464 4905) and Clanyard Bay (NX 1010 3800), have been correlated with stratigraphical units exposed between Glenluce (NX 2000 5755) and Port William (NX 3380 4350) (Table 2.5). It is suggested that those units which cannot be correlated, have either been 'cut out' by faulting or were only deposited within a limited area.

Biostratigraphical evidence indicates that the onset of greywacke sedimentation in the northern part of the Central Belt becomes progressively younger in successive tectonostratigraphical units from northwest to southeast (Figs. 2.2 and 2.3).

2.5. REGIONAL CORRELATION

2.5.1 The Southern Part of the Northern Belt

Table 2.4, summarises a correlation scheme, based on Welsh (1964), Floyd (1982), Morris (1983) and Craig (1984), for the stratigraphical units exposed in the southern part of the Northern Belt, in the Southern Uplands/Longford-Down zone. The correlations shown in Table 2.4 , excepting correlations with the North Down area, are consistent with those proposed by Welsh (1964), Floyd (1982) and Morris (1983). The correlations made by Craig (1984) are considered to be erroneous.

LONGFORD-DOWN (Morris 1983)	DOWN (Craig 1984)	RHINNS OF GALLOWAY (Kelling 1961)	GLENLUCE (Welsh 1964)	WEST NITHSDALE (Floyd 1982)
Red Island Fm.	Ballymacormick Block	Portpatrick Fm., Basic-clast Div.	Glenwhan Fm.	Scar Fm.
-	?	Portpatrick Fm., Acid-clast Div.	-	-
-	Orlock Block	Portayew Fm.	Boreland Fm.	Shinnel Fm.

Table 2.4: Regional correlation of the stratigraphical units exposed within the southern part of the Northern Belt in the Southern Uplands/ Longford-Down zone. Correlations are based on information in Morris (1983), Craig (1984), Kelling (1961), Welsh (1964), Floyd (1982) and information collected during the present study.

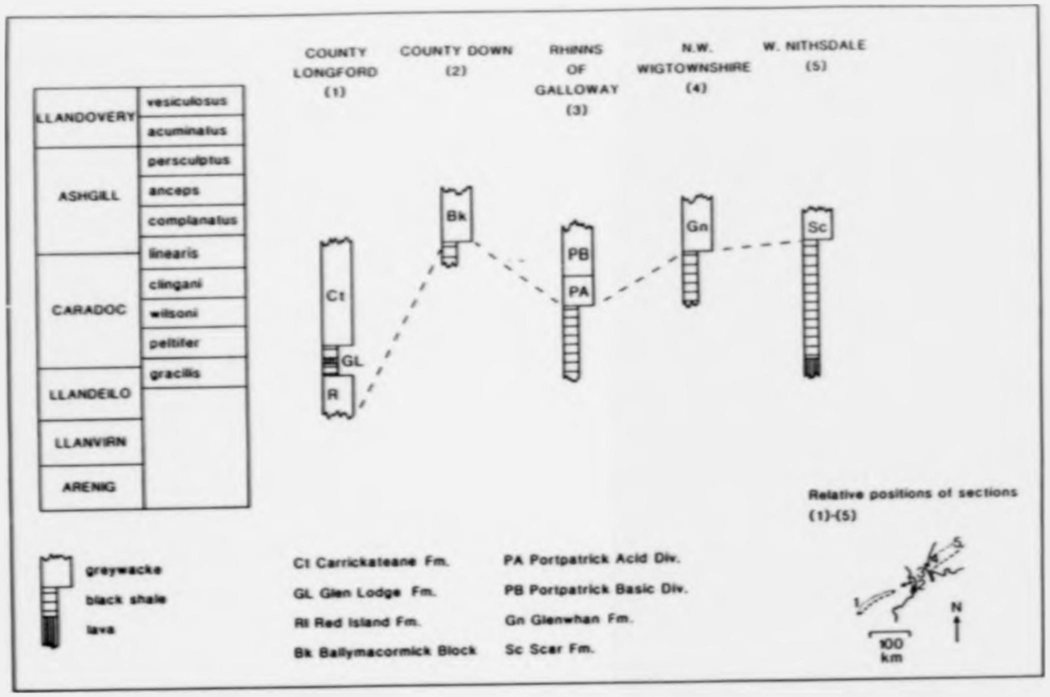


Figure 2.4: Diagram illustrating the along-strike diachronism displayed by the Portpatrick Group and its petrographical equivalents. Compiled from data in Morris (1983), Craig (1984), Kelling (1961) and Floyd (1982) (modified after Kelling et al. 1987).

Craig (1984) correlates the Portpatrick Formation and its correlatives with the Rockport and Grey Point Formations exposed in North Down. These are included within the northernmost 'block' or tectonostratigraphical unit exposed on the North Down coast, a structural position which most certainly is not comparable with that occupied by the Portpatrick Formation on the Rhinns. A close examination of the tectonostratigraphical scheme proposed by Craig (1984, her Fig. 4) and the petrographical data summarized in her Tables 2 and 3 indicate that the Ballymacormick Block is more likely to be the along-strike equivalent of the Portpatrick Formation for the following reasons:

(1) The Ballymacormick Block occupies a similar structural position within the North Down section to the Portpatrick Formation on the Rhinns section.

(2) The greywackes exposed within the Ballymacormick Block are petrographically similar to those exposed within the Portpatrick Formation, containing abundant andesite fragments, pyroxenes and amphiboles (including minor amounts of glaucophane).

It is consequently here suggested that the

Ballymacormick Block represents the lateral equivalent of Portpatrick Formation and that the Ballygrot Block may represent the lateral equivalent of the Corsewall Group of Kelling (1961).

If the above suggestion is correct then the Orlock Block probably represents the lateral equivalent of either the Portayew or the Cairngarroch Formation. This interpretation is incorporated into Table 2.4.

A study of the biostratigraphical ages of the Portpatrick Formation and its along-strike equivalents, indicates that the onset of greywacke sedimentation was diachronous from southwest to northeast (Fig. 2.4).

2.5.2 The Northern Part of the Central Belt

The stratigraphy of the Central Belt within the study area has until recently only been poorly understood. The regional remapping programme of the B.G.S., the work of their Palaeontology Division, the present study and a coeval Ph.D. study undertaken by J.A. McCurry have done much to improve upon this.

Barnes *et al*. (1987) have correlated the stratigraphical units exposed to the east and west of Luce Bay with those exposed on the Ards Peninsula in County Down (see their Fig. 5)(Fig. 1.1).

WEST OF LUCE BAY	EAST OF LUCE BAY	PEEBLESSHIRE (Walton 1955)
Money Head Fm.	-	Pyroxenous Group
Float Bay Fm.	Kilfillan -A Fm. Kilfillan -B Fm.	Intermediate Group
Stinking Bight Fm.	Garheugh -A Fm.	
Grennan Point Fm.	Garheugh -B Fm.	
Mull of Logan Fm.	Corwall Fm.	
Port Logan Fm.	(not identified)	
Clanyard Bay Fm.	(not identified)	

Table 2.5: Correlation of stratigraphical units exposed within the northern part of the Central Belt. For correlations with the stratigraphical units exposed on the Ards Peninsula see Barnes *et al*. (1987).

Petrographical studies (see Chapter 4) have identified a pyroxenous stratigraphical unit within the northern most part of the study area in the corridor situated to the west of Luce Bay. This stratigraphical unit, referred to as the Money Head Formation, may be a lateral equivalent of Walton's (1955) Pyroxenous Group. It is suggested, on petrographical data, that the rest of the stratigraphical units exposed within the study area are lateral equivalents of the Intermediate Group (Walton 1955) since they contain neither substantial amounts of pyroxene nor garnet, indicative of the Pyroxenous and Garnetiferous Groups respectively (Section 4.6.2).

2.6. SUMMARY

The sediments exposed within each of the study corridors have been subdivided into a series of stratigraphical units. Most of the stratigraphical units have lateral equivalents in the opposing corridor; some, however, do not (e.g. the Portpatrick Formation, Acid-clast Division and the Money Head Formation). These may have been structurally excised, or, may have only been deposited in a limited geographical area.

It is suggested that the maximum age of the stratigraphical units probably becomes progressively younger, from tract to tract, towards the northwest in the southern part of the Northern Belt. In the northern part of the Central Belt the reverse is true.

The stratigraphical units observed within the study area have been correlated with others recognized within the Southern Uplands Longford-Down zone. These regional correlations are summarised in Tables 2.4 and 2.5. A regional comparison of the ages of the Portpatrick Formation and its along-strike equivalents suggests that the onset of Portpatrick-type sedimentation was diachronous from southwest to northeast.

CHAPTER 3

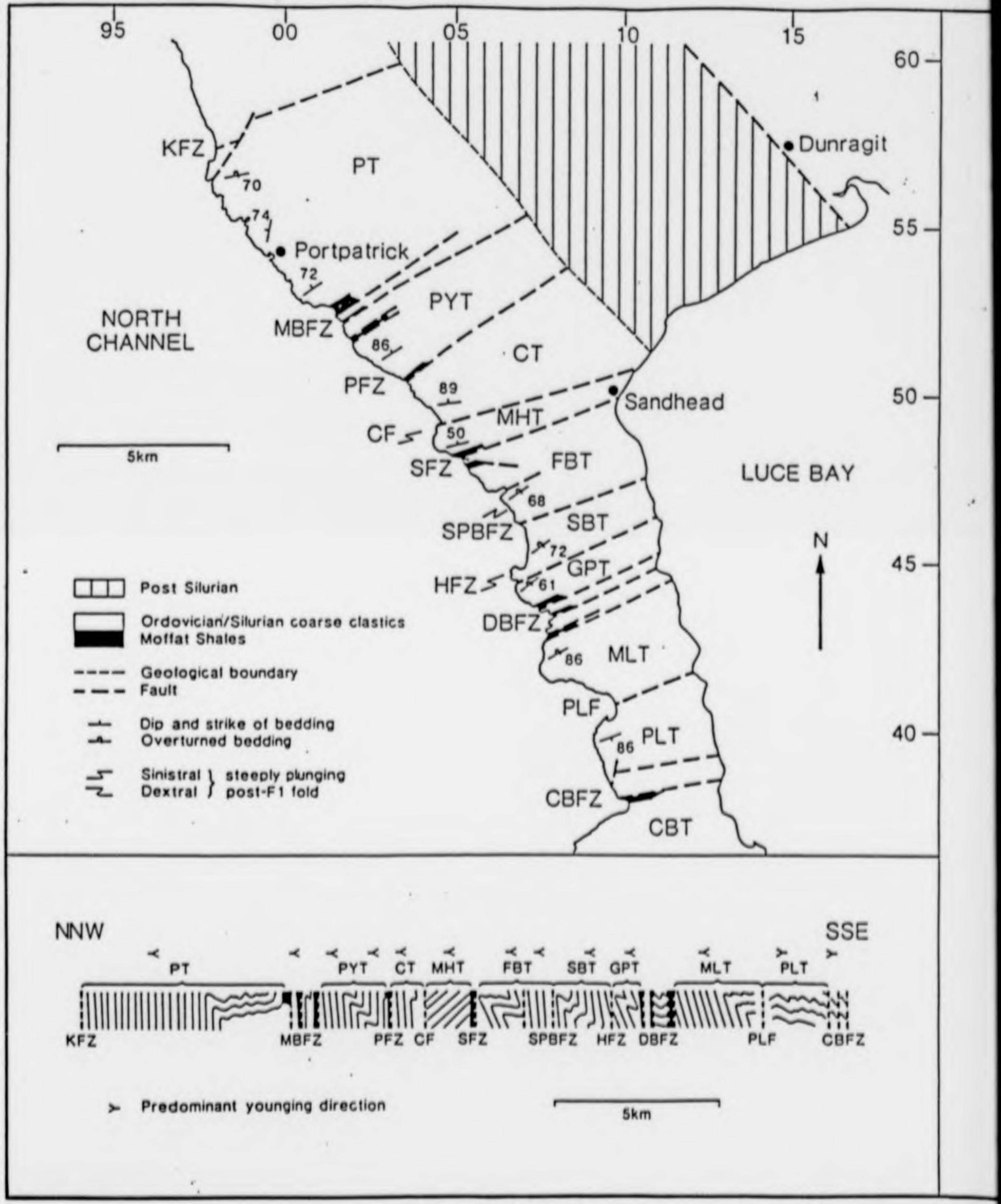
STRUCTURE

3.1 GENERAL

Structural studies in southwestern Scotland have recognized that major strike-faults act as the boundaries to discrete and internally deformed tracts (Kelling 1961; Gordon 1962; Welsh 1964; Barnes et al. 1987), a structural style which is exhibited by the Lower Palaeozoic rocks throughout the Southern Uplands (McKerrow et al. 1977; Leggett et al. 1979). In most contemporary structural models (Knipe and Needham 1986; Stone et al. 1987; Morris 1987) the Southern Uplands as a whole represents an imbricate thrust-stack, and each of the major strike-faults represents an individual thrust. Recent geotectonic models have suggested a variety of plate tectonic settings in which the imbricate zone might have developed, ranging from an accretionary forearc (McKerrow et al. 1977; Leggett et al. 1979) to a back-arc setting (Morris 1987; Stone et al. 1987).

This chapter is directly concerned with the structure of the rocks exposed within the two study corridors (Figs. 1.1, 3.1 and 3.2). The deformation structures

Figure 3.1: Map, section and stereograms illustrating the main structural characteristics of the central Rhinns of Galloway. KFZ, Killantringan Fault Zone; MBFZ, Morroch Bay Fault Zone; PFZ, Portayew Fault Zone; CF, Cairngarroch Fault; SFZ, Strand-foot Fault Zone; SPBFZ, Salt Pans Bay Fault Zone; HFZ, Hooies Fault Zone; DBFZ, Drumbreddan Bay Fault Zone; PLF, Port Logan Fault; CBFZ, Clanyard Bay Fault Zone; PT, Portpatrick Tract; PYT, Portayew Tract; CT, Cairngarroch Tract; MHT, Money Head Tract; FBT, Float Bay Tract; SBT, Stinking Bight Tract; GPT, Grennan Point Tract; MLT, Mull of Logan Tract; PLT, Port Logan Tract; CBT, Clanyard Bay Tract.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Portpatrick
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NORTH CHANNEL
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SFZ
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SPBFZ
SBT
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GPT
HFZ
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DBFZ
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MLT
PLF
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CBFZ
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Overturned bedding
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Dextral } post-F1 fold
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PYT
CT
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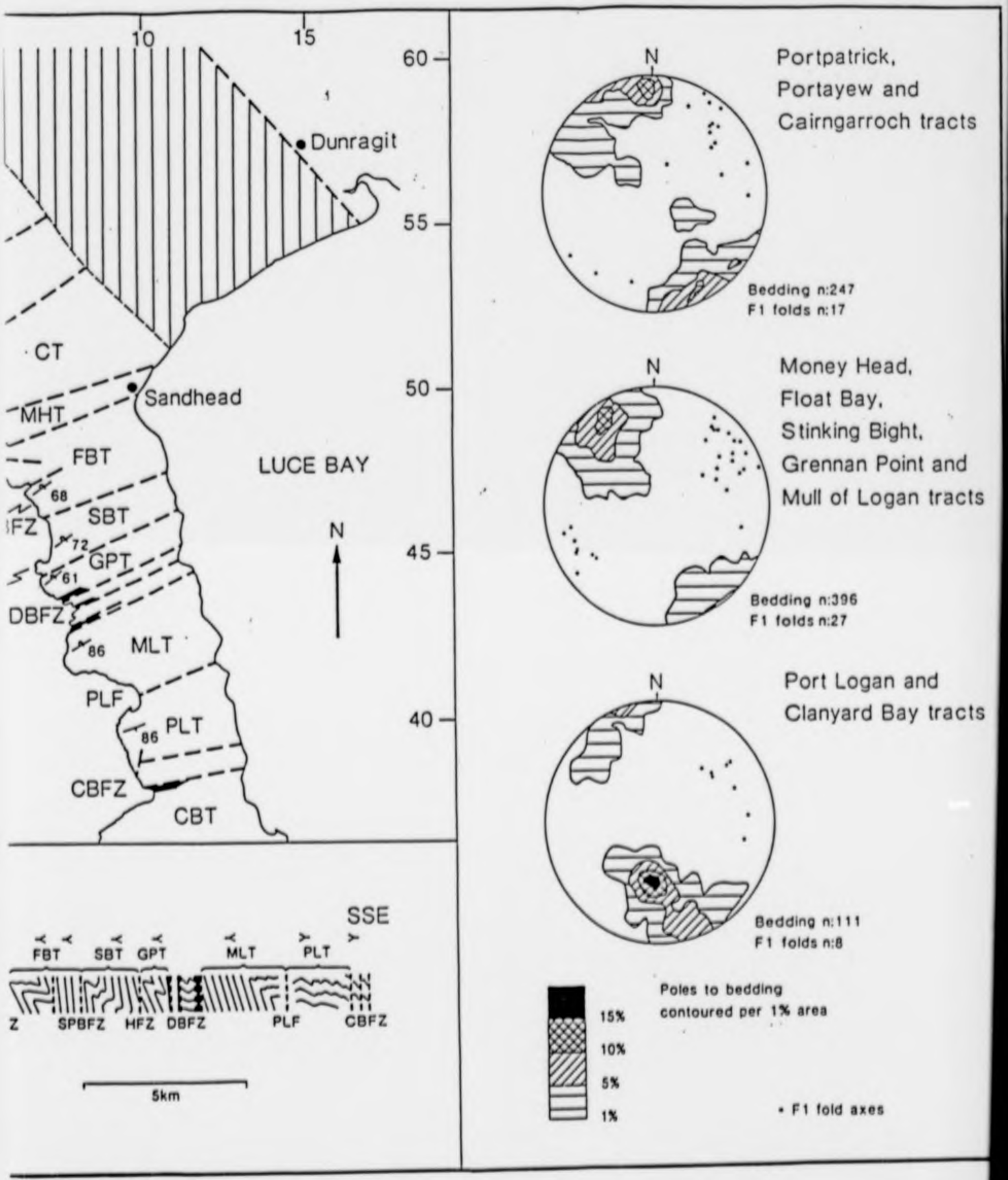
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Portpatrick,
Portayew and
Cairngarroch tracts
Bedding n:247
F1 folds n:17
N
Money Head,
Float Bay,
Stinking Bight,
Grennan Point and
Mull of Logan tracts
Bedding n:396
F1 folds n:27
N
Port Logan and
Clanyard Bay tracts
Bedding n:111
F1 folds n:8
Poles to bedding
contoured per 1% area
15%
10%
5%
1%
• F1 fold axes

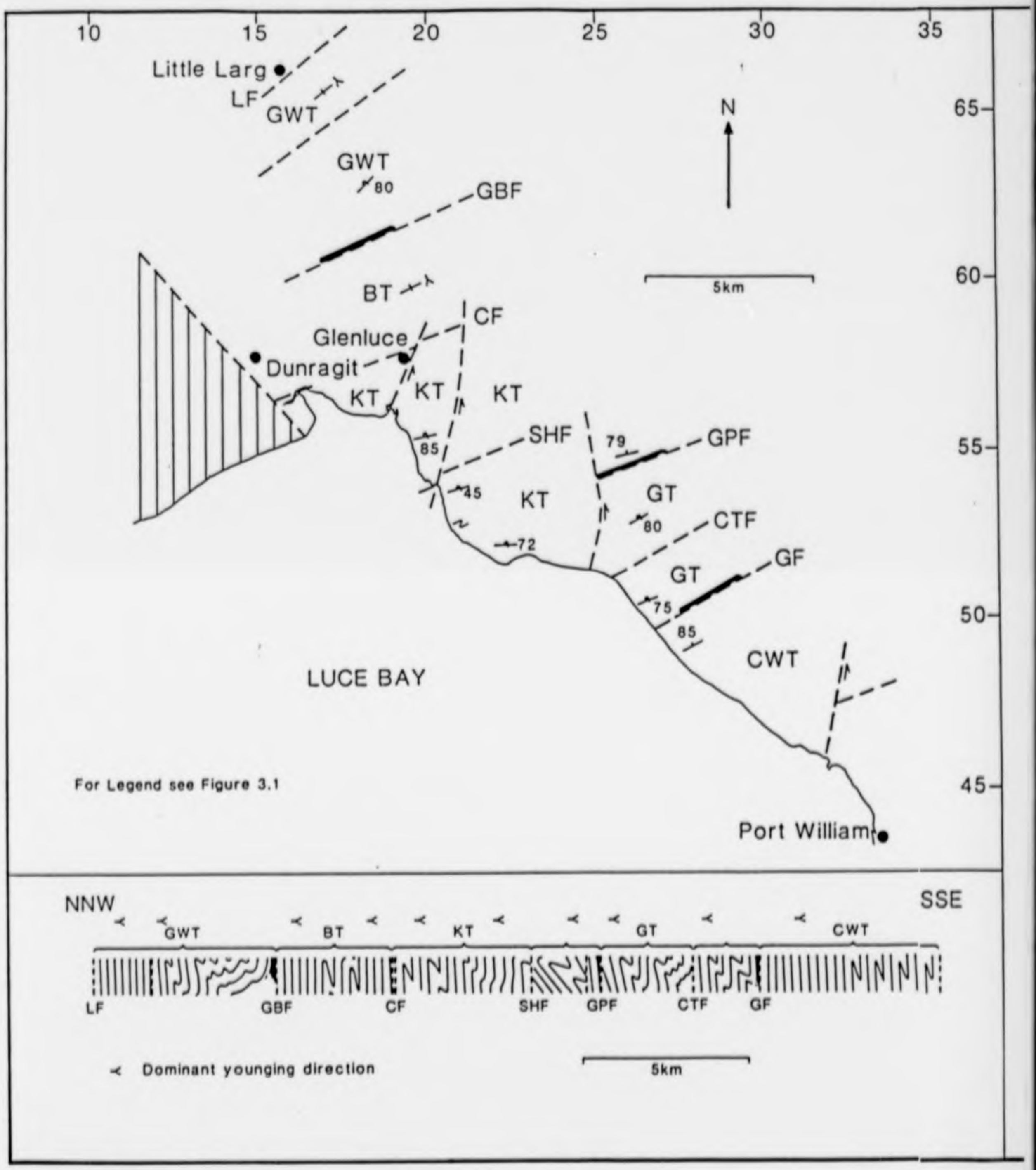
identified within these are described and the deformation history is discussed. A structural correlation between the two corridors is presented.

