SEDIMENTATION, STRATIGRAPHY AND TECTONICS IN THE DALRY BASIN, AYRSHIRE

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DECLARATION

I declare that this thesis has been composed by myself. Where data or conclusions from published work are used due reference is made in the text.

STUART K MONRO

ABSTRACT

The Visean and Namurian sediments of the Dalry Basin are re-examined to identify the depositional environments and the factors controlling sediment distribution through time. The principal outcrop data are assessed and data from an IGS drilling programme especially planned for this research presented and correlated. Where appropriate the nature of any cyclicity has been demonstrated using a simple mathematical technique. Isopach maps and maps of sediment distribution have been constructed using additional old borehole information re-assessed and re-interpreted in the light of more recent drilling.

The pattern of clastic sedimentation is dominantly deltaic but while simple prograding sequences are indicated during Limestone Coal Group times, the Upper Limestone Group sediments are more complex with widespread channelling. Clastic sediments in the Calciferous Sandstone Measures are thought to be coastal deposits, part of a transgressive sequence.

Marine sedimentation is dominantly shallow marine. Lateral variation in lithology is only significant in the Dockra Limestone where a bioclastic limestone, the 'Trearne' facies, is locally developed. The effects of slight fall in sea-level/uplift are demonstrated in the Lower Limestone Group where roots are commonly developed in the topmost beds of the limestones. A pedogenic horizon, the 'White Post', is locally developed at the top of the Dockra Limestone.

Tectonic control of sedimentation is recognised as particularly important during Upper Limestone Group times when both the Dusk Water and the Inchgotrick faults acted as barriers to marine transgression.

At other times contemporaneous faulting controls thickness variation.

Volcanism is an important influence on sedimentation in both the Calciferous Sandstone Measures and the Passage Group, changing the surface topography and providing a lithologically distinct sediment source. Lateritic weathering of these lavas and their erosion products form the kaolinite-rich deposit, bauxitic clay and to a lesser extent the tuffaceous mudstones of the Kirkwood Formation.

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Chapter 1 Introduction

1.1 Objectives

'Lithostratigraphic analyses of sedimentary basins concern fundamental concepts of tectonics and sedimentation ... the application of many methods and techniques ... geological mapping and the examination of sub-surface drill core. They are concerned with lithology, fossil and mineral content, grain characteristics, physical and chemical properties and the geometry of stratigraphic bodies of rock. Of paramount importance to any analysis is the quality and quantity of the data available.'

Conybeare, 1979

The stratigraphy of the Carboniferous System in Scotland is well known. In addition to natural outcrops there is an abundance of borehole and mining data resulting from the search for and the exploitation of economic minerals. This thesis analyses the history of sedimentation of one part of the Carboniferous System in Scotland, the Visean and Namurian rocks of the Dalry Basin, using the extensive data base of old borehole information and a drilling programme especially planned for this research. The study has evolved from revision mapping work done in the Dalry Basin as part of the programme of the South Lowlands Unit of the Institute of Geological Sciences, Edinburgh.

1.2 Area of the Dalry Basin

The Dalry Basin is defined geologically as the synclinal structure to the north of the Westphalian, Ayrshire Coalfield, within