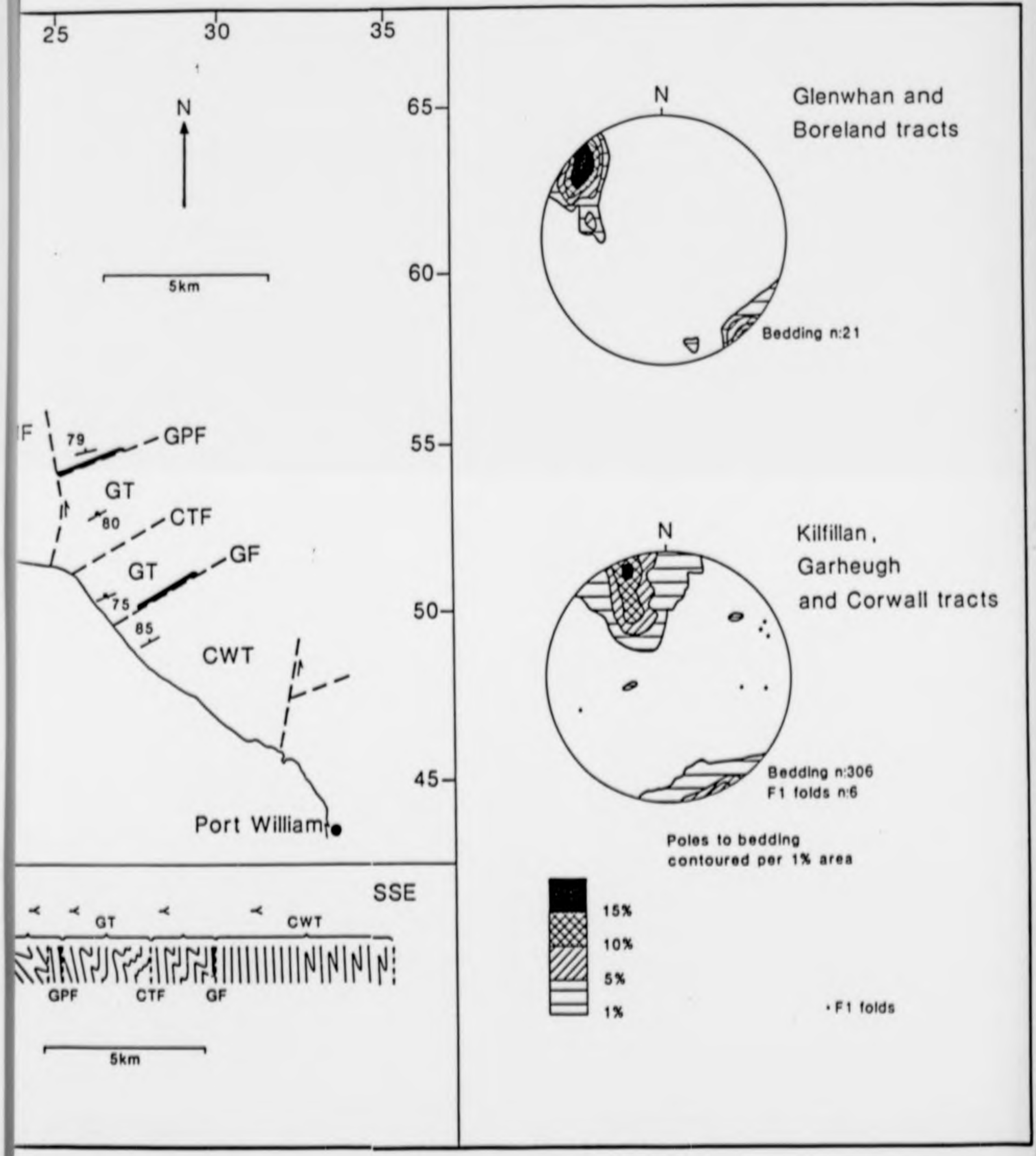
3.2 DEFORMATION HISTORY AND STRUCTURES

The deformation history of the Southern Uplands of Scotland was first fully described by Rust (1965), from a detailed study of the Hawick Rocks exposed on the Whithorn peninsula. Rust (1965) proposed a complicated sequence of deformation events involving numerous phases of folding and faulting. Weir (1968) studied the rocks exposed along strike in the Kirkcudbright area and confirmed the deformation history proposed by Rust (1965). More recent studies, principally those of Anderson and Cameron (1979), Stringer and Treagus (1980, 1981) and Knipe and Needham (1986), have however contested this view of the deformation history, proposing instead sequences involving just two or three phases of deformation.

It is currently accepted that deformation within the Southern Uplands was both diachronous from northwest to southeast (Anderson and Cameron 1979; Oliver and Leggett 1980) and progressive (Eales 1979; Knipe and Needham 1986). The simple classification of structures used in this study takes these factors into account and accepts that transitional structures are present.

Figure 3.2: Map, section and stereograms illustrating the main structural characteristics of the area to the east of Loch Ryan and Luce Bay. LF, Little Larg Fault; GBF, Gabsnout Burn Fault; CF, Cairngarroch Fault; SHF, Stair Haven Fault; GPF, Gillespie Burn Fault; CTF, Craignarget Fault; GF, Garheugh Fault; GWT, Glenwhan Tract; BT, Boreland Tract; KT, Kilfillan Tract; GT, Garheugh Tract; CWT, Corwall Tract.


For Legend see Figure 3.1


25
30
35
65
60
55
50
45
N
5km
F
79
GPF
GT
80
CTF
GT
GF
75
85
CWT
Port William
SSE
GT
CWT
GPF
CTF
GF
5km
N
Glenwhan and Boreland tracts
Bedding n:21
N
Kilfillan, Garheugh and Corwall tracts
Bedding n:306
F1 folds n:6
Poles to bedding contoured per 1% area
15%
10%
5%
1%
• F1 folds

The structures exposed within the study transects have been subdivided into three groups based on field data and on the structural subdivisions presented in Knipe and Needham (1986):

(1) early deformation structures (pre-D1),
(2) main deformation structures (D1),
(3) late deformation structures (post-D1).

The structures included within each of these subdivisions are described below and their origins are discussed.

3.2.1 Early deformation structures (pre-D1)

3.2.1.1 Description

This group of structures includes slump folds and soft-sediment faults, and is equivalent to the group of downslope gravity-driven structures described by Knipe and Needham (1986). Slump folds and soft-sediment faults are usually found closely associated with each other in slump sheets.

The slump sheets observed within the study transects most commonly exhibit thicknesses ranging between 10cm and 3m. However, there is evidence for larger scale slumping and slump sheets may attain thicknesses of 450m. Slump sheets with lateral continuities in excess of 40m have been observed.

The identification of a slump sheet depends on factors such as the recognition of an eroded upper surface, or of undeformed dewatering conduits passing through the deformed mass, or proof that the supposed slump sheet has been deformed by "main deformation structures" (D1).

Extensional structures are commonly found towards the rear of a slump sheet, whereas compressional structures are found towards the front (Fig.3.3). Figure 3.4 shows an example from the study area which displays this lateral relationship.

Extensional structures have been recognized at several localities. Normal faults, some of which are listric, and boudinaged sandstone horizons are common (Figs. 3.4 and 3.5). Some listric structures seem to penetrate down to decollement horizons upon which the slump sheets have moved (Fig. 3.4). Other faults terminate stratigraphically downwards in beds of greywacke (Fig. 3.5). Slight block rotation is sometimes evident (Fig. 3.5).

Compressional structures are exposed at several localities.. Thrusts and slump folds are commonly developed (Figs. 3.4 and 3.6). The thrusts often splay upwards from a basal decollement horizon (Fig. 3.6).

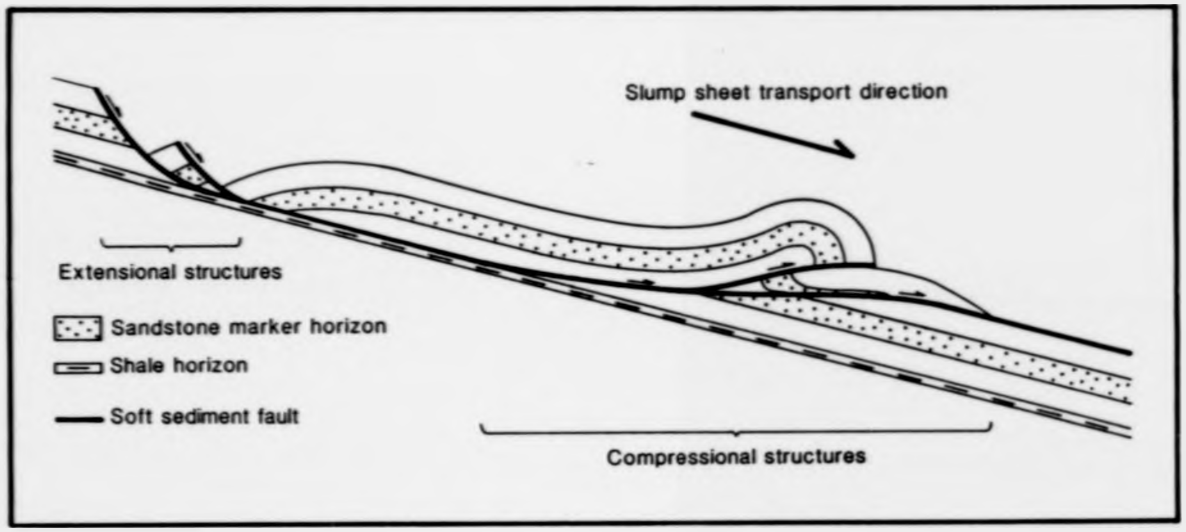


Figure 3.3: Diagrammatic section through a slump sheet showing the upslope and downslope relationships between extenstional and compressional structures.

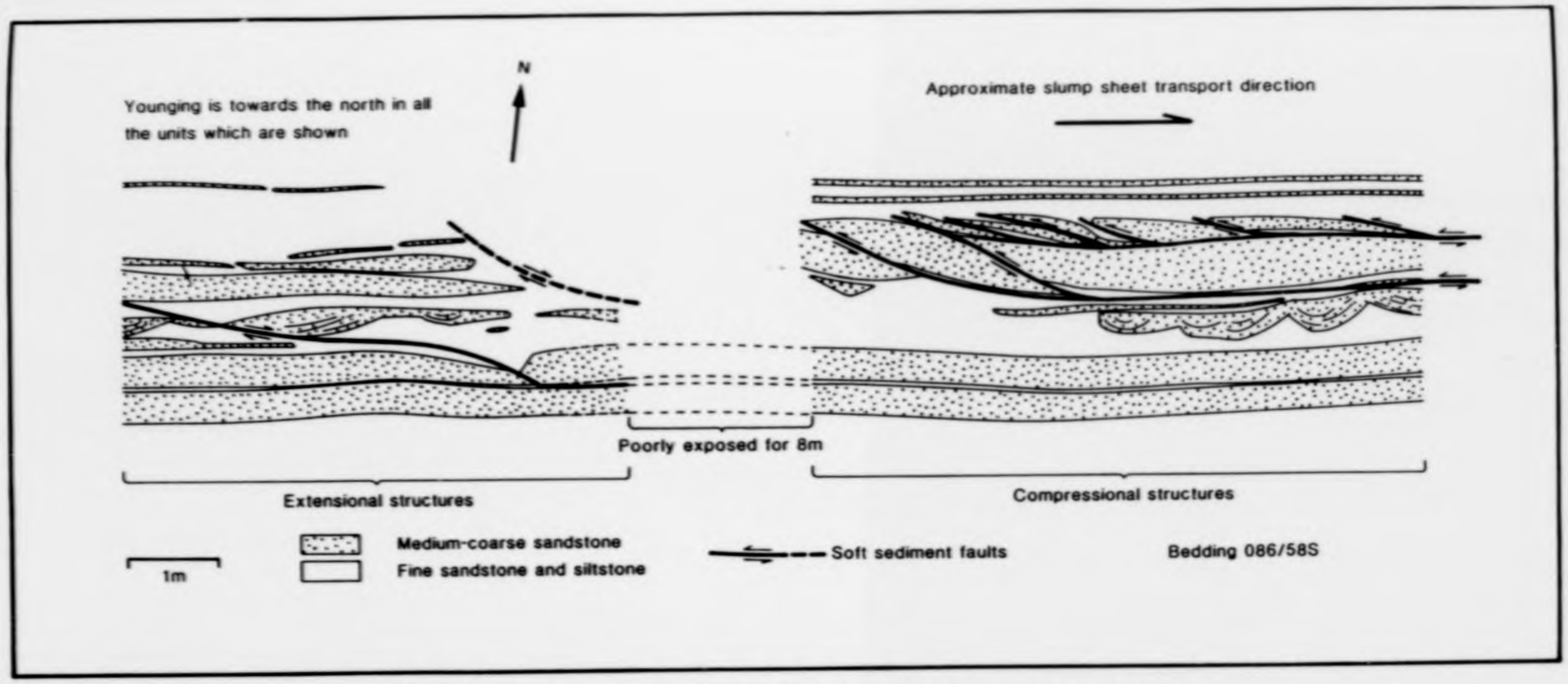


Figure 3.4: Measured sketch illustrating extensional and compressional slump structures developed within a single slump sheet. Extension is marked by boudinage and listric faults which cut down to a basal decollement surface, while compression is marked by backthrusting. Kilfillan -B Formation, 1.4km south of Stairhaven (NX 2070 5374).

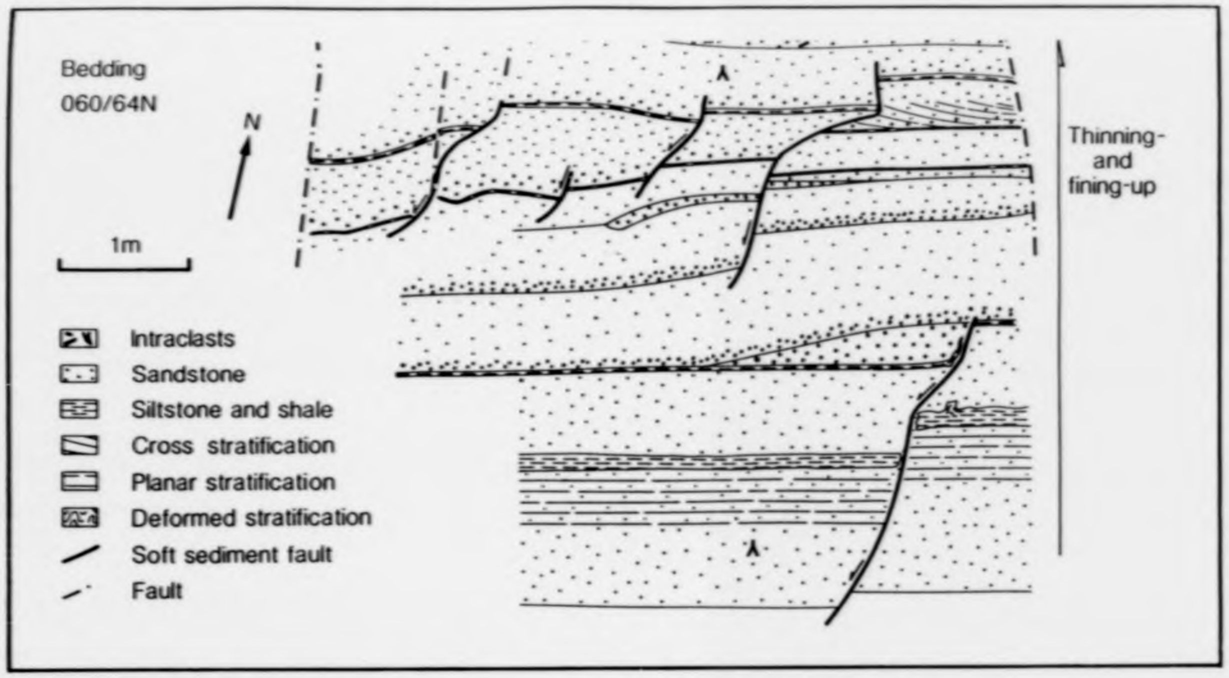


Figure 3.5: Measured sketch illustrating soft sediment normal faults developed within a channel sequence. Note that many of the faults terminate downwards in beds of greywacke. Note also the slight block rotation which accompanies some of the faults. These structures may be related to channel bank failure. Money Head Formation (NX 0485 4833), 300m north of Strand-foot (NX 0700 4620).

Slump folds are usually asymmetric and some slump sheets have been affected by more than one slump folding event (Fig. 3.6).

Some slump sheets have clearly lost their internal coherence during slumping, thus producing debris flow deposits (Fig. 3.7).

3.2.1.2 Structural development

It is generally accepted that slump sheets are developed as a result of the complete failure, downslope movement and deformation of coherent bodies of sediment on slopes which are as shallow as 0.5°. Immediately prior to, and upon failure, extensional structures are developed. Movement commonly occurs on a basal decollement surface of siltstone and, or shale. As the slump sheet decelerates compressional structures are formed.

It is suggested that the slump sheets observed within the study area were related to palaeoslopes of two kinds:

(1) Palaeoslopes created as a result of sedimentological processes, e.g. slopes associated with channel banks, levees and lobes.

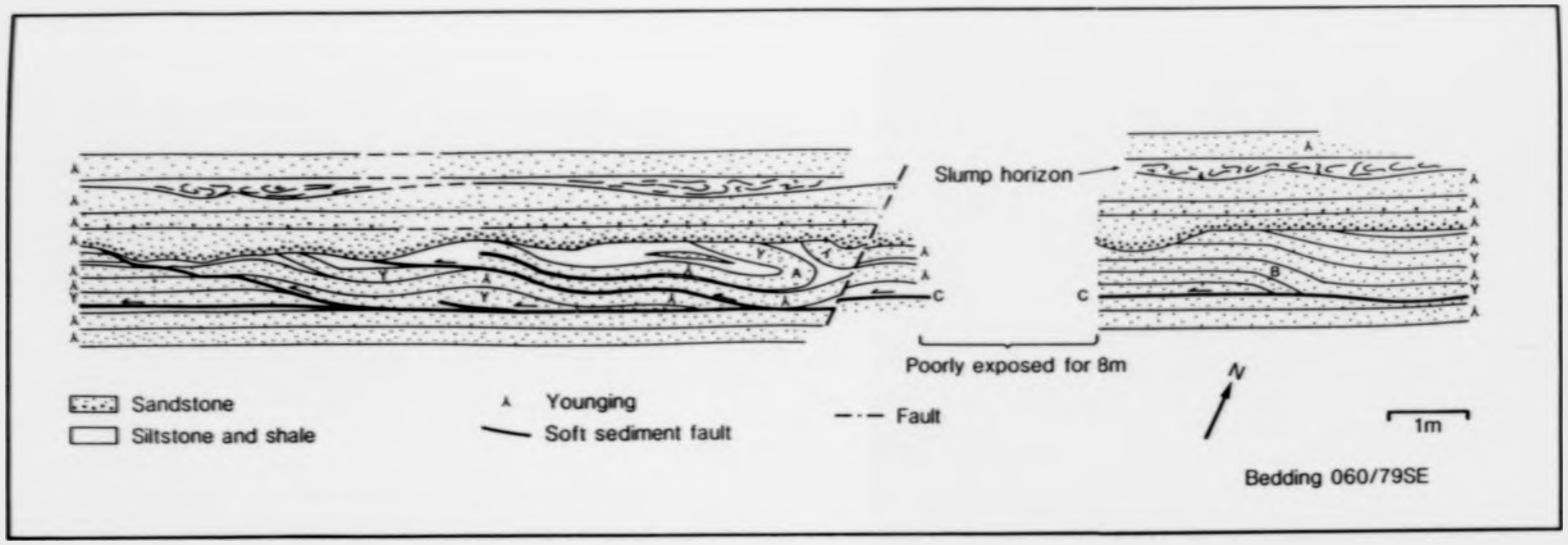


Figure 3.6: Measured sketch of compressional structures; soft sediment thrusts and folds. The thrusts splay upwards from a basal decollement horizon (c). Two types of fold are evident: (A) tight recumbent folds, probably developed during transportation of the slump sheet, and (B) open folds, probably developed as the slump sheet come to rest. Note that the upper surface of the slump sheet has been eroded. Grennan Point Formation, rocky point in Drumbreddan Bay (NX 0781 4370).

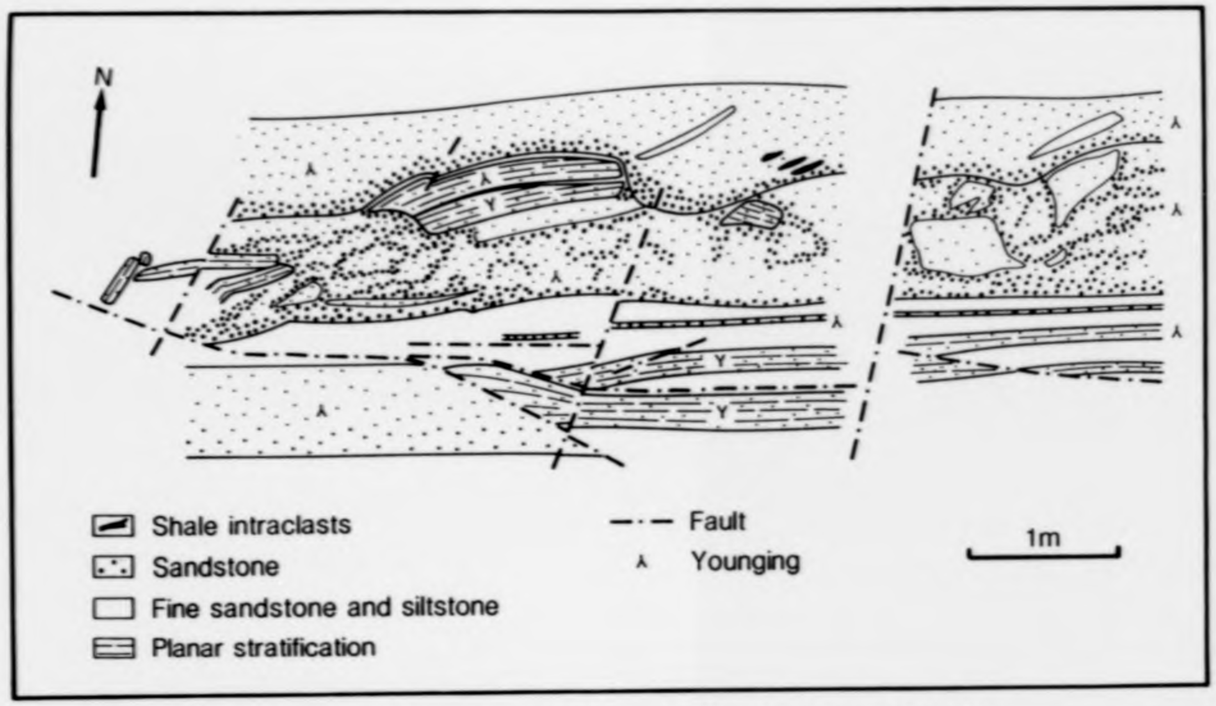


Figure 3.7: Measured sketch of debris-flow deposit, developed as a result of a loss of internal coherence of a slump sheet during transportation. Note the presence of a remnant fold closure (upper centre). Portpatrick Formation, Hairyhorroch Member, 800m south of Killantringan Bay (NW 9820 5700).

(2) Palaeoslopes created as a result of tectonic processes, e.g. slopes associated with the development of the imbricate thrust stack.

In order to ascertain whether slumping was related to a type (1) or (2) palaeoslope the orientations of the component slump stuctures must be analysed, since these hold the only real clue. Examination of the component structures within a slump sheet can reveal its transport direction and thus the approximate orientation of the palaeoslope (Jones 1940; Woodcock 1979). The movement direction of a slump sheet is assumed to have been perpendicular to the mean axis of the component slump folds, and generally in the same direction as fold vergence. The mean strike of the associated faults, both extensional and compressional, is assumed to be perpendicular to the movement direction of the slump sheet (Farrell 1984). It is suggested that the following criteria might be usefull in determining which type of slope was responsible for the generation of the various slump sheets:

(1) Slump sheets related to sedimentary processes are expected to contain evidence of transport down a wide range of slope orientations.

(2) It is suggested that slump sheets related to tectonic processes will probably contain evidence of transport down north-northwest or

south-southeast oriented slopes, since the dominant tectonic structures within the study area (the D1 structures) display east-northeasterly trends.

Figure 3.8 shows the reorientated plunges of slump folds and orientations of soft sediment faults from throughout the study area. It is clear, particularly from the wide scatter of fold plunge directions, that slopes with a wide variety of orientations were responsible for generating the slump structures. These slopes may have been related to both tectonic and sedimentological processes.

3.2.2 Main deformation structures (D1)

3.2.2.1 Description

This group of structures includes the majority of the strike-faults exposed within the study area (Fig. 3.1 and 3.2).

D1 Strike-faults

The vast majority of the east-northeast trending strike-faults exposed within the study area are thought to be back-rotated thrusts (Needham and Knipe 1986; Barnes *et al*. 1987: Figs. 3.1 and 3.2) Recognition of the major thrusts depends on the

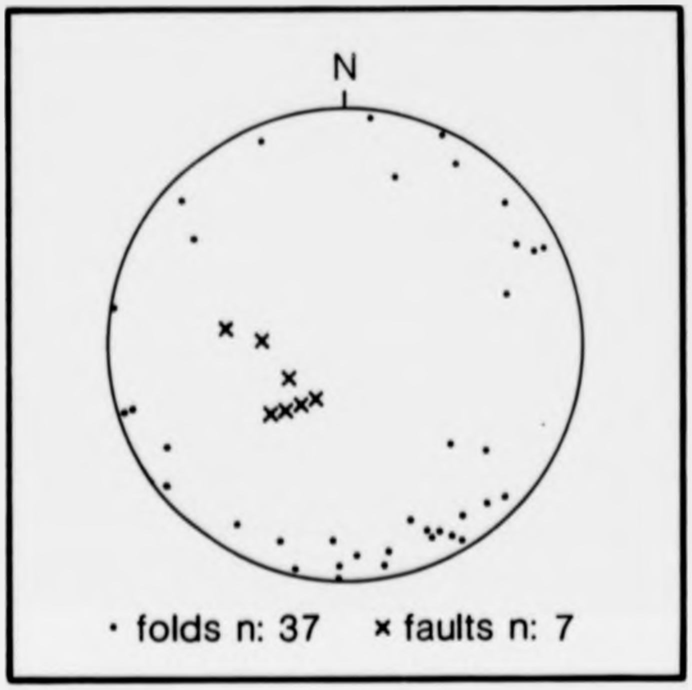


Figure 3.8: Stereogram of reorientated slump fold plunges and soft sediment fault orientations, from throughout the study area. Reorientation achieved by simply removing bedding.

identification of biostratigraphical, sedimentological and/or structural contrasts in adjacent greywacke sequences, testifying to substantial displacements on the inferred and observed faults.

The major and minor thrusts generally display steep or vertical inclinations. Two major thrusts, the Killantringan and Portayew Thrusts, were originally considered to be low-angle structures (Kelling 1961). Comparison with other fault zones exposed in the area, however, indicate that these structures are probably steeply inclined fault-zones which are cut by numerous minor low-angle fractures related to a later (post-D1) phase of deformation.

The major back-rotated thrusts act as the boundaries to discrete fault-bounded tracts (Figs. 3.1 and 3.2). They are commonly traced by imbricated Moffat Shale lithologies. Individual thrusts are marked by a range of deformation structures including anastomosing fault networks, shatter zones, and zones of boudinage. Citing examples from the Killantringan Fault Zone, Knipe and Needham (1986) suggest that some thrusts display a range of deformation features, indicative of deformation under a range of physical conditions (their Figs. 6 and 7). The deformation zones associated with individual faults range in thickness between 0.5m and 15m. Quartz veining is usually closely associated with the major thrusts.

Most of the major thrusts downthrow to the southeast. However, some, particularly those exposed or inferred in the southern part of the Rhinns of Galloway (Figs. 3.1 and 3.2), downthrow to the northwest (Barnes et al. 1987).

Minor strike-faults have been identified within the fault-bounded tracts. Many of these are here considered to be back-rotated thrusts. These structures are usually marked by 1cm to 10cm developments of intensely sheared shale and scaly clay gouges. Good thrust geometries are displayed by some of the better exposed of these structures (Fig. 3.9).

D1 Folds

The majority of the folds exposed in the study area are considered to be main deformation structures. They are simply referred to as F1-folds and are equivalent to the F1 structures described by Rust (1965) and Stringer and Treagus (1981).

The F1-folds are usually upright and asymmetric; they exhibit wavelengths of between 0.5m and 400m and plunge at shallow to moderate angles towards the northeast and southwest. The folds are usually open to isoclinal, exhibit rounded to angular closures, and most commonly display flattened-parallel morphologies (Plate 3.1).

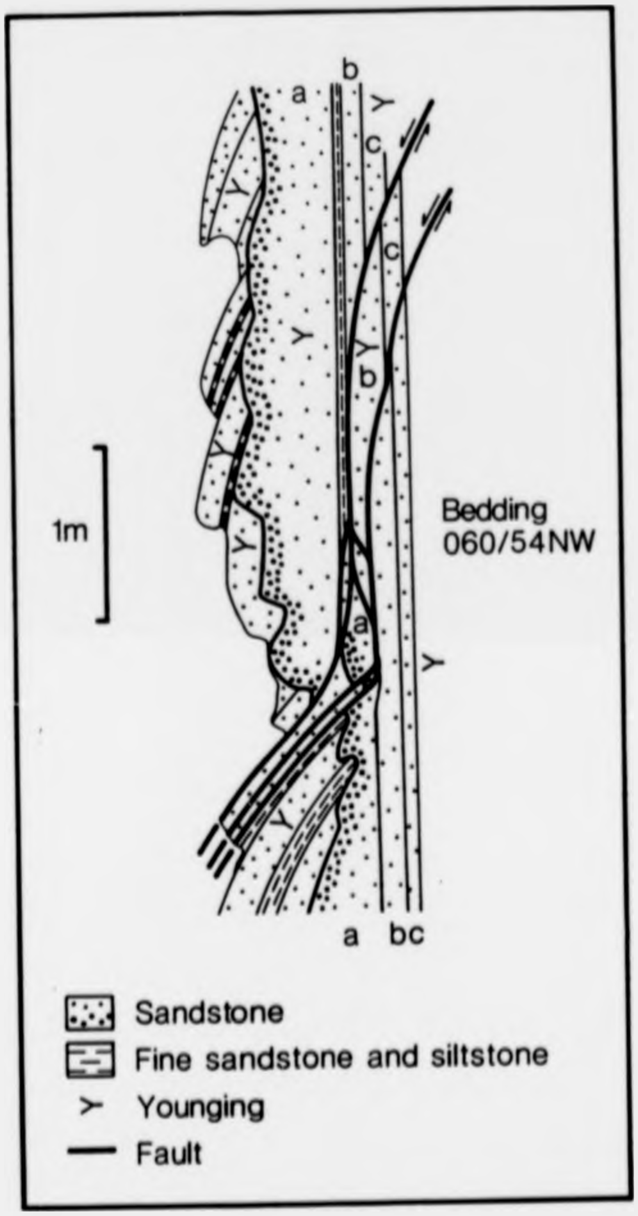


Figure 3.9: Measured sketch illustrating a minor D1 thrust. Note that the thrust cuts a slump horizon. Garheugh -B Formation, 700m west-southwest of Garheugh (NX 2738 5040).

Plate 3.1: Typical morphology of an F1 fold. View to northeast Quarry Bay (NX 0922 4032). Hammer for scale.

Accommodation structures are present in the cores of many folds (Plates 3.2 and 3.3).

A penetrative cleavage (S1) associated with the F1-folds is locally developed. The cleavage commonly transects the F1-fold axial planes in a clockwise manner, but is axial planar to some folds, particularly in the Ordovician tracts (Needham 1984; Barnes et al. 1987).

For the most part the F1-folds verge towards the southeast. However, in the southern part of the Rhinns of Galloway they verge predominantly towards the northwest (Figs. 3.1 and 3.2) (Barnes et al. 1987).

3.2.2.2 Structural development

The F1-fold axial traces are aligned parallel to the major and minor strike-faults implying that all were formed under the same compressive stress regime. At several localities (e.g. the south side of Grennan Bay (NX 0750 43751)) F1-folds are cut by strike-faults, suggesting that, at least in some instances, folds were developed prior to thrusting. The present-day attitude of the D1 thrusts is attributable to post formation rotation (Knipe and Needham 1986).

The non-axial-planar cleavage (S1) recognized within the study transects, has been noted from most areas

Plate 3.2: Typical F1 folds, note the development of accommodation structures in the fold to the left of the Plate. View to the northeast. Bonny Well Bay (NX 0855 4162). Hammer for scale.

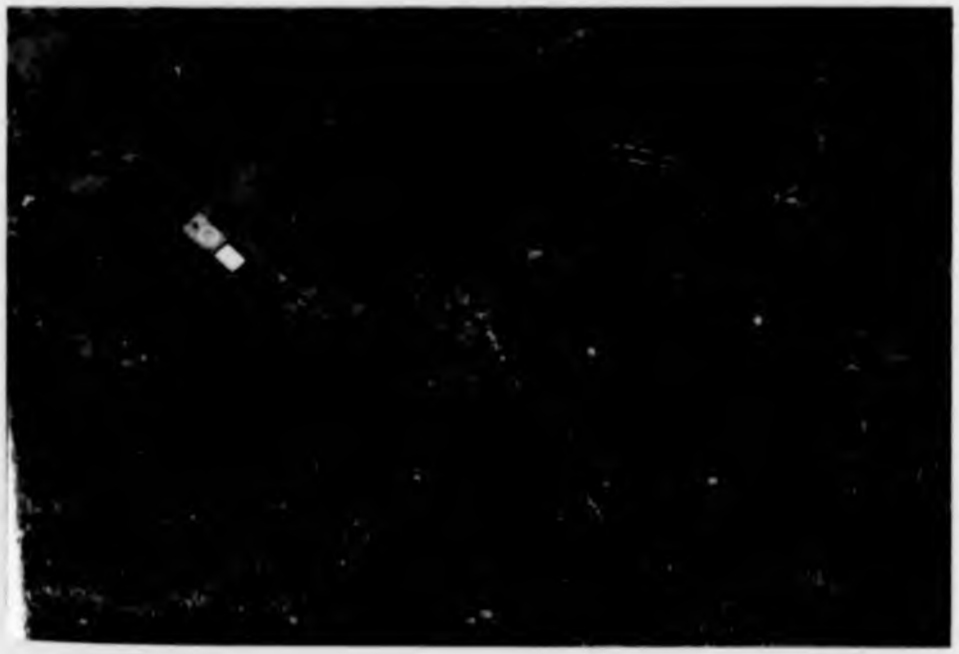


Plate 3.3: Accommodation structures developed within the core of an F1 fold. View down plunge to the northeast. Quarry Bay (NX 0922 4032). Compass for scale.

within the Southern Uplands (Stringer and Treagus 1980, 1981; Soper and Hutton 1984). It was probably imposed after early folding and initial rotation of bedding in a sinistral shear regime (Leggett and Casey 1982; Anderson 1987).

The downthrow directions on the major strike-faults suggest that overthrusting was predominently towards the southeast, and that overthrusting towards the northwest was only locally important. Barnes _et al_. (1987) interpret the northwest-directed D1 thrusts as back-thrusts.

3.2.3 Late deformation structures (post-D1)

This group includes a variety of fault and fold types. Wrench and thrust faults are included in addition to gently- and steeply-plunging folds.

3.2.3.1 Descriptions

Post-D1 Thrusts

Minor, gently inclined thrusts occur within both study corridors. The thrusts dip both to the northwest and to the southeast. Movement on the northwest dipping structures is directed to the southeast and _vice versa_. The thrusts are often marked by 1m wide breccia zones and quartz veining.

The appearance of these structures within some of the D1 strike-fault zones (e.g. the Killantringan and Portayew Fault Zones), has led to their interpretation as major, gently inclined D1 thrusts.

Post-D1 Wrench Faults

Two distinct types of wrench fault are exposed within the study area: (1) Those which have been developed in response to the strike-slip reactivation of older structures, particularly the D1 strike-faults, and (2) Those which have been formed independently of the older structures. Examples of wrench reactivated D1 strike-faults include structures exposed within the Salt Pans Bay and the Hooies Fault Zones, and the Cairngarroch Fault (Anderson and Oliver 1986). Relative lateral displacements are difficult to measure, but if Anderson and Oliver (1986) are correct with their estimate of the movement on the Cairngarroch Fault, the displacements may range up to 400km. The very intense deformation witnessed on the Cairngarroch Fault, particularly in Ireland is testimony to a substantial displacement. However the deformation is exceptional on this type of fault and the movement on other such structures in the area was probably much less.

A range of deformation fabrics and structures are associated with type (1) wrench faults. At the very least the rocks are shattered and brecciated. The fabric along some faults comprises a network of anastomosing subvertical shear fractures, which slice the rocks into lenticular blocks. Where best developed the fractures are traced by shaley films of up to 10cm in thickness. This type of fault fabric dominates the Cairngarroch Fault Zone ("Zone 1" of Anderson and Oliver 1984, their Fig. 3d). The most intensely deformed fault fabrics associated with wrenches, and displayed within the study transects, occur in association with the Cairngarroch Fault. The fabrics are strongly foliated and quartz veined ("Zone 2" of Anderson and Oliver 1986).

In some fault zones steeply-plunging folds are clear testimony to wrench reactivation (e.g. the Hooies Fault Zone, Fig. 3.10). Boudins related to initial D1 thrusting may, in some instances, be rotated (e.g. the Salt Pans Bay Fault Zones).

Type (2) wrench faults exhibit shattered and brecciated fault zones. Quartz veining is common along many of these late strucures.

The wrench faults exposed within the study area display a variety of orientations (Fig. 3.11). Type (1) faults are strike-parallel. Examination of the fabrics and structures associated with these faults indicates that

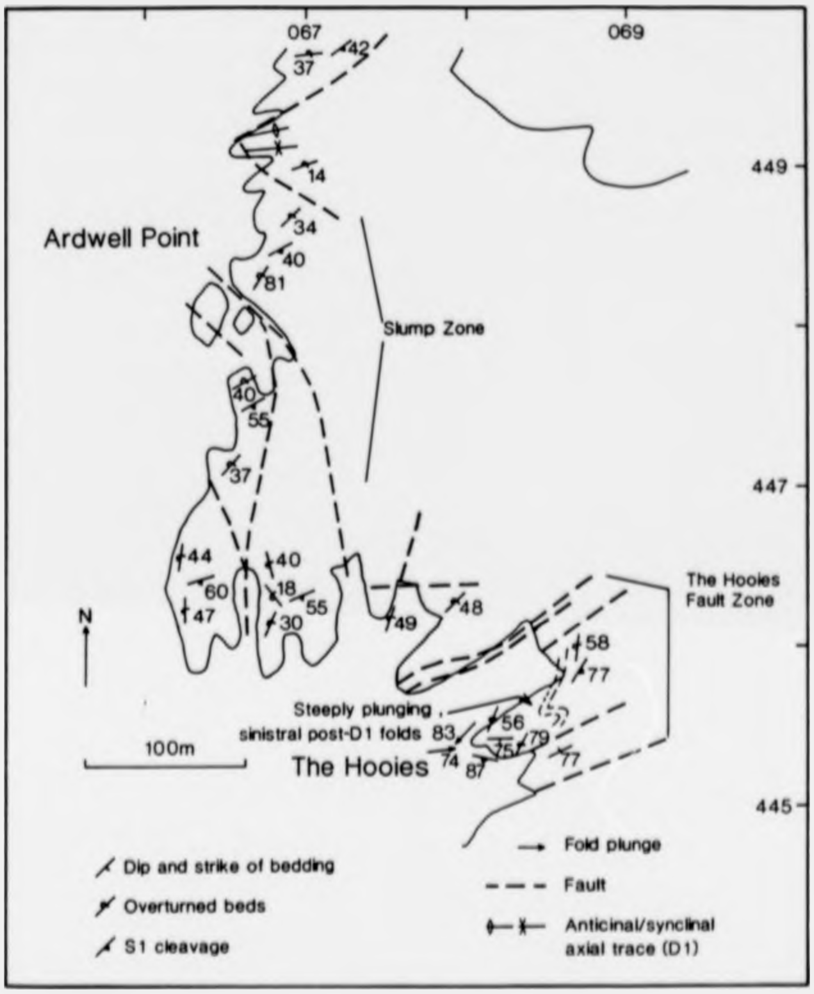


Figure 3.10: Sketch map of the area around the Hooies Fault Zone. The map shows the development of post-D1 steeply-plunging folds within the Fault Zone and also illustrates a probable major slump unit, exposed just to the north of the Fault Zone. Deformation to the north of the Fault must have a pre-D1 age, since the orientation of the S1 cleavage remains constant, while the strike of bedding swings from northeast-southwest to north-south.

they are mainly sinistral, although dextral displacements are sometimes evident. Type (2) faults exhibit both sinistral and dextral displacements. The sinistral faults mainly occupy north to south orientations, whereas the dextral faults exhibit northwest to southeast orientations (Fig.3.11). The faults form a conjugate set of structures and appear to have been formed as a result of north-northwest to south-southeast compression.

Post-D1 folds

The post-F1 folds which are exposed within the study area are of two types:

(1) Steeply-plunging folds; these are generally closely associated with the reactivated strike-faults (e.g. the Hooies and Salt Pans Bay Fault Zones, Fig. 3.10).

(2) Shallowly- to moderately-plunging folds; these display both upright and sub-horizontal axial surfacesand in some instances refold the main deformation folds (Fig. 3.12). The recumbent stuctures are closely related to the post-D1 thrusts described above (Fig. 3.12).

All post-D1 folds deform the regional S1 cleavage and

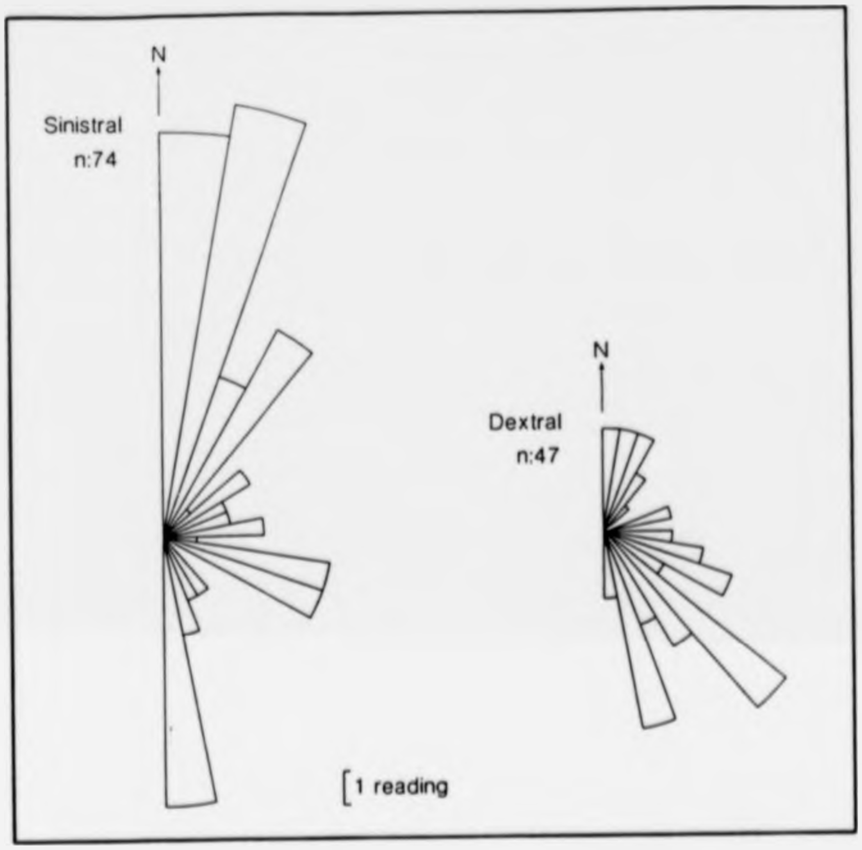


Figure 3.11: Diagrams illustrating the orientations of the post D1, sinistral and dextral wrench faults within the study area.

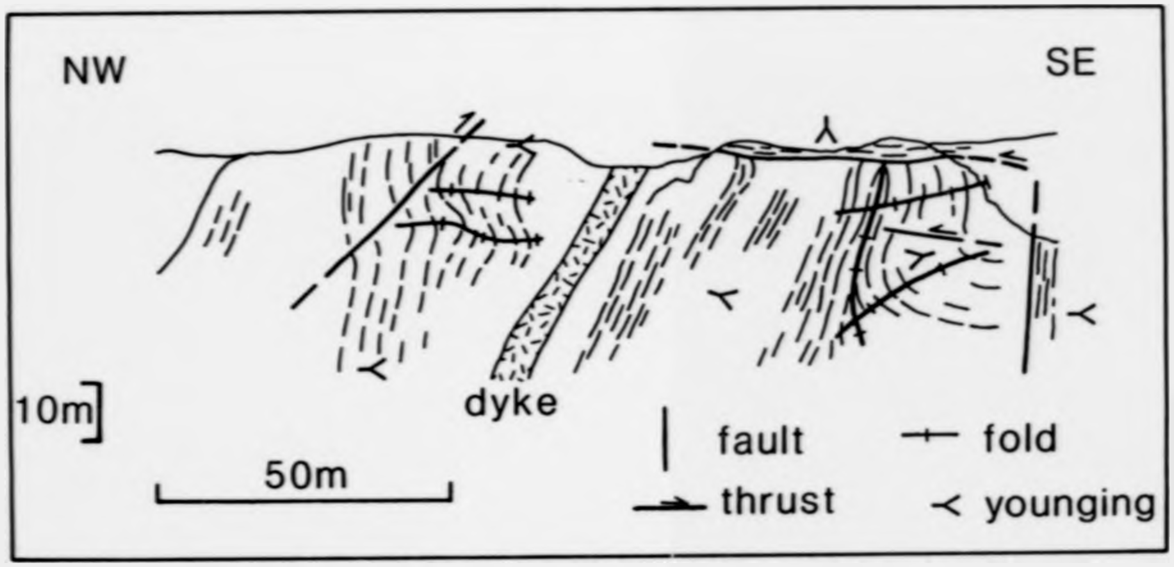


Figure 3.12: Sketch section of the cliff face surrounding Dunanrea Bay (NX 0300 5077) showing: (a) the development of gently inclined post-D1 thrusts, (b) the occurrence of post-D1 folds with gently inclined axial planes, and (c) an upright D1 fold, refolded and cut by these post-D1 structures (right of sketch).

occasionally display a locally developed crenulation cleavage (S2).

3.2.3.2 Structural development

Post-D1 deformation resulted in the formation of northwest and southeast dipping thrusts, sub-vertical wrench faults, and folds. The post-D1 thrusts cross-cut the D1 thrusts, and were clearly formed after these had been rotated to a sub-vertical attitude. The gently- to moderately-plunging post-F1 folds exhibit geometries which are consistent with development under the same compressive stress regime as the post-D1 thrusts.

Wrench reactivation of the strike-faults was also accomplished after rotation of the D1 thrusts. From cross-cutting evidence it seems that the minor (type 2) wrench faults were the last structures to be formed in the study area.

3.2.4 Summary

Structural studies in southwestern Scotland have shown that deformation was both diachronous from northwest to southeast (Anderson and Cameron 1979), and progressive (Eales 1979; Leggett and Oliver 1980). Knipe and Needham (1986) have suggested that specific groups of deformation structures represent specific structural sub-environments within an evolving accretionary prism complex. It is here argued that the structural environments within an accretionary prism complex will be essentially the same as those within any other evolving thrust-stack. Since deformation was diachronous there may have been some temporal overlap between the formation of those structures referrred to as pre-D1, D1 and post-D1.

Knipe and Needham (1986) attribute the occurrence of slump folds (early deformation structures) within the Southern Uplands exclusively to the failure of sediments on slopes related to the evolving thrust-stack, ignoring the possible importance of slopes related to channel banks, levees and so on. If the supposition made by Knipe and Needham (1986) is correct, then the reorientated geometries of the slump structures should be consistent with transport down east-northeast trending slopes. The reorientation of slump folds within the study transects show a wide variety of orientations (Fig. 3.8), probably suggesting that slumping occurred on slopes related both to tectonic processes and to sedimentary environments. There is substantial field evidence directly linking sediment facies with slump or early deformation structures (Fig. 3.5).

Early deformation stuctures would have been formed in three principal structural sub-environments; outboard of the thrust front and either on or at the toe of the evolving thrust-stack. These would then, as a result of continued thrusting, be incorporated into the thrust-stack.

Knipe and Needham (1986) suggest that the main deformation structures are the products of accretion-related thrusting. The original attitude of the thrusts is considered to have been sub-horizontal, and rotation to the sub-vertical is thought to have been accomplished by sequential underthrusting of sediment wedges at the toe of the accretion complex (McKerrow et al. 1977; Leggett et al. 1979; Knipe and Needham 1986). Underthrusting was supposedly towards the northeast.

The characteristics displayed by the main deformation stuctures observed within the study transects are consistent with formation during thrusting and subsequent rotation. The downthrow directions which have been observed on the D1 strike-faults are generally consistent with underthrusting towards the northwest or overthrusting towards the southeast. Some D1 thrusts, however, particularly those exposed or inferred in the southern Rhinns of Galloway (Fig. 3.1), 'overthrust' towards the northwest. Barnes et al. (1987) suggest that these structures are back-thrusts. F1-folds were developed simultaneously with the D1 thrusts, both forming under the same compressive stress regime and in the same structural environments; in the deformation front associated with the thrust-stack and at its leading edge. The non-axial-planar cleavage (S1) suggests that the folds were rotated after their formation and prior to the imposition of the cleavage, as a result of sinistral transpression.

As thrusting progressed, the D1 structures were incorporated into the evolving thrust stack and rotated. The variety of fabrics associated with the D1 strike-faults suggest that movement on some of the major thrusts continued at deepening structural levels (Knipe and Needham 1986). Tightening of the F1-folds might have occurred at this time.

The post-D1 thrusts observed within the study transects display geometries which are consistent with development under a stress regime in which the orientation of the maximum compressive stress was the same as that prevailing during D1. Progressive rotation of the D1 thrusts, during post-D1 deformation, is considered to be responsible for the contrasting present-day orientations of the two structural groups. Knipe and Needham (1986) suggest that the post-D1 thrusts and the folds associated with them were formed within the body of the thrust-stack.