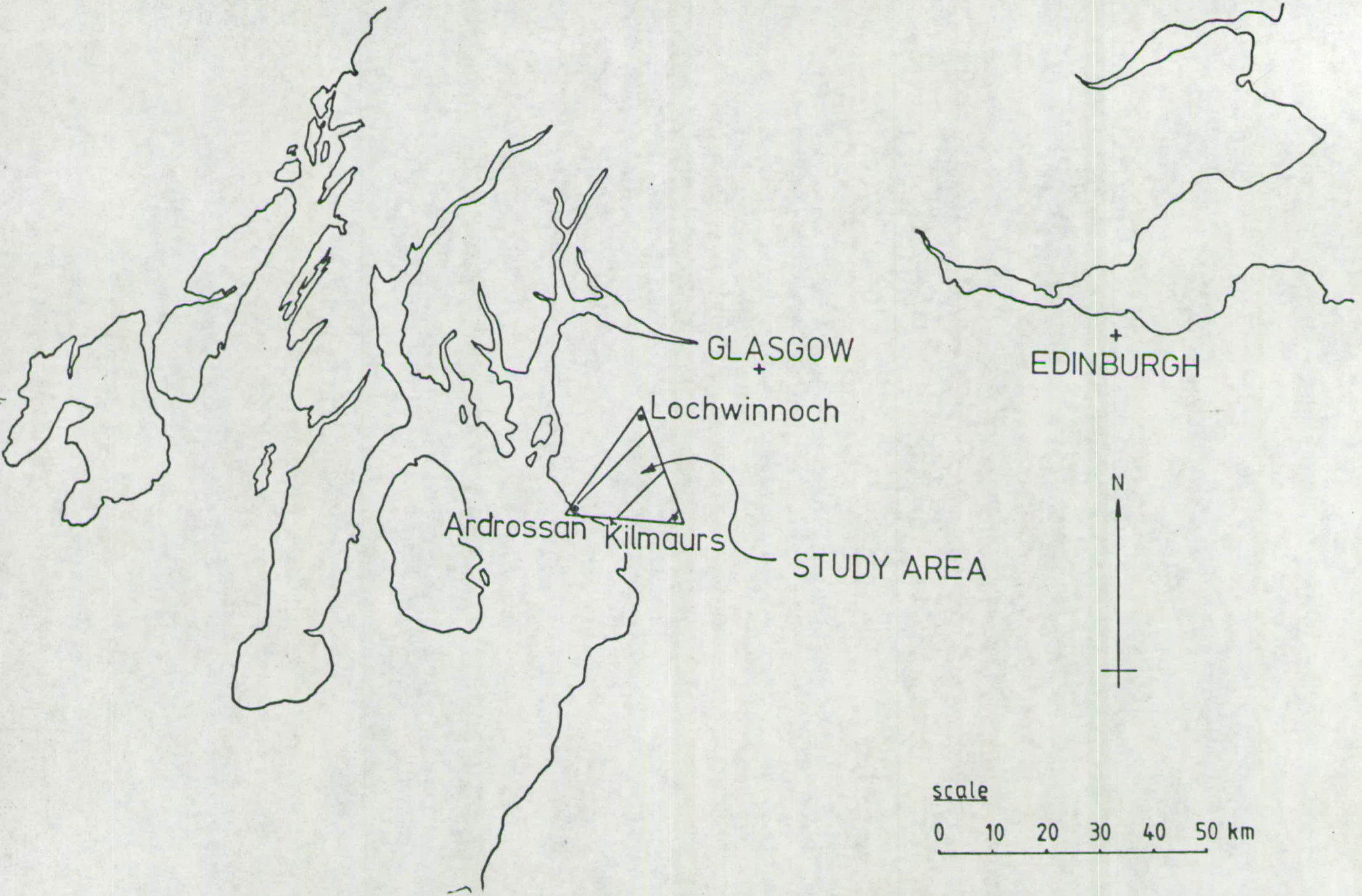
which sediments of Visean and Namurian age outcrop (fig. 1.1). Geographically it is roughly triangular in shape with the towns of Lochwinnoch to the north, Ardrossan to the west and Kilmaurs to the east (fig. 1.2). The ground is generally low-lying with a thick cover of glacial deposits, mostly till, and exposure is confined to shore and stream sections and abandoned quarries.

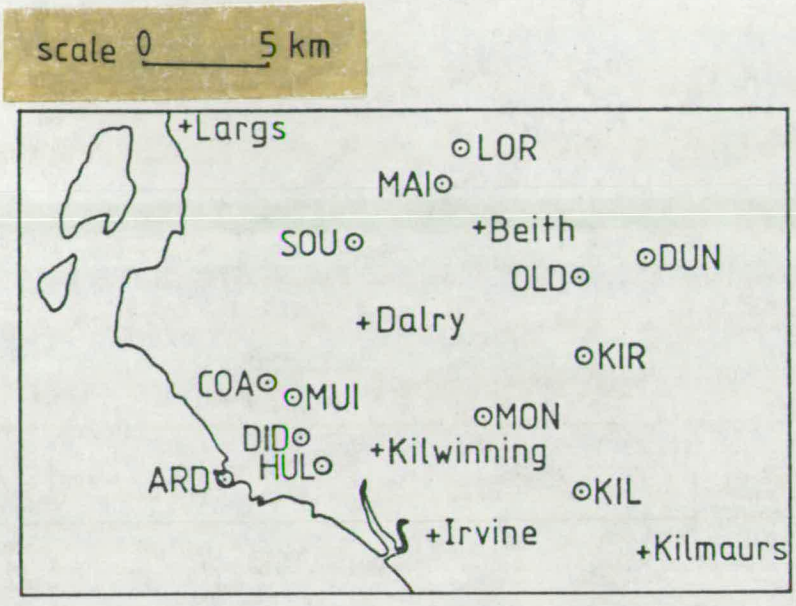
1.3 Methods and approach

The data base of old borehole information can be used effectively only in association with recently examined sections, where detail of both lithology and fauna are recorded. Much of the old borehole data was correlated solely on a lithostratigraphic basis but when these boreholes are compared with more recent sections with bio-stratigraphic control, a more reliable correlation is possible. Natural exposures giving complete sections through parts of the stratigraphic column are rare in the Dalry Basin and an extensive programme of drilling was initiated to improve this situation. Thirteen boreholes were drilled totalling 1145 m in the Dalry Basin between 1976 and 1978 (fig. 1.3) with a further two boreholes being drilled to the south of the Inchgotrick Fault at Harelaw /NS 4166 3300/ to a depth of 70 m in 1976 and at Deaconhill /NS 4893 3153/ to a depth of 323 m in 1981.