The wrench reactivated strike-faults are further testimony to sinistral transpression within the region of the evolving thrust-stack (Anderson 1987; Kemp 1987). The minor wrench faults cross-cut all other structural types and are considered to represent the final "deformation event" to have affected the Southern Uplands. According to Knipe and Needham (1986) these structures were formed within the body of the thrust-stack during collisional deformation.

3.3 GENERAL STRUCTURAL CHARACTERISTICS OF THE STUDY AREA

Structurally the study area is dominated by a number of major strike-faults, which act as the boundaries to discrete and internally deformed tracts (Figs. 3.1 and 3.2). The faults are commonly traced by Moffat Shales.

3.3.1 West of Luce Bay: Killantringan Bay (NW 9820 5700) to Clanyard Bay (NX 1010 3800)

Within this study corridor across-strike exposure is almost complete (see maps in Appendix 4). The area to the North of Portayew (NX 0385 5030) was originally mapped by Kelling (1961). Two fundamental structures are evident: (1) the Cairngarroch Fault, and (2) the Port Logan Fault.

The Cairngarroch Fault (Fig. 3.1), exposed at Calves Hole (NX 0464 4909) marks the boundary between the Northern and Central Belts and has recently been described in detail by Anderson and Oliver (1986). The fault-related deformation affects the S1 cleavage and clearly post-dates the main deformation phase (D1). Anderson and Oliver (1986) suggest that this Fault represents a major wrench structure. There is no significant change in structural style across the Fault; the sediments exposed immediately to the north and south of it dip steeply, young predominantly towards the north and are folded by F1 structures which exhibit gentle to moderate plunges towards the northeast and southwest (Fig. 3.1).

The unexposed Port Logan Fault (Fig. 3.1) separates two structurally contrasted zones. To the north of the Fault the sediments young predominantly northwards and most of the F1-folds verge southwards, whereas to the south of the Fault younging is predominantly towards the south and F1-folds verge towards the north (Barnes et al. 1987). Barnes et al. (1987) suggest that the structure approximates to the 'hinge-zone' of a major anticlinorium.

Early deformation structures (pre-D1) are exposed at intervals throughout the transect. Possible large pre-D1 structures are located within two fault zones: (1) the Morroch Bay Fault Zone, and (2) the Hooies Fault Zone (Fig. 3.10).

Post-D1 thrusts and their associated folds are particularly common in the southern part of the

Northern Belt, where they affect the southernmost Portpatrick, Portayew and Cairngarroch Formations. Although steeply plunging folds are found mainly in association with the wrench reactivated D1 strike-faults, some occur within tracts, particularly the Float Bay Tract (Fig. 3.1), where they are often spatially associated with minor D1 strike-faults.

3.3.2 East of Luce Bay: Little Larg (NX 1612 6615) to Port William (NX 3370 4355)

Exposure within this corridor (see Chapter 1) is far from complete. Parts of it have been mapped by Gordon (1962), Welsh (1964), Jackson (1985) and Barnes *et al*. (1987). The sediments young predominantly towards the northwest and F1-fold vergence is generally towards the southeast. Steeply-plunging post-D1 folds have been observed within this transect, mainly within fault-bounded tracts and particularly within the Kilfillan Tract (Fig. 3.2).

The structure of the Northern Belt, as presented in Fig. 3.2, is essentially the same as that deduced by Welsh (1962) and Jackson (1985). The interpretation of the structure of the northern part of the Central Belt, mapped by Gordon (1962) and Barnes *et al*. (1987) has been modified and now includes two more major strike-faults; the Stairhaven and Craignarget Faults. The unexposed Stairhaven Fault is recognized on the basis of biostratigraphical evidence. The sediments to the north of the Fault (the Kilfillan -A Formation) include the acuminatus and acinaces zones, whereas those to the south (the Kilfillan -B Formation) range in age between the acuminatus and gregarius zones. It is, however, important to note that the Kilfillan -B Formation youngs northwards from acuminatus to cyphus Zone age within 50m of its contact with the underlying Moffat Shales (this contact is exposed in the vicinity of Gillespie Burn (NX 2570 5395)). The rest of the Formation ranges in age between the cyphus and gregarius zones (Tunnicliff 1983; Rushton 1983). It is therefore clear that there is a tectonic discontinuity between these Formations.

The intensity of the fault fabric along the Craignarget Fault, in addition to the sedimentological contrasts which exist across it, suggests, in the absence of precise biostratigraphical data, that this fault is also of major structural importance.

3.3.3 Structural Correlation

The study corridors are each dominated by major east-northeast trending strike-faults which delineate a number of discrete fault-bounded tracts (Figs 3.1 and 3.2). Structural vergence suggests that the majority of the major strike-faults separating the tracts downthrow to the south. Identification of tracts with similar biostratigraphical ages and distinctive sedimentological and petrographical characteristics, has enabled a satisfactory correlation to be erected between the two study corridors (Fig. 3.13). Most of the tracts can be correlated, with the exception of the Money Head Tract (see Barnes et al. 1987). There are two possible reasons why this unit should only appear in one transect:

(1) The greywackes which dominate the tract (Money Head Formation) may originally have been restricted in lateral extent.

(2) The tract may have been excised along-strike by transverse faulting.

From the scant exposure it is impossible to determine which is the actual cause.

Generally the fault-bounded tracts and the strike-faults which define them are relatively continuous along-strike.

Some of the major D1 strike-faults display along-strike changes in deformation style, for example while the Salt Pans Bay Fault Zone and the Gillespie Burn Fault are equivalent structures, they exhibit contrasting structural characteristics. The latter is traced at outcrop by Moffat Shales which are absent from the

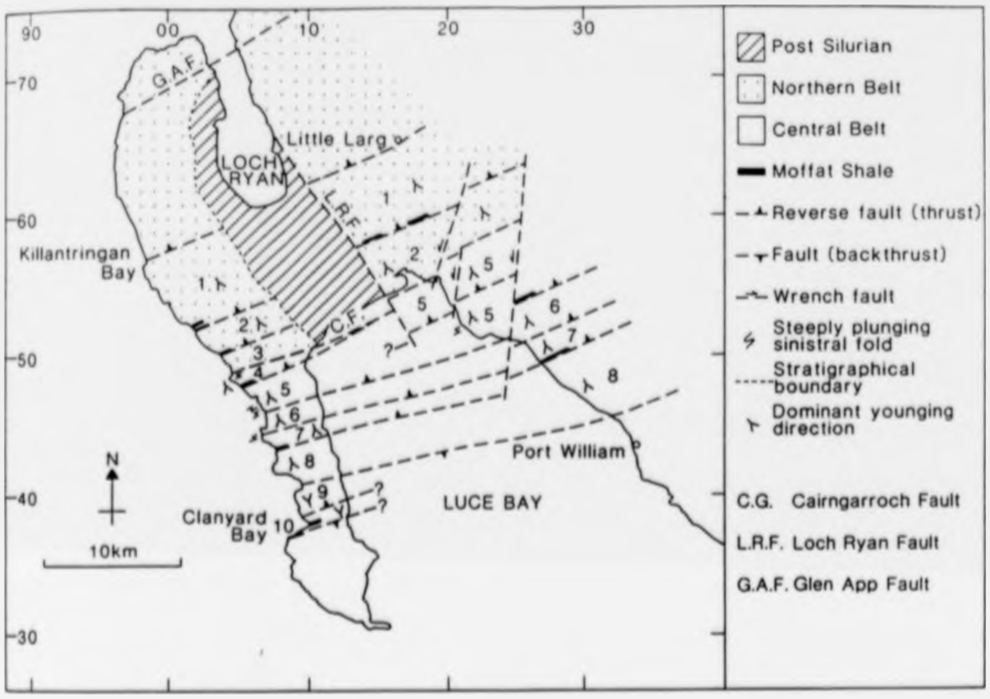


Figure 3.13: Correlation of the major strike-faults and tracts between areas to the west and east of Loch Ryan and Luce Bay. Numbers (1) to (9) identify correlated tracts. Based on information in this and Chapter 2, and Barnes et al. (1987). For names of structures and additional detail see Figures 3.1 and 3.2.

vicinity of the Salt Pans Bay fracture. The detailed stucture of individual strike-faults may vary, as minor imbricates within the fault zones braid and bifurcate. The maximum age of sediments within any one tract is also laterally variable.

Barnes et al. (1987) have recognized tracts dominated by south-younging sediments to the east of Luce Bay, and such sequences commence in approximately the same structural position to the west of the Bay. The poor exposure in the transect to the east of Luce Bay makes it difficult to assess the importance of south-younging within this area.

Some of the fault-bounded tracts which have been correlated on a stratigraphical basis also display distinctive deformation structures, strengthening the correlations, for example the Float Bay and Kilfillan -B tracts both display steeply plunging, meso-scale post-D1 fold pairs, a feature which is relatively uncommon within the other tracts.

3.4 SUMMARY

Published data which suggest that the Southern Uplands of Scotland as a whole represents an imbricate thrust-stack are both extensive and convincing (McKerrow et al. 1977; Leggett et al. 1979; Leggett and Casey 1982; Stone et al. 1987; Kemp 1987). The present subvertical attitude of the component thrusts indicates that at some time during its evolution the thrust-stack has been rotated.

The apparently complex deformation history has been clarified greatly by the work of Anderson and Oliver (1979), Stringer and Treagus (1980), Knipe and Needham (1986) and Needham and Knipe (1986). The simple sequence of deformation events presented in this Chapter is based on field observations and the above studies. Deformation is currently considered to have been both diachronous from north to south (Anderson and Cameron 1979) and progressive (Eales 1979). The structures produced during each of the deformation phases are considered to have been formed within a specific structural sub-environment within the evolving thrust-stack (Knipe and Needham 1986). During the evolution of the thrust-stack individual rock units would encounter these sub-environments sequentially, giving rise to a series of deformation structures and therefore a deformation sequence (Fig. 3.14).

It appears that the three broad groups of deformation structures which have been recognized within the study area were formed in three distinct structural sub-environments, associated with the thrust-stack:

(1) The early deformation structures (pre-D1) were formed as a result of sediment failure

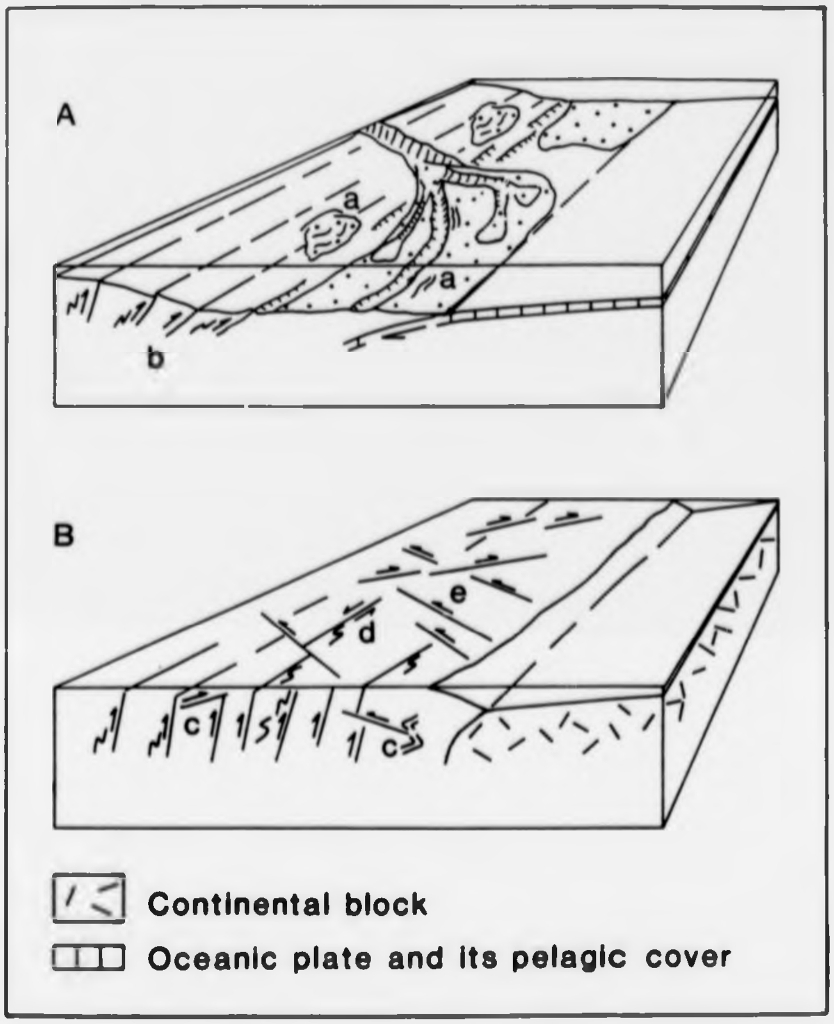


Figure 3.14: Structural model: (A) early (pre-D1) and main (D1) deformation structures, (a) slumping (pre-D1) on depositional slopes and slopes formed by tectonic processes, (b) formation of D1 thrusts and folds, and their progressive back-rotation; (B) late deformation structures (post-D1), related to collision, (c) formation of low-angle thrusts, (d) strike-slip reactivation of the now sub-vertical D1 thrusts, (e) development of a conjugate set of minor wrench faults.

on slopes either related to depositional environment (channel banks, levees and lobes) or tectonic uplift. Knipe and Needham (1986) suggest that the latter is the main cause for the development of the early deformation structures witnessed in the Southern Uplands. This view is, however, contested since there are localities which show a clear relationship between sedimentary environment and deformation style (Fig. 3.5). Thus the early deformation structures may have been formed in structural environments outboard of the evolving thrust-stack or immediately adjacent to it (Fig. 3.14).

(2) The main deformation structures (D1) were formed as a result of thrusting. Knipe and Needham (1986) suggest that these structures might have been developed at the toe of the evolving thrust-stack. Examination of the downthrow directions on the major strike-faults suggests that back-thrusting was locally important, particularly in the southern part of the Rhinns of Galloway. Sequential underthrusting of packets of sediment at the toe of the thrust-stack may have been the cause of back-rotation (Fig. 3.14).

(3) The late deformation structures (post-D1) were formed after rotation of the thrusts, and possibly as a result of collision related to the closure of the Iapetus Ocean (Knipe and Needham 1986; Needham and Knipe 1986; Fig. 3.14).

The across-strike characteristics of the strike-faults within the study area suggest that many developed as imbricate thrust zones. Lateral changes such as the thickness of fault-bounded tracts, the variations in maximum age and the discontinuous nature of the Moffat Shales associated with some strike-faults, suggest that the D1 thrusts changed their level of decollement laterally by ramping or that splay faults were developed.

There is evidence for sinistral transpression in the Southern Uplands/Longford-Down Zone from the Llandovery onwards (Anderson 1987). Evidence derives from the presence of a regional non-axial-planar cleavage (S1), sinistral steeply-plunging folds (post-D1) and the predominance of sinistral wrench faults throughout the zone. These structures particularly the non-axial-planar cleavage, become more accentuated towards the south. It has been suggested that sinistral transpression within the zone may be related to non-orthogonal convergence between the overthrusting and underthrusting structural units.

The Southern Uplands/Longford-Down represents a back-rotated thrust-stack. Whether this formed as an accretionary prism or not cannot be determined from structural characteristics alone. The accretionary prism model does, however, provide an elegant solution to the structural and stratigraphical problems.

CHAPTER 4

PETROGRAPHY

4.1 GENERAL

It is the purpose of this Chapter to summarize the petrographical characteristics of the sediments exposed within the study area and to discuss the probable geological characteristics of the terrains from which they appear to have been derived. Petrographical variation has helped to define the various stratigraphical units identified within the two study corridors (see Chapter 1) and has proved a useful tool for correlation purposes, particularly within the Northern Belt where variations are marked. Central Belt greywackes are petrographically far more homogeneous and the usefulness of petrography as a stratigraphical tool is consequently reduced. Several previous studies have been concerned with the petrographical characteristics of the greywackes exposed within the present study area. In the southern part of the Northern Belt Kelling (1958, 1961 and 1962) studied the rocks exposed between Killantringan Bay (NW 9820 5700) and Portayew (NX 0385 5030), while to the east-northeast Welsh (1964) studied the sediments exposed between Little Larg (NX 1612 6615) and Glenluce (NX 2000 5755). In the northern part of the Central Belt, Gordon (1962) studied the petrography of the sediments occurring approximately between Glenluce (NX2000 5755) and Drumblair (NX 2820 5040).

4.2 A NOTE ON SAMPLING

For the purposes of point counting only medium to coarse sand grade sandstones have been sampled. Where conditions are favourable samples have been taken at vertical intervals of about 30m to 80m. Sample density was increased at the boundaries of some stratigraphical units. It should be noted that the sampling of sediments at regular intervals has not always been feasible for the following reasons:

(1) Inaccessibility of parts of the coastal sections.

(2) Poor exposure in the inland sections.

(3) The scarcity of suitable sediments in parts of both the coastal and inland sections due both to intense structural disruption and weathering, and marked inter- and intraformational variation in lithology.

As a further result of lithological variation it has not been practical to collect consistently from a specific sedimentary facies type (Pickering et al. 1986; Chapter 5), or from a specific Bouma interval (Bouma 1962).

4.3 A NOTE ON THE METHOD USED FOR POINT COUNTING

Point counts have been carried out exclusively on samples of medium to coarse sand grade. A total of 1000 points was counted for each analysed sample. Each point was assigned to one of ten categories (Table 4.1) covering the main types of detrital mineral and lithic clast, and matrix. The detrital grain/matrix boundary size employed in the point count analyses was 0.0625mm and a point spacing of 0.25mm was used. It should be noted that any quartz grain which can be seen to include more than one crystal was counted as a polycrystalline quartz grain.

Dickinson (1985) suggests that any single crystal grain with a visible diameter of more than 0.0625mm which occurs within a lithic grain should be counted as a detrital mineral grain. This technique has been discarded within this study since it would not allow coarse grained lithic fragments, such as microgranite, to be properly recognized and represented within the point count results, and since lithic clasts constitute a considerable proportion of the greywackes which have been studied it is the authors opinion that such a disruption of the results would not reflect the true nature of the sediments or the provenance areas.

4.4 PETROGRAPHICAL CHARACTERISTICS OF THE STRATIGRAPHICAL UNITS

Within this section the petrographical characteristics of the stratigraphical units identified within the study area are described. The general petrographical characteristics of the various stratigraphical units are described in Table 4.1 their compositions are graphically summarized on triangular diagrams (Figs. 4.1 to 4.7). Five types of triangular diagram have been used:

(1) Q, F, L.
(2) Qp, Lv, Ls.
(3) Qm, F, Lt.
(4) Lm, Lv, Ls.
(5) Q+Lm, F+Lv+Hm, M+Ls.

The abbreviations which are used are defined in Table 4.1. The triangular diagrams allow easy qualitative comparisons to be made between different petrographical groups within the study area, and between these and those occurring in other areas. The triangular diagram types which are used have all been used in other studies of the Southern Uplands (e.g. Casey 1983) for ease of comparison. The diagrams also allow general provenance types to be assessed. The selected end members on different triangular diagrams having been chosen to show the relative maturity and lithic composition of the source area.

Dickinson (1985) recognizes four broad provenance types:

(1) Continental interiors, passive platforms and rift and transform uplifts combine to form the <u>continental block</u> provenance type. The derivative sands are quartz- and feldspar-rich and display low lithic clast concentrations.

(2) Island and continental arcs form the <u>magmatic arc</u> provenance type. The derivative sands are rich in feldspar and volcanilithics, compositions may grade to quartz- and feldspar-rich batholith derived sands.

(3) Subduction complexes, back-arc fold-thrust belts and suture belts form the recycled orogen provenance type. The derivative sands are quartz- and lithic fragment-rich.

The provenance fields which are used in this thesis were based on studies of sand composition in modern depositional areas with known provenances (Dickinson and Suczek 1979). The results of these studies have been supported by other subsequent similar investigations (e.g. Suczek and Ingersoll 1984; Dickinson et al. 1983). Thus it appears that their is a reasonable statistical basis which supports the validity of the provenance fields.

4.4.1 The Southern Part of the Northern Belt

The petrographical characteristics of the sediments included within the Portpatrick, Portayew and Cairngarroch Formations, exposed between Killantringan Bay (NW 9820 5700) and Cairngarroch Bay (NX 0464 4905) (Figs. 1.1 and 2.1) and the Glenwhan and Boreland Formations, exposed between Little Larg (NX 1612 6615) and Glenluce (NX 0200 5755), are described within this section (Figs. 1.1 and 2.1).

Four petrographically distinctive sandstone types are recognized (Figs. 4.1, 4.2 and 4.3). Three of these are associated with the stratigraphically correlated Portpatrick and Glenwhan Formations. The fourth occurs throughout the stratigraphically correlated Portayew and Boreland Formations, and also characterises the Cairngarroch Formation. The four sandstone types and their stratigraphical occurrences are summarized below (Table 4.2):

Type A:	Volcanilithic-rich greywackes dominate and are confined to the Acid-clast Division of the Portpatrick Formation. This petrographical type has not been identified within the Glenwhan Formation.
Type B:	Volcanilithic and ferromagnesian mineral-rich greywackes dominate and are confined to the Basic-clast Division of the Portpatrick Formation of the Glenwhan Formation.
Type C:	Quartz, metalithic and acid volcanilithic-rich greywackes are confined to the Port of Spittal Bay and Hairyhorroch Members of the Portpatrick Formation, Basic-clast Division, where they are inter-bedded with Type B greywackes. It is important to note

Point Count Categories

(1)	Qm	Monocrystalline Quartz
(2)	Qp	Polycrystalline Quartz
(3)	F	Feldspar
(4)	Ls	Sedimentary Lithic Clasts
(5)	Lm	Metamorphic Lithic Clasts
(6)	Lv	Volcanic Lithic Clasts
(7)	Li	Intrusive Igneous Lithic Clasts
(8)	Hm	Pyroxenes, Amphibole, Micas and all other minerals which exhibit a high relief or are strongly birefringent
(9)	Mis.	Opaques and unidentified minerals
(10)	M	Matrix

Other Abbreviations

Q	Total Quartz, Qm + Qp
Lt	Total lithic content, Ls + Lm + Lv + Li

Table 4.1: Point count categories and abbreviations used in this Chapter.

GROUP	STRATIGRAPHICAL UNIT		MAIN DETRITAL COMPONENTS % (AVERAGE)								DETRITAL MINERALS	DETRITAL LITHICS	COMMENTS
			Qm	Qp	F	Ls	Lm	Lv	P/A	Mi			
A	**Acid-clast Division (Portpatrick Fm.)**		12.9	3.9	12.8	--	--	29.5	4.4	--	Quartz, Plagioclase, Kspar, Hornblende, Pyroxene, Epidote, Spinel, Sphene, Chlorite, Biotite, Muscovite & Zircon.	Rhyolite, Felsite, Andesite (phyric & aphyric), Spilite, Cataclasite, Sandatone, Siltstone & Limestone.	Amphiboles & pyroxenes fresh & euhedral, feldspars serictised.
B	Basic-clast Division (Portpatrick Fm.)	Glenwhan Fm.	7.4	3.1	10.3	--	--	34.9	8.1	--	Quartz, Plagioclase, Pyroxene, Hornblende, Epidote, Biotite, Glaucophane, Garnet, Sphene & Zircon.	Andesite (phyric & aphyric), Rhyolite, Schist, Granophyre, Micrograntite, Sandstone & Siltstone.	Amphiboles & pyroxenes fresh & euhedral, feldspars sericitised.
C	Hairyhorroch Mbr. & Port of Spittal Bay Mbr. (Portpatrick Fm.)		23.1	13.0	10.5	--	7.9	9.7	--	6.7	Quartz, Plagioclase, Kspar, Biotite, Chlorite, Garnet, Epidote & Sphene.	Schist, Meta-quartzite, Rhyolite, Chert, Sandstone & Siltstone.	All components are fresh, rock is very poorly sorted.
D	Portayew Fm. Cairngarroch Fm	Boreland Fm.	18.9	4.8	14.2	--	3.1	17.1	4.3	--	Quartz, Plagioclase, Kspar, Hornblende, Pyroxene, Epidote, Biotite, Sphene & Chlorite.	Rhyolite, Felsite, Andesite (phyric & aphyric), Spilite, Sandstone & Siltstone.	Amphiboles and pyroxenes fresh, micas fresh.
E	Money Head Fm.		22.1	6.6	14.9	--	3.1	19.6	3.3	--	Quartz, Plagioclase, Kspar, Hornblende, Pyroxene, Epidote, Biotite, Sphene & Chlorite.	Rhyolite, Felsite, Andesite (phyric & aphyric), Spilite, Limestone, Sandstone & Siltstone.	Amphiboles and pyroxenes subhedral and small.
F	Float Bay Fm. Stinking Bight Fm. Grennan Point Fm.	Kilfillan-A Fm. Kilfillan-B Fm. Garheugh-A Fm. Garheugh-B Fm.	27.7	6.4	12.6	--	4.7	11.0	--	4.7	Quartz, Plagioclase, Kspar, Garnet, Amphibole, Epidote, Apatite & Chlorite.	Rhyolite, Felsite, Granite, Schist, Sandstone & Siltstone.	Texturally very variable.
G	Mull of Logan Fm.	Corwall Fm.	19.1	5.8	16.9	--	2.3	16.7	--	4.2	Quartz, Plagioclase, Kspar, Mica, Garnet & Epidote.	Rhyolite , Tuff, Felsite Microgranite & Granophyre.	All components are fresh.
H	Port Logan Fm. Clanyard Bay Fm.		43.1	6.4	8.6	--	6.4	4.2	--	5.6	Quartz, Plagioclase, Kspar, Garnet, Epidote, Chlorite, Apatite & Sphene.	Schist, Meta-quartzite Felsite, Rhyolite & Siltstone.	All components are fresh.

Table 4.2: Table summarizing the mean percentage proportions of the major detrital components in groups A, B, C, D, E, F, G and H, and the general petrographical characteristics of these. It should be noted that where components make-up less than 3% of the bulk composition they are ignored. The % of matrix is also ignored. The Table has been largely compiled from Appendix 2.

Abbreviations, all are listed in Table 4.1 except: A/P-amphiboles/pyroxenes, Mi-micas.

that these siliceous units are moderately well graded and display very well developed Tabc, Tbc and Tc Bouma (1962) sequences. These features suggest that they are 'classical' turbidite deposits. In addition, the very distinctive petrographical characteristics of the siliceous units rules out any suggestion that they may owe their development to winnowing of the compositionally immature sediments with which they are interbedded (Type B).

Type D: Quartz-rich greywackes with a minor ferromagnesian mineral content dominate and, in the southernmost part of the Northern Belt, are confined to the coeval Portayew and Boreland Formations and the Cairngarroch Formation.

The general petrographical characteristics of the above are graphically summarized in Figures 4.1, 4.2 and 4.3. The petrographical varieties summarised above are each described in greater detail below.

4.4.1.1 Type A: The volcanilithic-rich greywackes of the Acid-clast Division, Portpatrick Formation

These greywackes are very rich in volcanilithic fragments and contain moderate to minor amounts of detrital quartz and feldspar (Fig. 4.1, Plates 4.1a and 4.1b, and Table 4.2).

A wide variety of detrital mineral grains is recognized the most common of which are quartz and feldspar (K-feldspar and plagioclase). A large proportion of the feldspars are partially to wholly sericitised. Amphiboles (particularly hornblende) and pyroxenes are relatively common as detrital grains. Significantly, these are usually fresh and display subhedral and euhedral shapes. Detrital micas and chlorite are also quite common. Other, relatively rare, detrital minerals include epidote, sphene and zircon.

A wide variety of lithic clasts are included within these sediments (Plates 4.1a and 4.1b). Volcanilithic clasts occur far more commonly than either metalithic or sedimentary lithic fragments (Fig. 4.1).

Several types of volcanilithic clast are recognized, including both aphyric and porphyritic rhyolites and

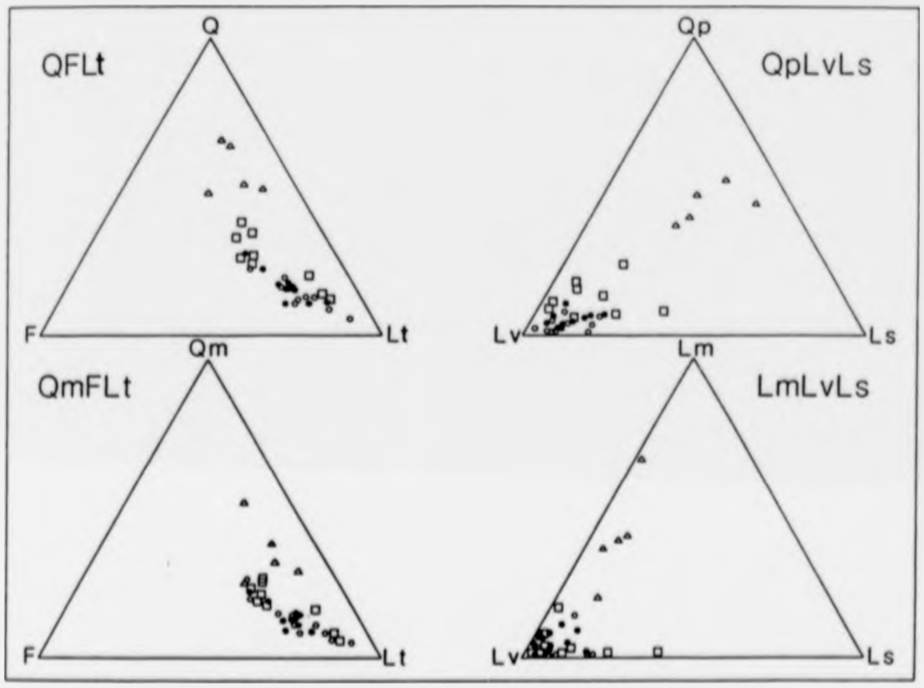
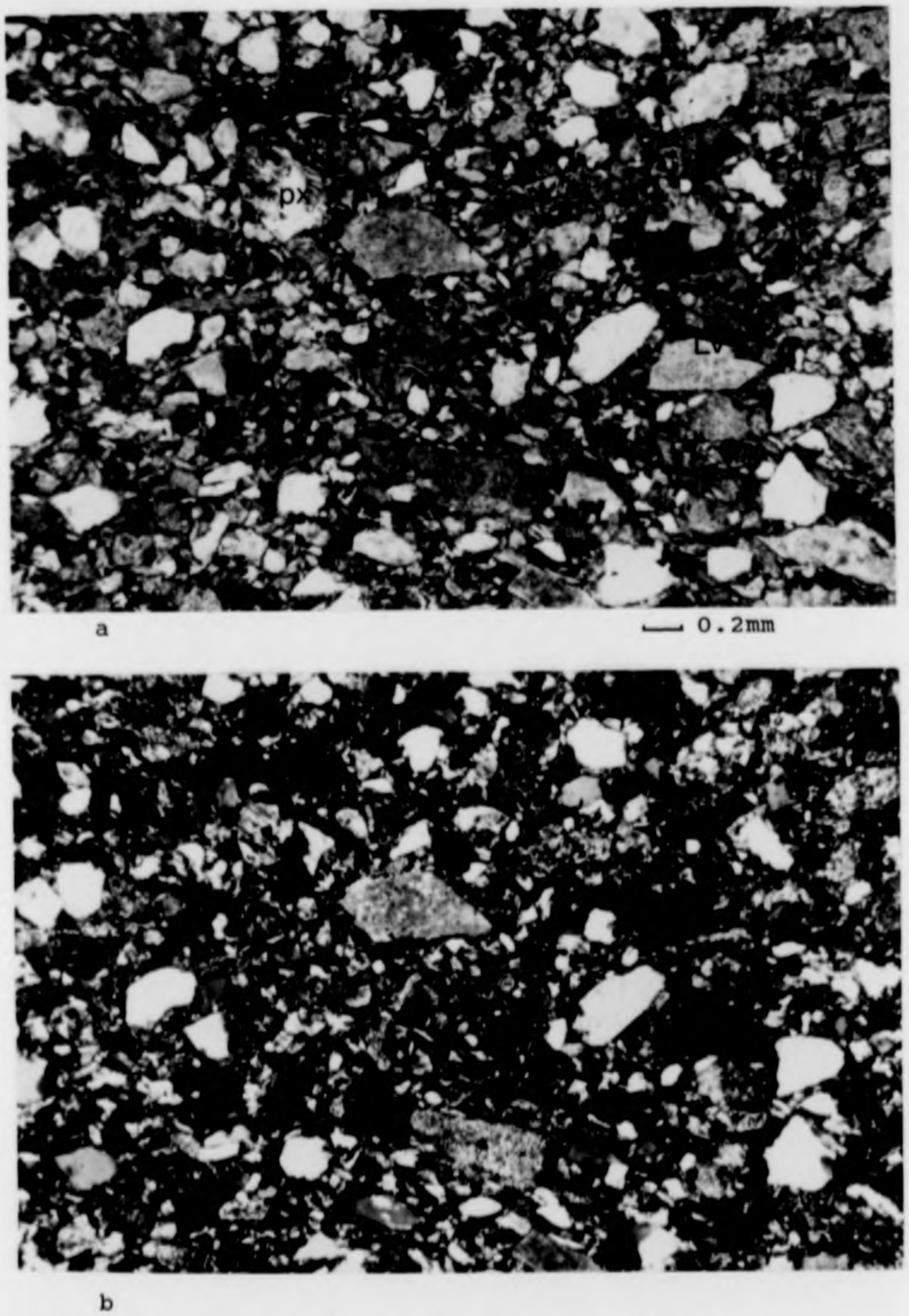


Figure 4.1: Triangular plots (after Dickinson and Suczek 1979) illustrating the compositional characteristics of: Type A greywackes (Portpatrick Fm., Acid-clast Division, □ , n = 9), Type B greywackes (Portpatrick Fm., Basic-clast Division, ○ , n = 10; Glenwhan Fm., ● , n = 10), Type C greywackes (Portpatrick Fm., Hairyhorroch and Port of Spittal Bay Mbrs., △ , n = 5).



Plates 4.1a and b: Typical petrographical characteristics of Type A greywackes, (a) ppl, (b) xpl. Note the occurrence of pyroxene (px) and volcanilithic clasts (Lv). Sample R9-84, (NX 0098 5277), Portpatrick Formation, Acid-clast Division.

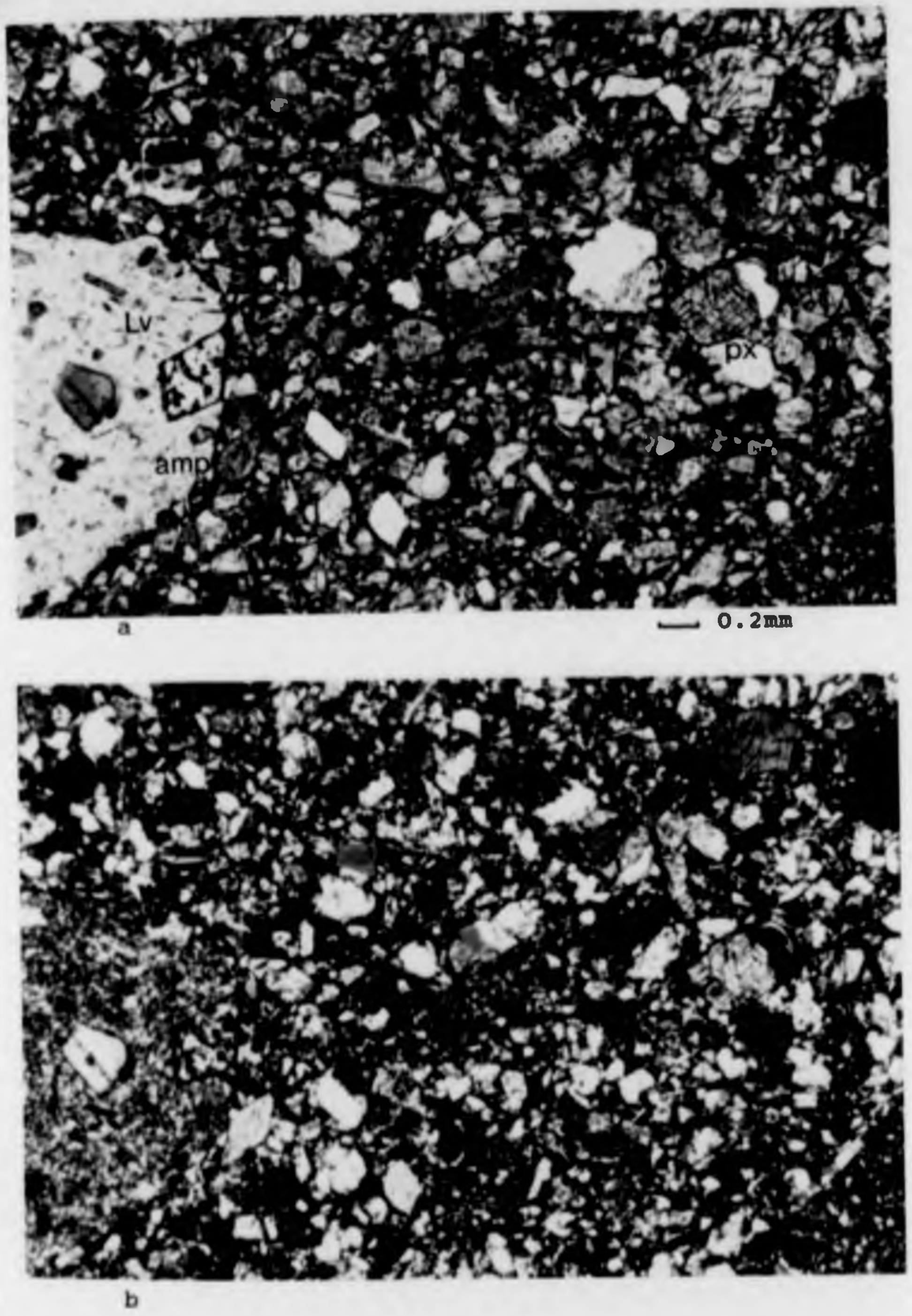
andesites. The porphyritic rhyolites contain anhedral phenocrysts of quartz in a very fine groundmass. The porphyritic andesites include subhedral to euhedral phenocrysts of plagioclase, hornblende and pyroxene, in a fine groundmass composed primarily of fine needles of plagioclase.

Lithic clasts representing intrusive igneous rocks are conspicuous by their variety and relative abundance. Granite, mnicrogranite, granophyre, felsite, diorite and dolerite have all been identified.

Quartz-mica schists and metaquartzites make up the metalithic clast fraction, while siltstone, greywacke and arkose clasts constitute the sedimentary lithic fraction.

4.4.1.2 Type B: The volcanilithic and ferromagnesian mineral-rich greywackes of the Basic-clast Division, Portpatrick Formation, and the Glenwhan Formation

The greywackes of the Basic-clast Division, Portpatrick Formation and the Glenwhan Formation have been described in some detail by Kelling (1962) and Welsh (1964), respectively. The general petrographical characteristics of these rocks are summarized in Figure 4.1 and Plates 4.2a and 4.2b, and Table 4.2



Plates 4.2a and b: Typical petrographical characteristics of Type B greywackes, (a) ppl, (b) xpl. Note the abundance, euhedral shapes and fresh state of detrital pyroxenes (px) and amphiboles (amp) and the abundance of volcanic clasts (Lv). Sample 86-S-84 (NW 9850 5554), Portpatrick Formation, Basic-clast Division.

A wide variety of detrital minerals are included within these sediments. Feldspars, mainly plagioclase, pyroxenes and amphiboles (mainly hornblende) are common. Plagioclase grains are often sericitised, while the pyroxenes and the commonly occurring amphiboles usually display a fresh, unaltered appearance, and, in addition, they commonly exhibit subhedral to euhedral shapes (Plates 4.2a and 4.2b). Other less common detrital minerals include quartz, biotite, K-feldspar, garnet, sphene, apatite and zircon. In addition, although only a very minor component, glaucophane occurs as detrital grains (Kelling 1962).

A broad range of lithic clast types are present. Volcanilithic clasts are very abundant, constituting a substantial fraction of the total detrital clast population of these sediments (Fig. 4.1, Plates 4.2a and 4.2b). Porphyritic andesites, containing euhedral phenocrysts of pyroxene, amphibole (hornblende) and plagioclase, are common (Plates 4.2a and 4.2b). Rhyolites and spilites also occur as clasts.

Lithic clasts of intrusive igneous origin are present and include granite, granophyre, diorite and gabbro.

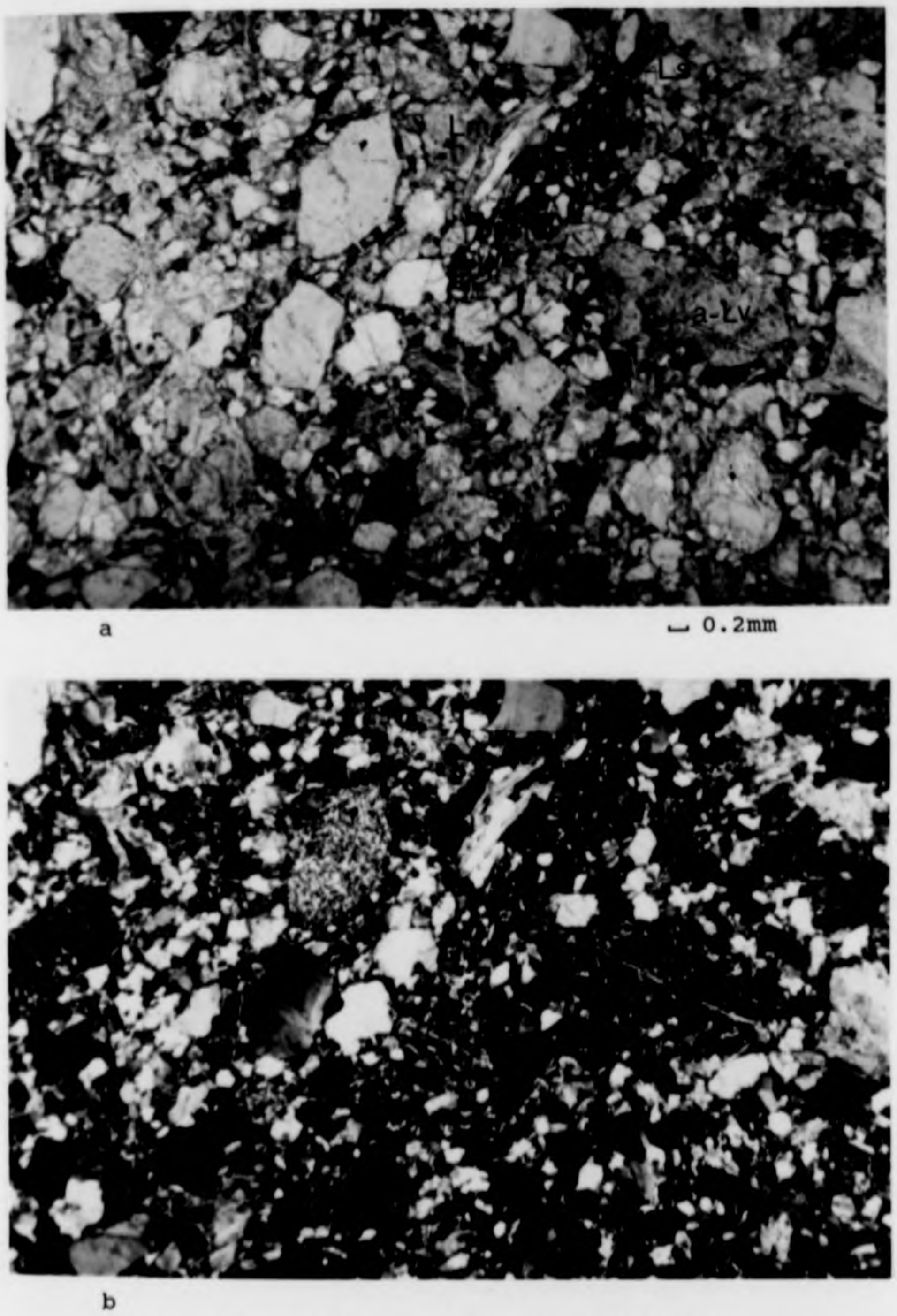
Kelling (1962) recognized a wide variety of metalithic clast types including glaucophane-schist, muscovite-schist, gneiss and granulite. The schists are often intensely micro-folded. Metaquartzite fragments also form a part of the metalithic clast fraction. Sedimentary lithic clasts include siltstones, greywackes and cherts.

4.4.1.3 Type C: The siliceous units within the Port of Spittal Bay and Hairyhorroch Members, Basic-clast Division, Portpatrick Formation

The siliceous units present within the Port of Spittal Bay and Hairyhorroch Members are quartz-rich and contain appreciable amounts of acid-igneous and metalithic detritus (Fig. 4.1, Plates 4.3a and 4.3b).

The most common detrital minerals are quartz and feldspar (mainly K-feldspar and some plagioclase). Other detrital minerals include mica, chlorite and epidote. It is important to note that pyroxenes and amphiboles are absent from these siliceous units.

Volcanilithic clasts are predominantly rhyolitic and may be either aphyric or porphyritic (Plates 4.3a and 4.3b). In the latter clasts subhedral phenocrysts of feldspar and anhedral phenocrysts of quartz commonly occur.



Plates 4.3a and b: Typical petrographical characteristics of Type C greywackes, (a) ppl, (b) xpl. Note the abundance of quartz and acid-volcanic clasts (a-Lv) and metamorphic clasts (Lm). Sedimentary lithic clasts are present (Ls). Sample R5b-84 (NW 9822 5608), Hairyhorroch Member.

Intrusive igneous lithic clasts include granites, microgranites and felsites.

Quartz-mica schists and metaquartzite fragments are relatively common and make up the metalithic fraction (Plate 4.3a and 4.3b), while siltstone and quartzite clasts constitute the sedimentary lithic clast fraction.

4.4.1.4 Type D: The quartz-rich greywackes of the Portayew, Boreland and Cairngarroch Formations

The quartz-rich greywackes of the Portayew, Boreland and Cairngarroch Formtions contain only minor amounts of ferromagnesian mineral detritus. The petrographical characteristics of the rocks included within the Boreland Formation have been described by Welsh (1964). The general petrographical characteristics of the greywackes included within the Portayew, Boreland and Cairngarroch Formations are summarized in Figures 4.2. and 4.3 and in Plates 4.4a and 4.4b, and Table 4.2.

Quartz and feldspar (K-feldspar and plagioclase) are the main detrital minerals. Other less common detrital minerals include pyroxene, amphibole (hornblende), mica, chlorite and garnet.

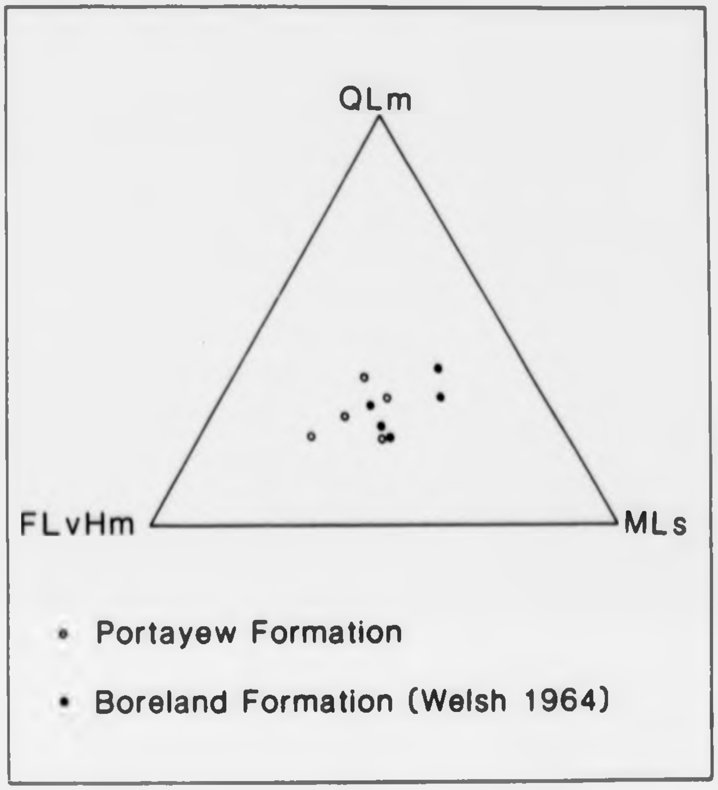


Figure 4.2: Triangular plot illustrating the compositional similarity between the greywackes included within the Portayew (n = 5) and Boreland (n = 5) Formations. Both contain Type D greywackes.

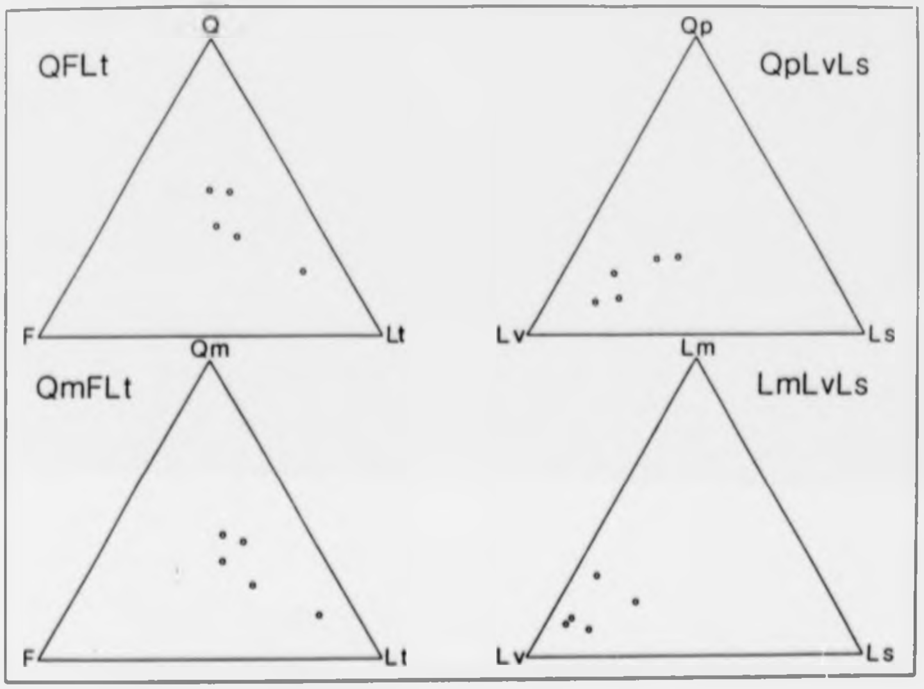
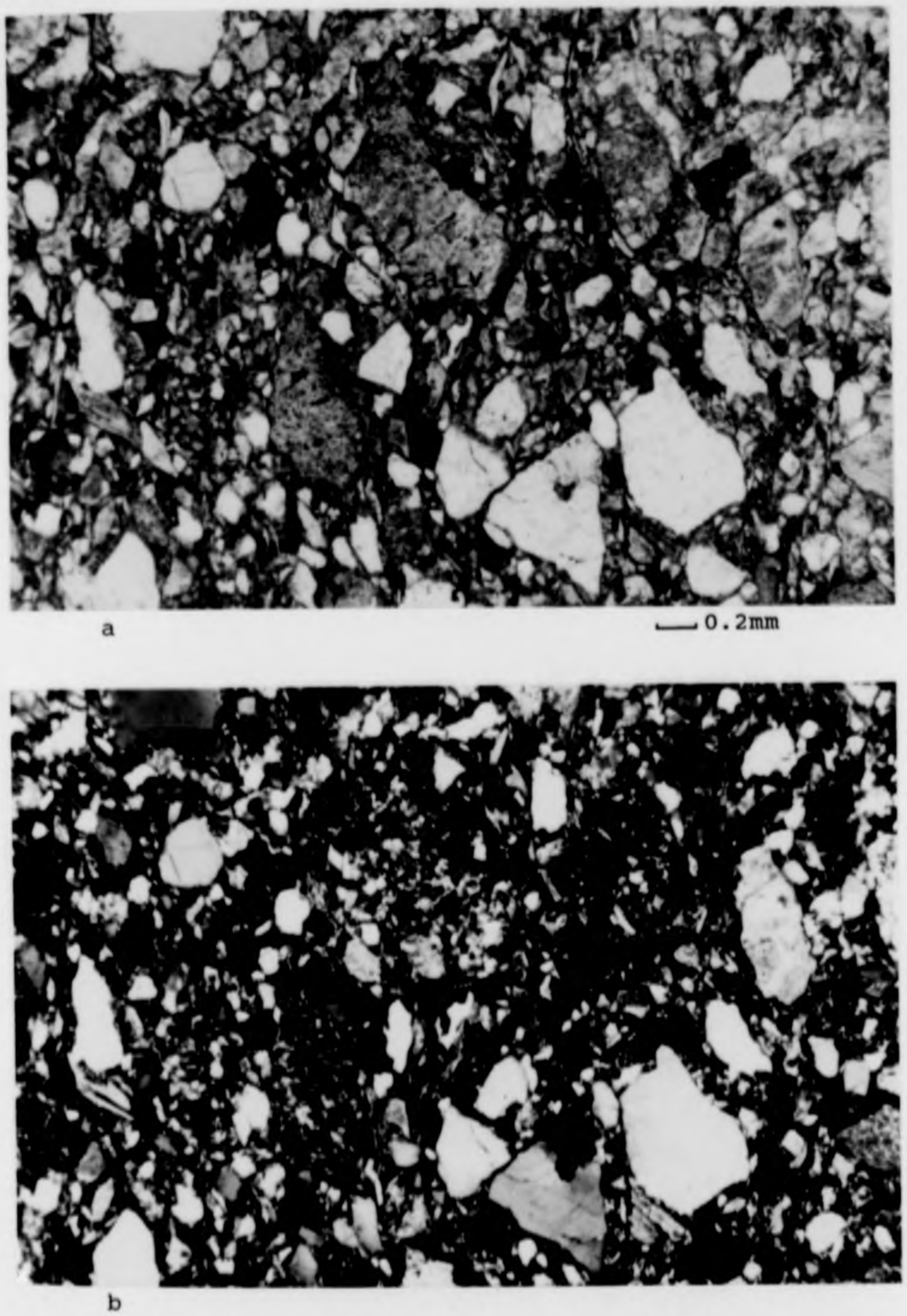


Figure 4.3: Triangular plots illustrating the compositional chracteristics of the Type D greywackes included within the Portayew Formation (n = 5). Considered here, also to be representative of the greywackes within the Boreland and Cairngarroch Formations.



Plates 4.4a and b: Typical petrographical characteristics of Type D greywackes, (a) ppl, (b) xpl. Note the occurrence of acid-volcanic clasts (a-Lv). Sample R19-83 (NX 0263 5100), Portayew Formation.

Volcanilithic clasts include andesites and rhyolites. The andesites are often porphyritic, containing euhedral phenocrysts of plagioclase, hornblende and pyroxene.

Intrusive igneous detritus is present within these sediments and includes fragments of granite, microgranite, felsite and diorite.

Quartz-mica schists and metaquartzites make up the metalithic fraction, while, siltstone and greywacke clasts form the sedimentary lithic fraction.

4.4.2 The Northern Part of the Central Belt

The petrographical characteristics of the sediments included within the Money Head, Float Bay, Stinking Bight, Grennan Point, Mull of Logan, Port Logan and Clanyard Bay Formations, exposed between Cairngarroch Bay (NX 0464 4905) and Clanyard Bay (NX 1010 3800), together with the Kilfillan -A, Kilfillan -B, Garheugh -A, Garheugh -B and Corwall formations exposed between Glenluce (NX 2000 5755) and Port William (NX 3380 4350), are described within this section.

Petrographical variation within the northern part of the Central Belt is not nearly so marked as that observed within the southern part of the Northern Belt. While twelve formations have been identified within this area, only four petrographically distinctive sandstone types, have been recognized (Figs. 4.4 to 4.7). The four sandstone types and their stratigraphical occurrences are summarized below (Table 4.2):

Type E: Quartz and volcanilithic-rich, occasionally pyroxenous, greywackes dominate and are confined to the Money Head Formation.

Type F: Quartz-rich greywackes dominate the following correlated stratigraphical units:

(i) The Float Bay and the Kilfillan -A and -B formations.

(ii) The Stinking Bight and the Garheugh -A formations.

(iii) The Grennan Point and the Garheugh -B formations.

Type G: Quartz and acid-volcanilithic rich greywackes dominate the correlated Mull of Logan and Corwall formations.

Type H: Micaceous, quartz and metalithic-rich greywackes dominate the Port Logan and Clanyard Bay formations.

The gerneral petrographical characteristics of the above are graphically summarized in Figures 4.4, 4.5, 4.6 and 4.7. The petrographical varieties summarized above are described in greater detail below.

4.4.2.1 Type E: The quartz and volcanilithic-rich, occasionally pyroxenous greywackes of the Money Head Formation

While these greywackes are dominated by quartz and volcanilithic detritus they also commonly contain appreciable amounts of ferromagnesian minerals (Plates 4.5a and 4.5b). Figure 4.4 graphically summarizes their main petrographical characteristics.

Quartz and feldspar (K-feldspar and plagioclase) are the most commonly occurring detrital minerals within these greywackes. Pyroxenes, hornblende, epidote and mica are relatively abundant (Plates 4.5a and 4.5b), together constituting up to 7.3% of the rock content (Appendix 2). Other detrital minerals include sphene and zircon, but these are very rare.

Volcanilithic clasts appear to be mainly rhyolitic, but andesitic clasts also occur. The rhyolites and

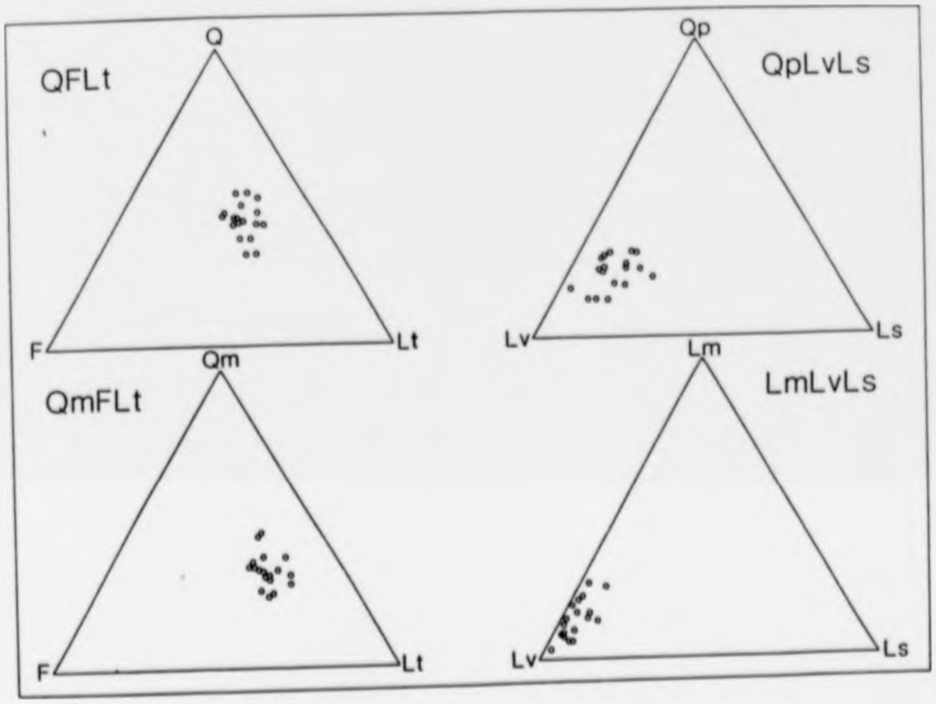
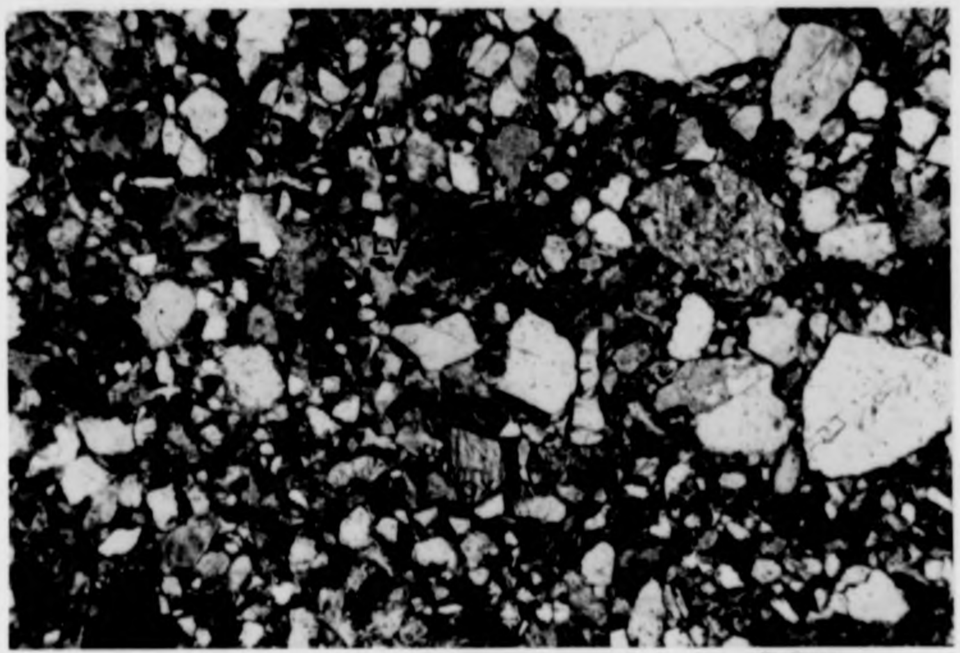
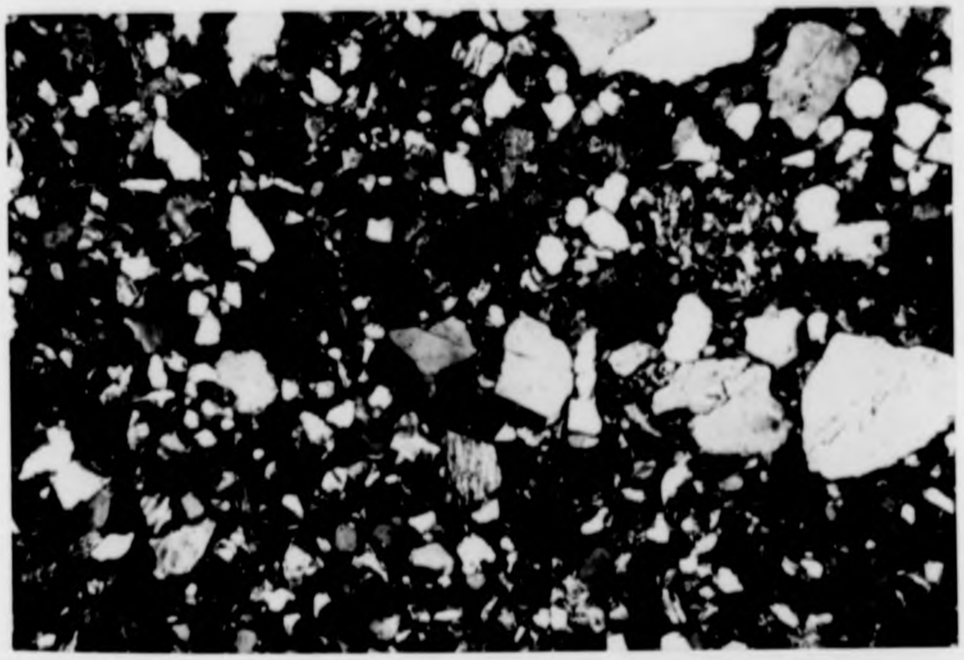


Figure 4.4: Triangular plots illustrating the compositional characteristics of Type E greywackes (Money Head Formation, n = 18).



a



b

Plates 4.5a and b: Typical petrographical characteristics of Type E greywackes, (a) ppl, (b) xpl. Note the occurrence of detrital pyroxenes (px) and volcanic clasts (Lv). Sample R366-S-84 (NX 0451 4839), Money Head Formation.

andesite are both often porphyritic. Subhedral to euhedral phenocrysts of feldspar are common within both and many are concentrically zoned. Quartz phenocrysts within the rhyolites are commonly anhedral. Pyroxene and hornblende phenocrysts within the andesites are subhedral to euhedral in shape.

Lithic clasts representing intrusive igneous rocks are included within these sediments. Felsite and diorite clasts have been recognized.

Quartz-mica schists and metaquartzites constitute the metalithic content, while siltstone, sandstone, chert and limestone clasts comprise within the sedimentary lithic fraction.

4.4.2.2 Type F: The quartzose greywackes of the Float Bay, Stinking Bight, Grennan Point, Kilfillan -A and -B and Garheugh -A and -B Formations

Although these greywackes are rich in quartz they also contain substantial amounts of volcanilithic detritus(Plates 4.6a and 4.6b). Figure 4.5 graphically summarises the main petrographical characteristics of these sediments (Table 4.2).

The main detrital minerals contained within these sediments are quartz and feldspar (K-feldspar and

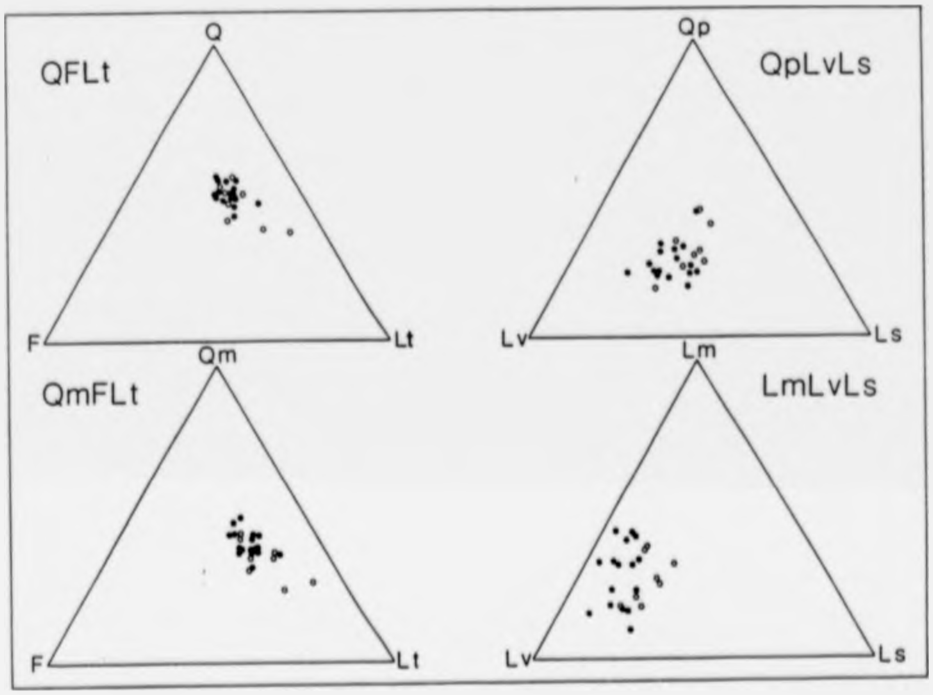


Figure 4.5a: Triangular plots illustrating the compositional characteristics of the Type F greywackes included within the Float Bay (○ , n = 8) and the Kilfillan -A and -B (● , n = 16) Formations.

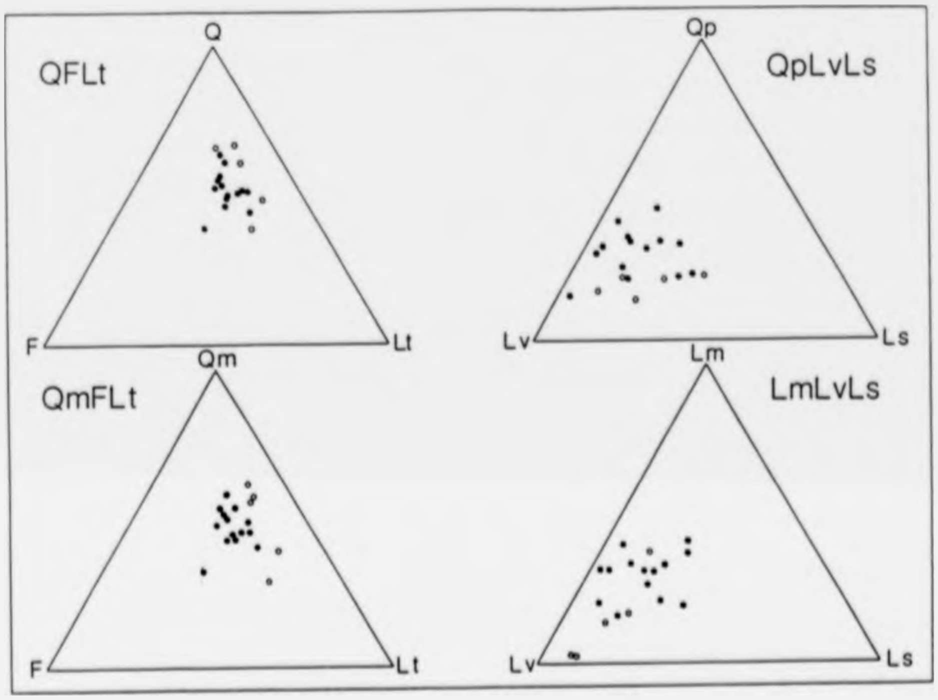


Figure 4.5b: Triangular plots illustrating the compositional characteristics of the Type F greywackes included within the Stinking Bight (O , n = 5) and Garheugh -A (● , n = 14) Formations.

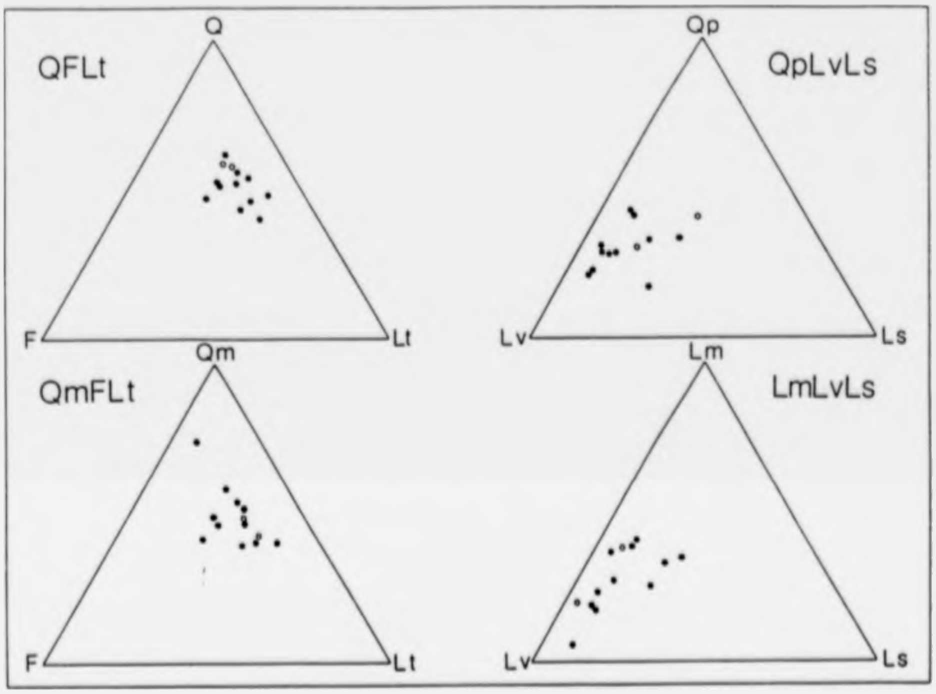
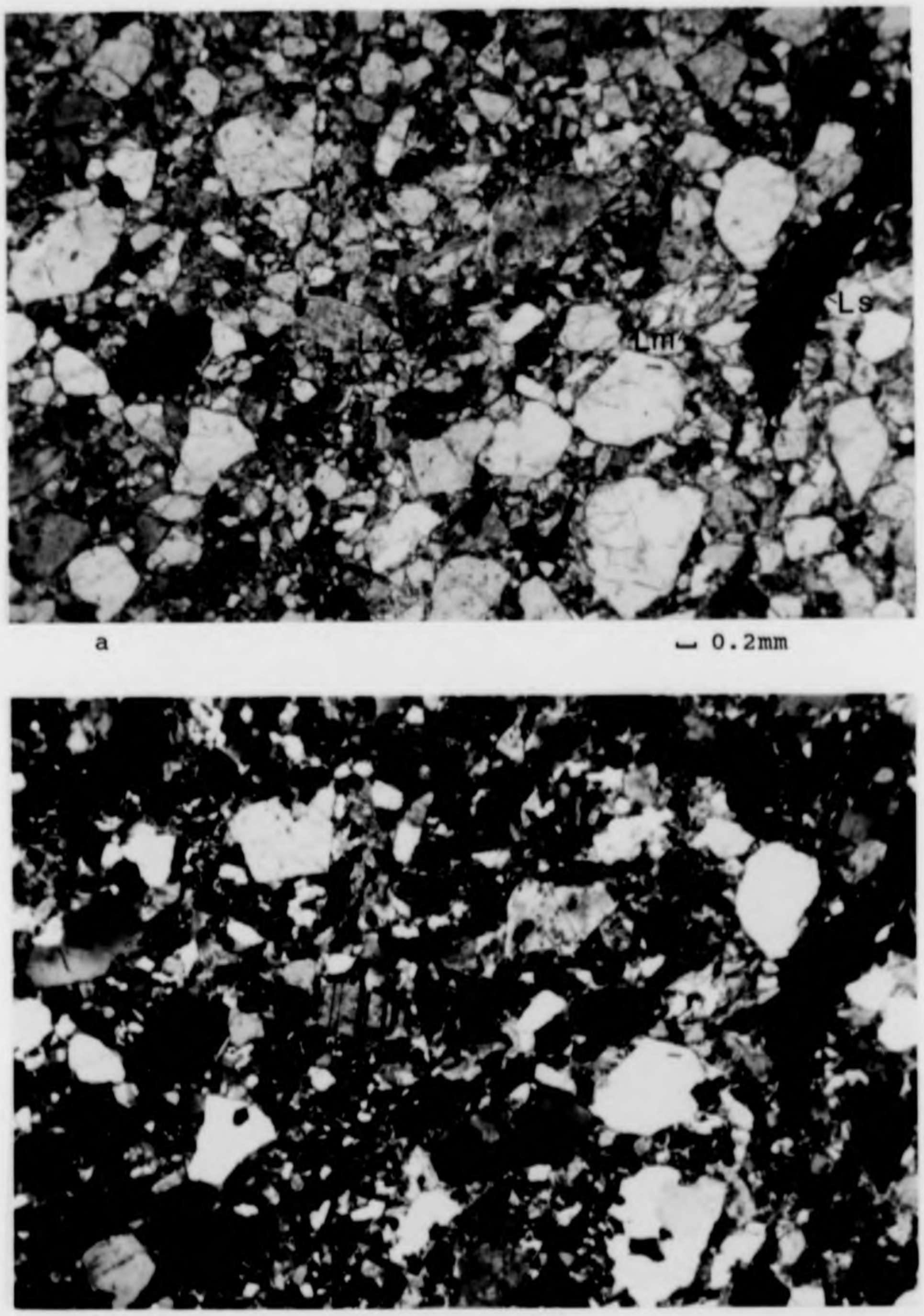


Figure 4.5c: Triangular plots illustrating the compositional characteristics of the Type F greywackes included within the Grennan Point (○ , n = 2) and Garheugh -B (● , n = 11) Formations.



Plates 4.6a and b: Typical petrographical characteristics of Type F greywackes, (a) ppl, (b) xpl. Note the presence of metamorphic (Lm), sedimentary (Ls) and volcanic (Lv) clasts. Sample R29-83 (NX 0710 4604), Stinking Bight Formation.

plagioclase). Other detrital minerals include mica (biotite and white mica), amphibole, garnet, epidote, apatite and chlorite.

Acid-volcanilithic fragments, including both aphyric and porphyritic rhyolites with subhedral phenocrysts of feldspar and anhedral phenocrysts of quartz are relatively common. Intrusive igneous rocks are represented by fragments of felsite, micro-granite and granophyre.

Metalithic clasts include both strongly foliated quartz-mica schists (Plates 4.6a and 4.6b) and intensely deformed metaquartzites. The sedimentary lithic fraction is dominated by siltstone (Plates 4.6a and 4.6b) and sandstone fragments.

4.4.2.3 Type G: The quartz and acid-volcanilithic rich greywackes of the Mull of Logan and Corwall Formations

Figure 4.6 and Plates 4.7a, 4.7b, 4.8a and 4.8b, graphically summarize the main petrograpahical characteristics of these sediments (Table 4.2).

The main detrital minerals are quartz and feldspar (K-feldspar and plagioclase). Other detrital minerals include mica, hornblende, garnet, epidote and sphene (Plates 4.7a, 4.7b, 4.8a and 4.8b).

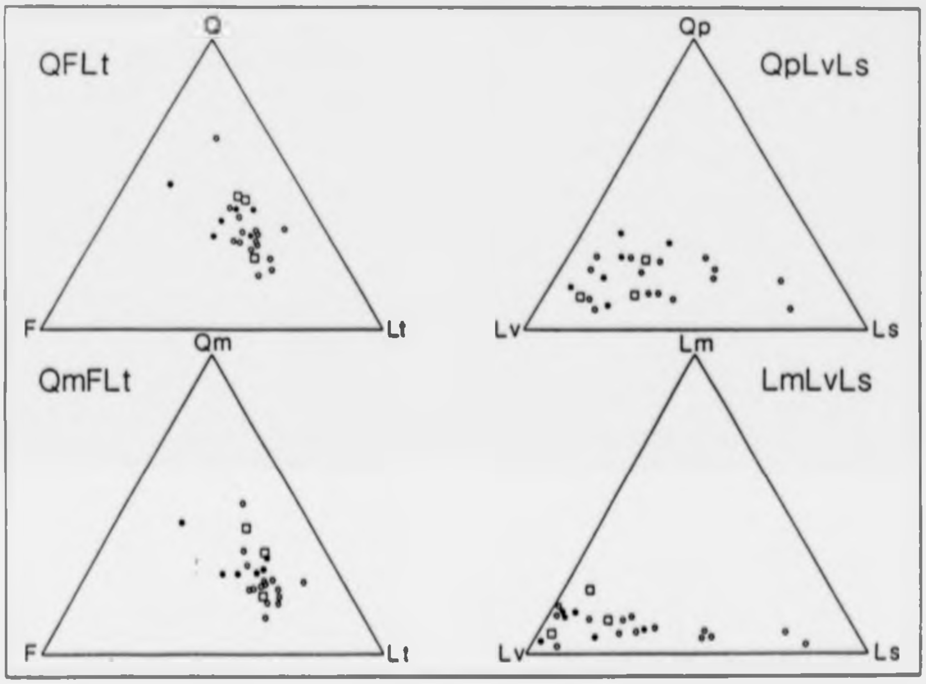
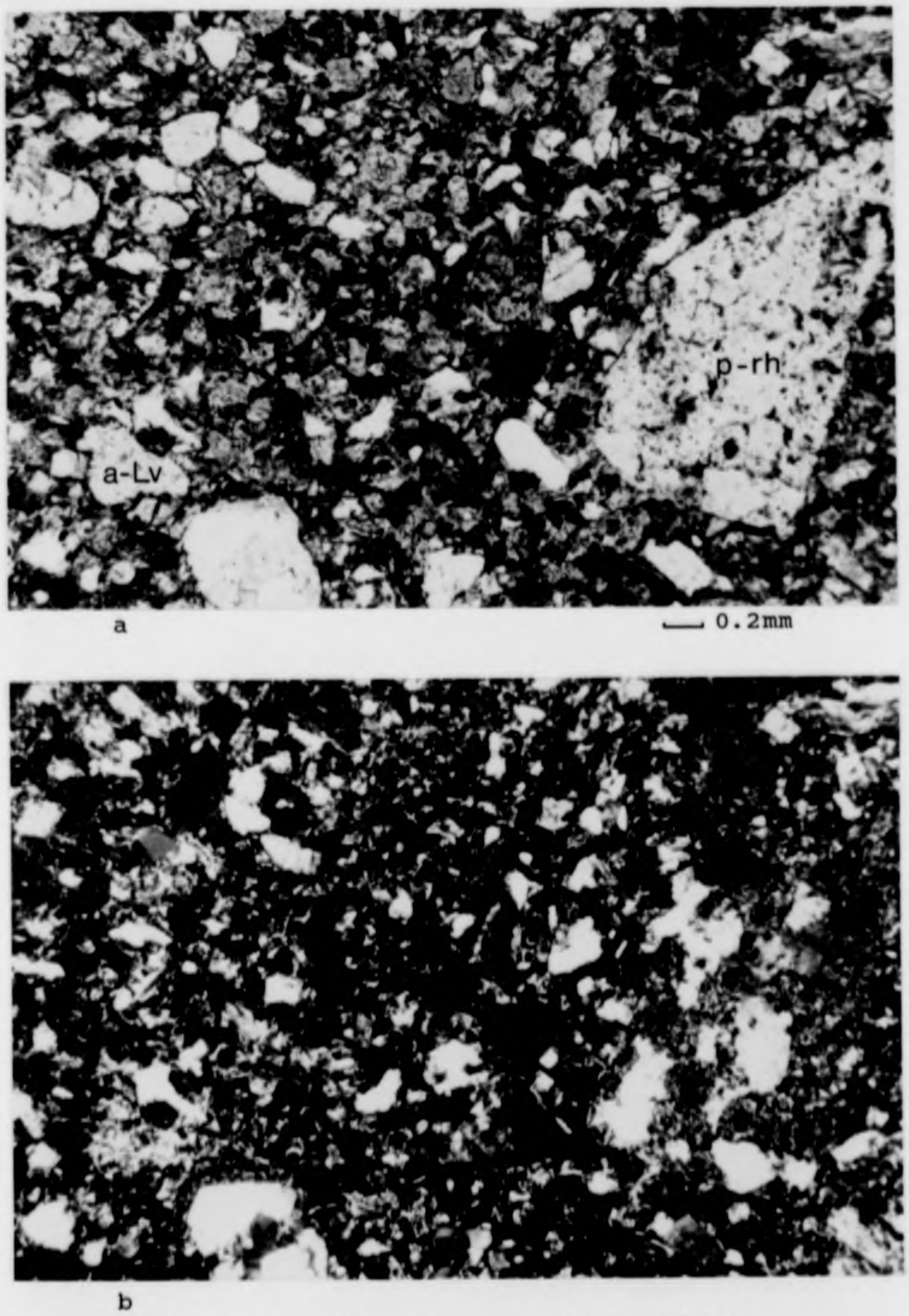
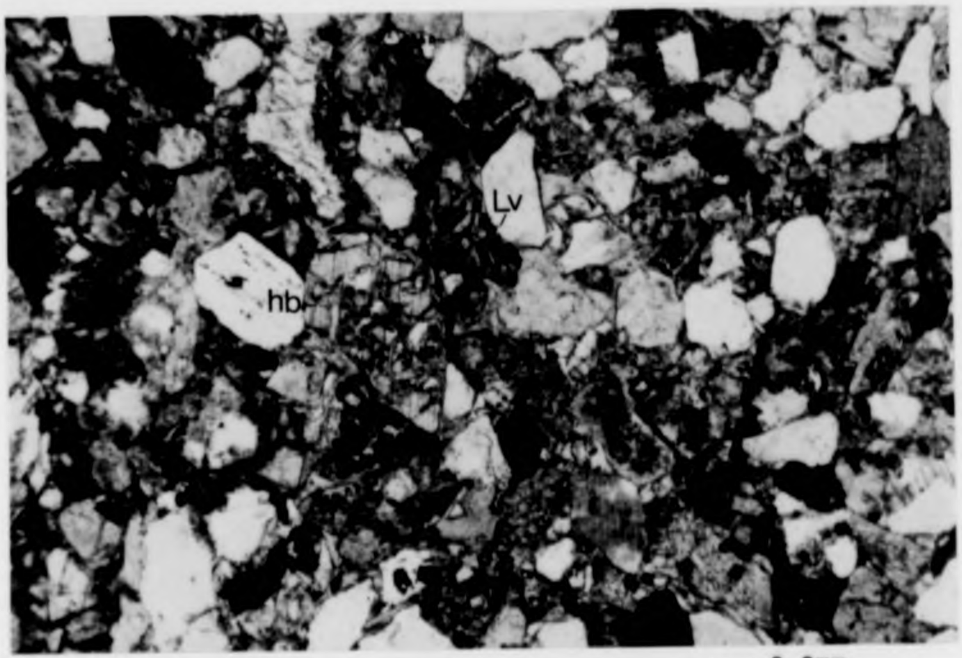


Figure 4.6: Triangular plots illustrating the compositional characteristics of Type G greywackes (Mull of Logan Fm., ○ , n = 15, clasts within the Duniehinnie Mbr., □ , n = 3; Corwall Fm., ●, n = 6).



Plates 4.7a and b: Typical petrographical characteristics of Type G greywackes, (a) ppl, (b) xpl. Note the abundance of acid-volcanic clasts (a-Lv) including porphyritic rhyolite (p-rh). Sample GL91-S-85 (NX 2905 4978), Corwall Formation.



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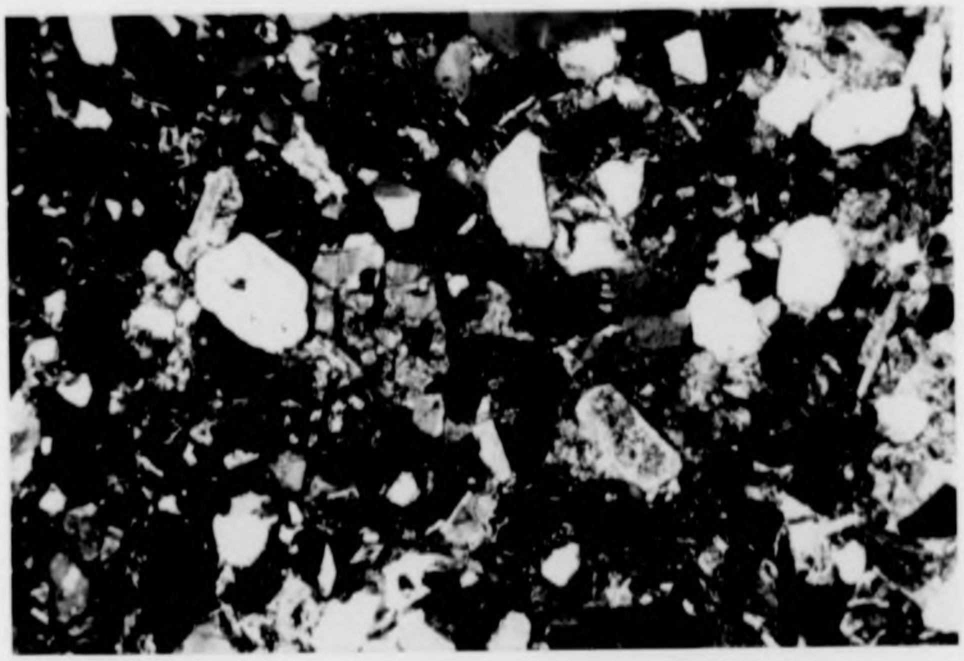


b

Plates 4.8a and b: The presence of hornblende (hb) within Type G greywackes, (a) ppl, (b) xpl. Note the presence of volcanic clasts (Lv). Sample R155-S-84 (NX 0759 4245), Mull of Logan Formation.

These sediments contain a variety of acid-volcanilithic lithologies, of which aphyric and porphyritic rhyolites (Plates 4.7a and 4.7b) and acid tuffs are the most common. Phenocrysts of euhedral, commonly zoned feldspars, and anhedral quartz are common. Intrusive igneous detritus includes fragments of granite, granophyre and felsite.

Metalithic clasts include quartz-mica schists and metaquartzites. The sedimentary lithic fraction is dominated by siltstone and sandstone fragments.

4.4.2.4 Type H: The micaceous, quartz and metalithic-rich greywackes of the Port Logan and Clanyard Bay Formations

These greywackes are conspicuously micaceous and also contain very substantial amounts of quartz and metalithic detritus (Plates 4.9a, 4.9b, 4.10a and 4.10b). Figure 4.7 graphically summarizes the main petrographical characteristics of these sediments.

The main detrital minerals included within these sediments are quartz, feldspar (K-feldspar and plagioclase) and mica (biotite and white mica) (Plates 4.9a and 4.9b). Garnet (Plates 4.10a and 4.10b), epidote, chlorite, sphene and apatite are also present, but are much less common.

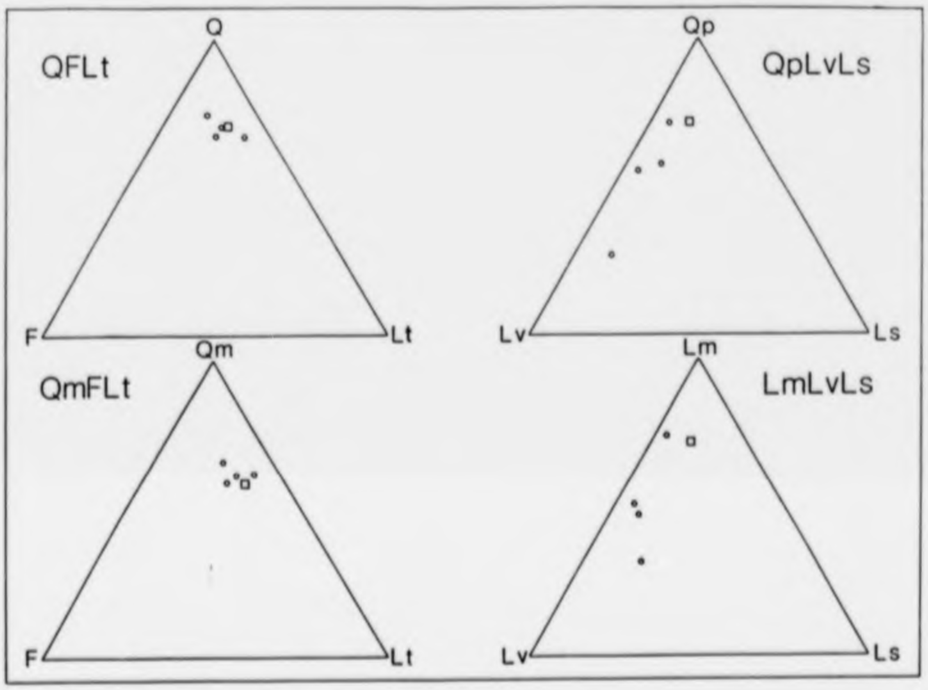
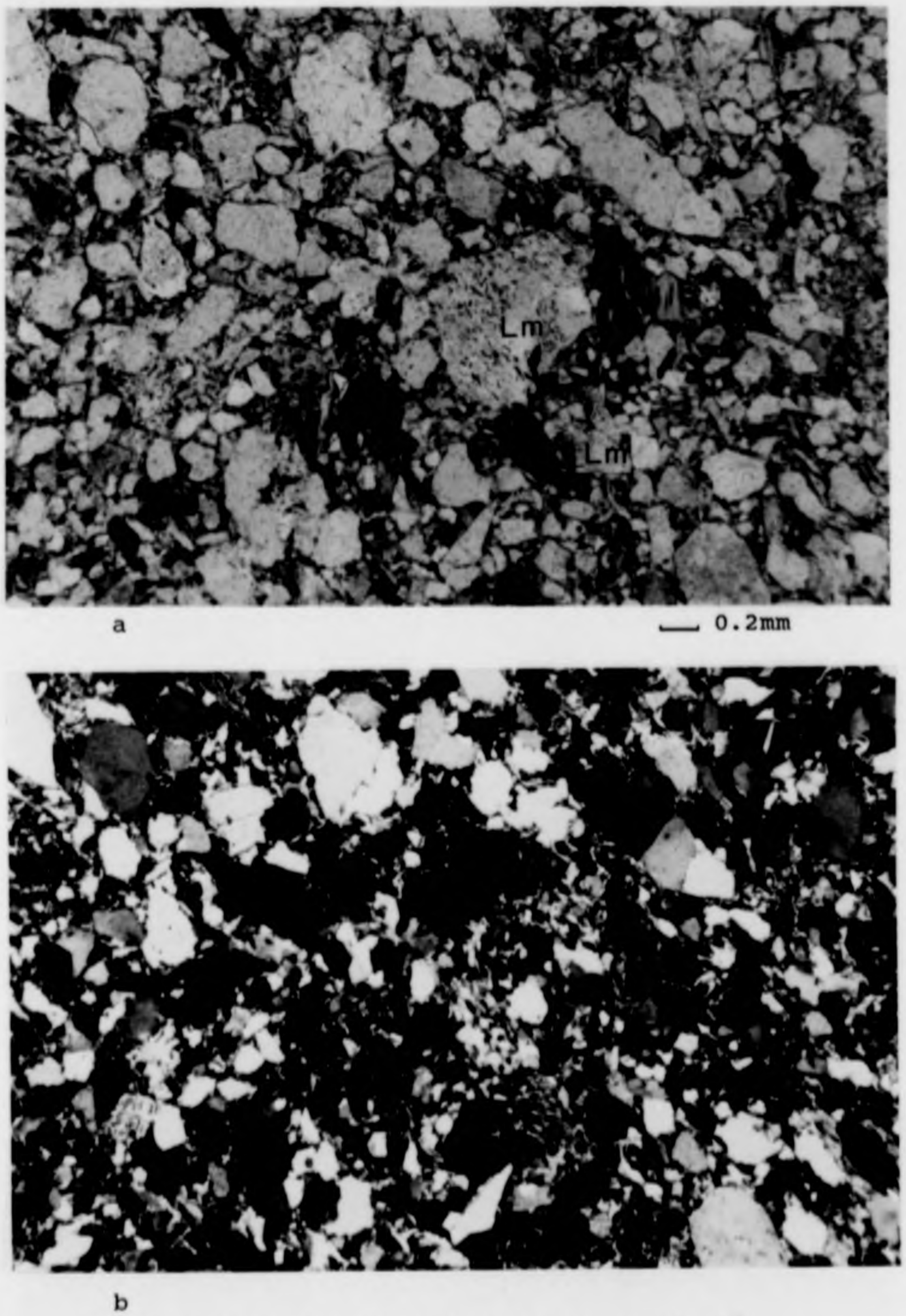
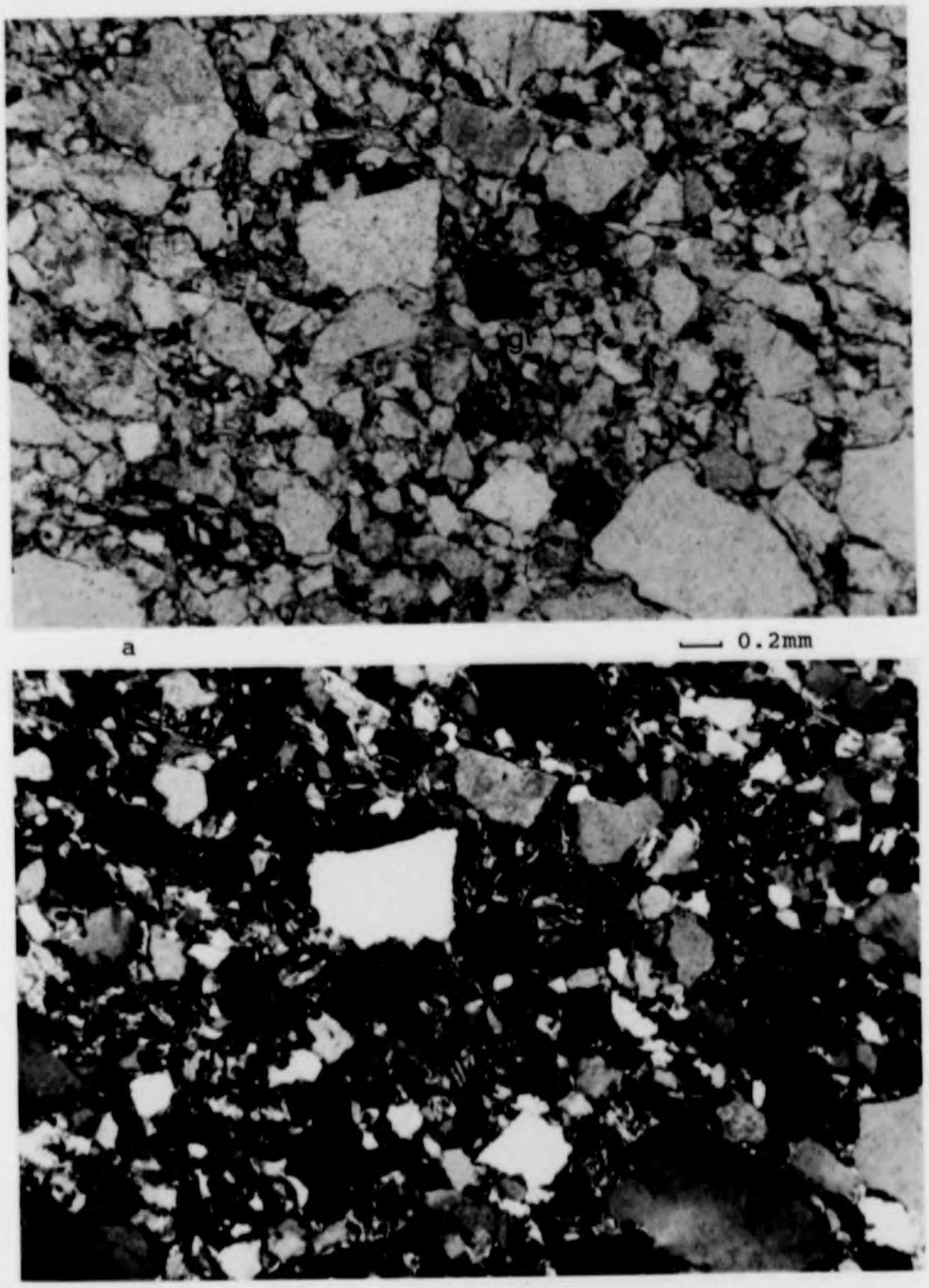


Figure 4.7: Triangular plots illustrating the compositional characteristics of Type G greywackes (Port Logan Fm., ○ , n = 4); Clanyard Bay Fm., □ , n = 1).



Plates 4.9a and b: Typical petrographical characteristics of Type H greywackes, (a) ppl, (b) xpl. Note their very siliceous nature and abundance of metalithic detritus (Lm) and mica. Sample R411-S-84 (NX 0904 3987), Port Logan Formation.



Plates 4.10a and b: The rare occurrence of garnet (gt) within Type H greywackes, (a) ppl, (b) xpl. Sample R234-S-84 (NX 0945 3927), Port Logan Formation.

Volcanilithic clasts are predominantly rhyolitic. Aphyric and porphyritic varieties have been noted. Anhedral quartz and subhedral phenocrysts of feldspar occur within the porphyritic varieties. Intrusive igneous detritus includes fragments of felsite and microgranite.

Metalithic clasts are common and include quartz-mica schists (many of which are intensely micro-folded) and metaquartzite (Plates 4.9a and 4.9b). Probable gneissic fragments have been noted. The rare sedimentary lithic clasts are mainly siltstones.

4.5 PROVENANCE

This section is concerned with assessing the nature of the terrains from which the eight petrographically distinctive sandstone types, described above, have been derived. The provenance discrimination diagrams of Dickinson and Suczek (1979) are employed to assist in this task. These diagrams discriminate between three major geotectonic provenance terrains (Dickinson and Suczek 1979; Dickinson 1985):

(1) Continental block,
(2) Recycled orogen,
(3) Magmatic arc.

4.5.1 The Southern Part of the Northern Belt

Four petrographically distinctive sandstone types have been identified within the southern part of the Northern Belt. These can be grouped into two broadly contrasted classes:

(1) The Type A (volcanilithic) greywackes of the Acid-clast Division of the Portpatrick Formation (Fig. 4.1 and Plates 4.1a and 4.1b), the Type B (volcanilithic/ ferromagnesian) greywackes of the Basic-clast Division of the Portpatrick Formation and the Glenwhan Formation (Fig. 4.1 and Plates 4.2a and 4.2b), and the Type D (quartz- rich) greywackes of the Portayew, Boreland and Cairngarroch Formations (Figs. 4.2 and 4.3 and Plates 4.4a and 4.4b), form one class characterised by a substantial volcanilithic content and a variable, but always conspicuous, ferromagnesian mineral content.

(2) The Type C (quartz, metalithic and acid-volcanilithic) greywackes within the Port of Spittal Bay and Hairyhorroch members of the Portpatrick Formation, Basic-clast Division (Fig. 4.1 and Plates 4.3a and 4.3b), represent the second class.

The compositional characteristics of the greywackes included within class (1), above, are consistent with a magmatic arc provenance, while the greywackes included within class (2) display compositions consistent with a recycled orogen provenance (Fig. 4.8; Dickinson 1985).

The Type A (volcanilithic-rich) greywackes which make up the Acid-clast Division of the Portpatrick Formation, contain a conspicuous amount of intrusive (plutonic) igneous detritus, including fragments of granite and granophyre, together with a substantial amount of acid-volcanilithic material. The aggregate compositional characteristics of these greywackes (Figs. 4.1, 4.3 and 4.8), strongly indicate derivation from a partially dissected magmatic arc.

The Type B (volcanilithic and ferromagnesian mineral-rich) greywackes which dominate the Basic-clast Division, stratigraphically overlying the Acid-clast Division, display compositional characteristics (Fig. 4.1, 4.3 and 4.8) which imply a magmatic arc provenance (Dickinson 1985). These greywackes are extremely rich in volcanilithic and ferromagnesian mineral detritus. The contained pyroxenes and amphiboles are usually very fresh and exhibit good euhedral shapes. These characteristics strongly suggest derivation from a contemporaneous, active

Figure 4.8: Triangular plots comparing the compositional characteristics of: Type A (Portpatrick Fm., Acid-clast Division, □ , n = 9); Type B (Portpatrick Fm., Basic-clast Division, ○ , n = 10); Glenwhan Fm., ● , n = 10); Type C (Portpatrick Fm., Hairyhorroch and Port of Spittal Bay Mbrs., △ , n = 5); Type D (Portayew Fm., ■ , n = 5) greywackes, with the provenance fields of Dickinson and Suczek (1979) (as in Dickinson 1985).

volcanic arc, and probably from tuffaceous deposits rather than lavas (Kelling 1961, 1962; Sanders and Morris 1978). On the basis of pyroxene mineral chemistry studies Sanders and Morris (1978) have suggested that the volcanic arc was calc-alkaline in character. Moreover, the presence of a minor amount of glaucophane and metalithic detritus within these greywackes suggests that an exhumed subduction zone complex and sialic crustal component was probably contained within the arc source terrain.

The Type D, quartz-rich and slightly ferromagnesian greywackes which dominate the Portayew, Boreland and Cairngarroch Formations, were probably deposited prior to the Type A volcanilithic and ferromagnesian greywackes which dominate the Acid-clast Division (see Chapter 2). Although these two greywacke types appear to be petrographically different, both plot in the magmatic arc field of Dickinson and Suczek (1979) (Fig. 4.8) and are thus considered to be genetically related. The siliceous nature of the greywackes which dominate the Portayew, Boreland and Cairngarroch Formations, however, implies a dissected arc provenance.

Within the Hairyhorroch and Port of Spittal Bay Members of the Basic-clast Division, occasional Type C highly siliceous greywackes are interbedded with the Type B, volcanilithic/ferromagnesian greywackes which typify this Division The general compositional characteristics of Type C sandstones indicate a recycled orogen provenance (Fig. 4.8; Dickinson 1985).

The Type A, volcanilithic greywackes, which dominate the Acid-clast Division were probably derived from an active, partially dissected magmatic arc. The upward passage of these into the Type B, volcanilithic/ /ferromagnesian sands of the Basic-clast Division suggests that there was an important resurgence of volcanic activity. The Type C siliceous, units, present within the Hairyhorroch and Port of Spittal Bay Members, testify to the activity of a provenance terrain, quite distinct from the dominant magmatic arc, during the accumulation of the Basic-clast Division sediments (Type B). This secondary source appears to have been a recycled orogen. The Type D greywackes which dominate the Portayew, Boreland and Cairgarroch Formations were probably derived from a dissected volcanic arc terrain. These sediments were probably deposited prior to the Type A greywackes of the Acid-clast Division. It is suggested that this volcanic arc later became progressively more active supplying detritus to the Acid- and Basic-clast Divisions of the Portpatrick Formation.

4.5.2 The Northern Part of the Central Belt

Four petrographically distinctive greywacke types have been identified within the northern part of the Central Belt.

The Type E, quartzose, volcanilithic, occasionally pyroxenous, greywackes dominate the Money Head Formation, have general compositional characteristics which imply either a recycled orogen or magmatic arc provenance (Figs. 4.4 and 4.9; Dickinson 1985). The importance of volcanilithic detritus, however, favours a magmatic arc provenance. This arc probably was strongly dissected but, judged by the fresh state of the included pyroxenes and amphiboles, the arc may have been sporadically and contemporaneously active.

The Type F, quartzose, greywackes which dominate the Float Bay, Stinking Bight, Grennan Point, Kilfinnan -A and -B and Garheugh -A and -B Formations exhibit an age range which partially overlaps that of the Money Head Formation. Their general compositional characteristics suggest a recycled orogen source (Figs. 4.5 and 4.10; Dickinson 1985). The true source may simply have been the Northern Belt which contains all the necessary mineralogical and lithological components.

Figure 4.9: Triangular plots comparing the compositional characteristics of Type E greywackes (Money Head Fm., n = 18) with the provenance fields of Dickinson and Suczek (1979) (as in Dickinson 1985).

Figure 4.10a: Triangular plots comparing the compositional characteristics of the Type F, greywackes included within the Float Bay (O , n = 8) and the Kilfillan -A and -B (● , n = 16) Formations, with the provenance fields of Dickinson and Suczek (1979) (as in Dickinson 1985).

Figure 4.10b: Triangular plots comparing the compositional characteristics of the Type F greywackes, included within the Stinking Bight (○ , n = 5) and Garheugh -A (● , n = 14) Formations, with the provenance fields of Dickinson and Suczek (1979) (as in Dickinson 1985).

Figure 4.10c: Triangular plots comparing the compositional characteristics of the Type F greywackes, included within the Grennan Point (○ , n = 2) and Garheugh -B (● , n = 11) Formations, with the provenance fields of Dickinson and Suczek (1979) (as in Dickinson 1985).

The Type G, volcanilithic, greywackes which dominate the Mull of Logan and Corwall Formations are probably younger than the quartzose greywackes which dominate the Float Bay and petrographically related formations. The general compositional characteristics of the Type G sandstones are indicative of a magmatic arc provenance (Figs. 4.6 and 4.11). The volcanilithic clasts are mainly acidic, and tuffs are conspicuous. There is no strong evidence to suggest that volcanic activity was contemporaneous with deposition and detritus may have been derived from a part of a recycled orogen particularly rich in acid volcanics, for example, the Northern Belt and remnants of the volcanic arc, which had supplied parts of it.

The Type H, micaceous, quartzose and metalithic, greywackes of the Port Logan and Clanyard Bay Formations are comparable in age to the volcanilithic greywackes which dominate the Mull of Logan and Corwall Formations. The general compositional characteristics of the Type H greywackes are strongly suggestive of a recycled orogen provenance and strong continental block influence (Figs. 4.7 and 4.12).

In summary, therefore, the Type E, quartzose and volcanilithic greywackes of the Money Head Formation were probably derived from a dissected, sporadically and contemporaneously active volcanic arc, perhaps

Figure 4.11: Triangular plots comparing the compositional characteristics of Type G greywackes (Mull of Logan Fm., ○ , n = 15, clasts within the Duniehinnie Mbr., □ , n = 3; Corwall Fm., ● , n = 6) with the provenance fields of Dickinson and Suczek (1979) (as in Dickinson 1985).

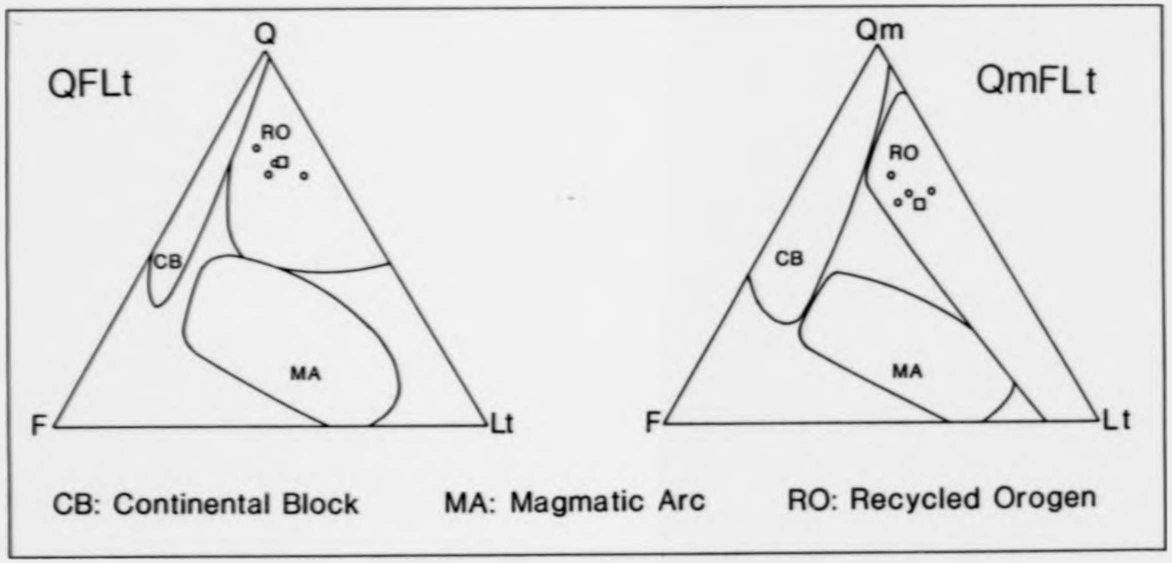


Figure 4.12: Triangular plots comparing the general compositional characteristics of Type H greywackes (Port Logan Fm., ○ , n = 4; Clanyard Bay Fm., □ , n = 1) with the provenance fields of Dickinson and Suczek (1979) (as in Dickinson 1985).

the same arc which had suplied sediments to parts of the Northern Belt (e.g. the Portpatrick Formation). Deposition of the Type F quartzose greywackes which dominate the Float Bay, and its petrographically relations formations, was at least partly contemporaneous with the more volcanilithic Money Head greywackes. The latter, however, are considered to have been derived from a recycled orogen source. These two greywacke types may have been derived from a single compound source terrain; a magmatic arc, partially tectonically incorporated into a recycled orogen terrain (the deformed Northern Belt perhaps). The contemporaneous deposition of these volcanilithic and quartzose greywackes, suggests that each sandstone type was deposited in a discrete geographical area.

The subsequent deposition of the volcanilithic greywackes of the Mull of Logan and Corwall Formations could be indicative of: (1) recrudescent volcanic activity in the source terrain, or (2) a change in the overall character of the source sediment, due to the progressive erosion of the recycled orogen terrain (the uplifted and deformed Northern Belt) which was an important source for the stratigraphically older quartzose greywackes, which dominate the Float Bay and petrographically related formations. The micaceous, quartzose and metalithic greywackes of the Port Logan and Clanyard Bay

Formations are comparable in age to the volcanilithic greywackes of the Mull of Logan and Clanyard Bay Formations. Their general compositional characteristics are indicative of a recycled orogen provenance, with a strong continental influence. In view of their contrasting petrographical characteristics, the partly contemporaneous volcanilithic Mull of Logan and Corwall greywackes and the siliceous and metalithic Port Logan and Clanyard Bay greywackes, must have been deposited in geographically separate areas, and sourced in different terrains which may have been compositionally distinct, laterally related portions of the same margin.

4.5.3 The Petrographical transition between the Northern and Central Belts

Within the study area, the Northern/Central Belt boundary is considered to be represented by the Cairngarroch Fault (Anderson and Oliver 1986). On the Rhinns of Galloway the quartz-rich greywackes which dominate the Portayew, Boreland and Cairngarroch Formations (Type D), crop out immediately to the north of the Fault, while quartzose and volcanilithic greywackes, which dominate the Money Head Formation (Type E), occur immediately to the south. The Money Head Formation has not been identified within the Glenluce (NX 0200 5755) area, and there appear to be two possible reasons for its absence:

(1) This formation could have been removed by strike-faulting.

(2) It may never have been deposited within this area.

In either case, the stratigraphical succession appears to be more complete on the Rhinns of Galloway.

The quartz-rich greywackes of the Portayew and Cairngarroch Formations, are closely similar to quartz and volcanilithic-rich greywackes of the Money Head Formation (Table 4.2). The inference is that there is a petrographical transition across the Northern/Central Belt boundary and although there may have been considerable strike-slip movements on the Cairngarroch Fault (Anderson and Oliver 1986) the belts are petrographically related.

The compositional characteristics of the Type E greywackes, which make up the Money Head Formation, suggest a derivation from a dissected sporadically and contemporaneously active volcanic arc. This type of provenance has also been proposed for the Types A, B and D greywackes, which constitute the Portpatrick and Portayew Formations exposed immediately to the north of the Cairngarroch Fault. Thus, the greywackes exposed both immediately to the north and south of the Northern /Central Belt boundary may have shared a common volcanic source terrain.

4.6 PETROGRAPHICAL CORRELATIONS WITH OTHER AREAS

4.6.1 The Southern Part of the Northern Belt

Equivalents of the Type A, volcanilithic-rich greywackes of the Portpatrick Formation, Acid-clast Division, have not been recorded from localities to the north-northeast in the Southern Uplands. However, although Craig (1984) has recognized equivalents in the Grey Point Formation of the Ballygrot Block in County Down, this correlation is here considered to be erroneous (Chapter 2, Section 5.5.1.). (It should be noted that Morris's (1987) use of the term Acid-clast petrofacies is not synonymous with the term Acid-clast Division).

Equivalents of the Type B, volcanilithic and ferromagnesian-rich greywackes which dominate the Portpatrick Formation, Basic-clast Division, and the Glenwhan Formation, occur widely throughout the Southern Uplands/Longford-Down zone. This greywacke type dominates the Red Island Formation in the Longford-Down area (Sanders and Morris 1978; Morris 1979), the Ballymacormick Block in County Down (Craig 1984) and the Scar Formation of West Nithsdale (Floyd 1982).

Probable equivalents of the Type C, quartzose units contained within the Hairyhorroch and Port of Spittal Bay Members have been identified towards the base of the Scar Formation in Nithsdale (Floyd 1982, his Fig. 4b).

Equivalents of the Type D, quartz-rich greywackes which dominate the Portayew, Boreland and Cairngarroch Formations, are considered to form the Orlock Block (Chapter 2, Section 5.5.1) to the west-southwest in County Down (Craig 1984) and the Shinnel Formation to the east-northeast in Nithsdale (Floyd 1982). Morris (1987), however, suggests that the greywackes included within the Portayew and Shinnel Formations are significantly different, the latter being much more quartzose. This suggestion appears to be based on modal analysis averages, and is here considered to be erroneous, since the quartz content within both formations, while comparable, is very variable (Floyd 1982, his Fig.2; Appendix 2).

4.6.2 The Northern Part of the Central Belt

Petrographically, the greywackes included within the Central Belt are much less diverse than those within the Northern Belt. Walton (1955) studied the petrographical characteristics of the greywackes occurring within the Central Belt in Peeblesshire and suggested that three petrographically distinctive greywacke types are present within this area. From north to south these form the Pyroxenous, Intermediate and Garnetiferous groups. Many subsequent studies have been related to this pioneer research.

The Type E, quartzose, volcanilithic, occasionally pyroxenous, greywackes which dominate the Money Head Formation, are probably related to the Pyroxenous Group in Peeblesshire (Walton 1955) (compare Figs. 4.4 and 4.13), the Craignell (basic) Formation in Galloway (Cook and Weir 1980) and the Tassan Group in the Longford-Down area (Morris et al. 1986).

The relative scarcity of garnet and pyroxene; within the Type F, quartzose greywackes of the Float Bay, Stinking Bight, Grennan Point, Kilfillan -A and -B and Garheugh -A and -B Formations; the Type G quartz and acid-volcanilithic rich greywackes of the Mull of Logan and Corwall Formations; and the Type H micaceous, quartz and metalithic -rich greywackes of

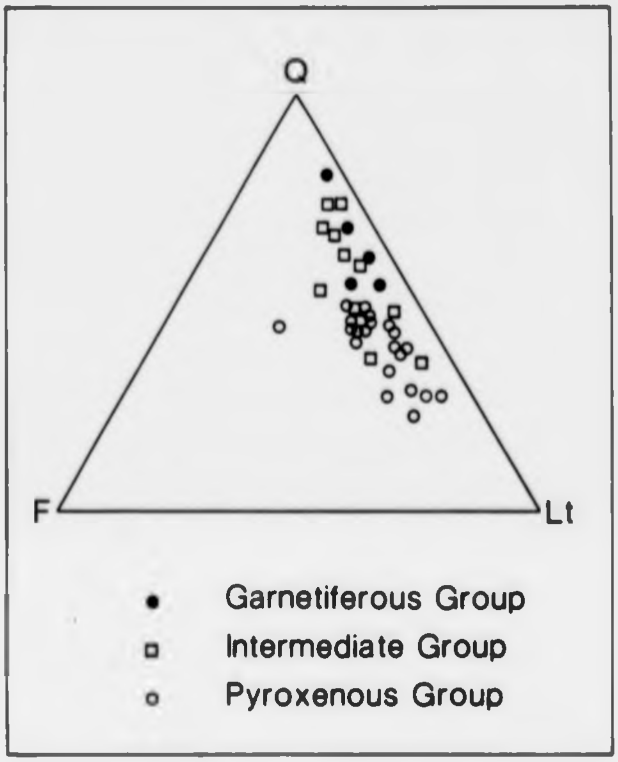


Figure 4.13: Triangular plot illustrating the compositional characteristics of the Silurian greywackes of Peeblesshire. Plotted from point count data in Walton (1955).

the Port Logan and Clanyard Bay Formations and compositional data indicates that these greywacke types are all petrographically related to the greywackes of the Intermediate Group (Walton 1955) (compare Figs. 4.5a, b, c, 4.6 and 4.7 with Fig. 4.13). Equivalents of the Intermediate Group greywackes have also been recognized within the Craignell (lithic) Formation (Cook and Weir 1980) and the Tassan Group (Morris et al. 1986).

4.7. SUMMARY

Eight petrographically distinctive greywacke types are recognized within the study area. The four greywacke types which occur within the Northern Belt and their stratigraphical distribution can be summarised as follows:

(1) Type A: volcanilithic-rich greywackes; these dominate the Portpatrick Formation, Acid-clast Division.

(2) Type B: volcanilithic and ferromagnesian mineral-rich greywackes; these dominate the Portpatrick Formation, Basic-clast Division and the Glenwhan Formation.

(3) Type C: quartz, metalithic and acid-volcanilithic-rich greywackes; these occur

as isolated units within the Hairyhorroch and Port of Spittal Bay Members, Portpatrick Formation, Basic-clast Division.

(4) Type D: quartz-rich, occasionally pyroxenous greywackes; these dominate the Portayew, Boreland and Cairngarroch Formations.

The general compositional characteristics of greywacke types (A), (B) and (D) (Figs. 4.1, 4.2 and 4.3) are indicative of a magmatic arc provenance (Fig.4.8). The extremely high content of volcanilithics, fresh pyroxenes and amphiboles of the type (2) greywackes suggest that an active volcanic arc was situated adjacent to the depositional area.

The influence of a second distinctive provenance terrain, probably a recycled orogen (Fig. 4.8), is indicated by the presence of greywacke Type (C), the general compositional characteristics of this unit are shown in Figure 4.1.

Four distinctive greywacke types occur within the Central Belt, these are summarised below:

(1) Type E: quartz and volcanilithic-rich,

occasionally pyroxenous greywackes, dominating the Money Head Formation.

(2) Type F: quartz-rich greywackes, dominating the Float, Stinking Bight, Grennan Point, Kilfillan -(a) and -(b), and Gorheugh -(a) and -(b) Formations.

(3) Type G: quartz and acid-volcanilithic-rich greywackes, characteristic of the Mull of Logan and Corwall Formations.

(4) Type H: micaceous, quartz and metalithic-rich greywackes, which dominate the Port Logan and Clanyard Bay Formations.

The general compositional characteristics of the Type (E) greywackes suggest derivation from a dissected, probably occasionallly active, magmatic arc provenance (Figs. 4.4 and 4.9). The general compositional characteristics of greywacke types (F), (G) and (H) suggest that these were derived from different portions and erosional levels of a recycled orogen terrain (Figs. 4.5a, b, c, 4.6 and 4.7). The general abundance of volcanic detritus encountered within the Type (G) greywackes, may be indicative of local, sporadic, contemporaneous volcanic activity.

These petrographical variations, which are particularly well developed in the rocks of the Northern Belt, provide convenient stratigraphical markers.