The geological objectives of each of the boreholes were to determine the stratigraphic sequence between (see fig 2.1)

1. the Top Hosie Limestone and the Clyde Plateau Volcanic Formation -
   - Ardrossan Borehole
   - Coalhill No 2 Borehole
   - Dunniflat Borehole
   - Kirkwood Borehole
   - Lora Burn Borehole
   - Muirlaught Borehole


GLASGOW
EDINBURGH
Lochwinnoch
Ardrossan
Kilmaurs
STUDY AREA
N
scale
0 10 20 30 40 50 km



Location map - IGS boreholes 1976-78

Name	Abbrev.	Grid Ref.	Depth (m)
Ardrossan	ARD	NS 2308 4191	78
Coalhill No 2	COA	NS 2432 4653	140
Diddup	DID	NS 2651 4406	174
Dunniflat	DUN	NS 4203 5314	58
Hullerhirst	HUL	NS 2730 4260	76
Kilmaurs	KIL	NS 3955 4124	85
Kirkwood	KIR	NS 3885 4716	78
Lora Burn	LOR	NS 3336 5841	45
Maich Water	MAI	NS 3290 5637	57
Montgreenan	MON	NS 3503 4523	161
Muirlaught	MUI	NS 2604 4614	100
Old Mill	OLD	NS 3897 5239	67
South Hourat	SOU	NS 2883 5378	26

Footnote: Detailed logs lodged with IGS, Edinburgh

2. the Dockra Limestone and the Clyde Plateau Volcanic Formation - Old Mill Borehole
South Hourat Borehole;

3. the Passage Group Volcanic Formation and the Broadstone Limestone - Montgreenan Borehole;

4. the Passage Group Volcanic Formation and the base of the Upper Limestone Group - Diddup Borehole
Hullerhirst Borehole
Kilmaurs Borehole;

5. the Maich Shell Bed and the Johnstone Shell Bed in the Limestone Coal Group - Maich Water Borehole;

6. the Passage Group Volcanic Formation and a sequence of late-Tournasian cementstone-bearing rocks south of the Inchgotrick Fault - Harelaw Borehole;

7. the Passage Group Volcanic Formation and the unconformity at the base of the Upper Old Red Sandstone south of the Inchgotrick Fault - Deaconhill Borehole.

Each borehole was successful, though Coalhill No 2 Borehole was a second attempt. Coalhill No 1 Borehole, sited some 10 m to the south, penetrated faulted strata near the top of the borehole. Each borehole was cored from rockhead to total depth. The technique employed was air-flush drilling, which proved successful with good core recovery. In the Diddup Borehole water-flush technique was used to obtain the bottom 20 m of core while at Deaconhill, having a greater estimated depth, drilling mud was used throughout.

The lithological and palaeontological data from these boreholes were used to confirm or revise the correlation of the old borehole

data, prior to use in the geological analysis.

The thesis begins by examining the criteria which may be used to divide the sediments of the Dalry Basin into stratigraphic units. This is done to establish a practical basis for description and comparison both within the basin and with areas outside. The criteria which are examined include lithostratigraphy, bio/chronostratigraphy, major cycles and the integrated litho/bio/chronostratigraphy used on current IGS maps.

Having determined the stratigraphic framework which is most applicable to the Dalry Basin, each major grouping is examined separately. The principal outcrop data are assessed and the data from the IGS drilling programme presented and correlated. Where appropriate the nature of any cyclicity has been demonstrated using a simple mathematical technique and, using additional old borehole information, isopach maps and maps of sediment distribution have been constructed. Finally the palaeogeography, the depositional environment and the factors controlling sediment distribution are assessed for each major stratigraphic grouping.

In the final chapters the depositional and tectonic environments are discussed and compared with modern and other ancient analogues in order to construct a history of deposition in the Dalry Basin.

1.4 Summary of previous geological research

The Pioneers

The earliest account of the strata in and around the Dalry Basin appeared in 'Prize Essays and Transactions of the Highland and Agricultural Society of Scotland' in 1839 when Montgomery proposed a 3-fold stratigraphic division. 'Coal Formation', 'Trap Rock' and

Old Red Sandstone were proposed, the 'Coal Formation' being what is now regarded as the sediments of Carboniferous age. In the following year J Craig (1840) presented a stratigraphic sub-division of the Carboniferous sediments of the Glasgow area to the British Association. He recognised a 'lower coal series', a 'limestone series', an 'upper coal series' and a 'red sandstone series' corresponding to what would now be termed the Limestone Coal Group, the Upper Limestone Group, the Lower and Middle Coal Measures and the Upper Coal Measures respectively.

The New Statistical Account of Scotland, published in 1845, gave details of the economic deposits, coal, limestone etc which were worked, and included detailed sections of the coal-bearing strata of the Kilbirnie area.

The Primary Geological Survey

The first edition of the geological map, Sheet 22, was published in 1870 with a sheet explanation by A Geikie, J Geikie, R L Jack and R Etheridge, jun, following in 1872. In this, the first comprehensive account of the rocks of the area, the Carboniferous strata were divided into three major units shown below.

Coal Measures	(b) red sandstones, marls, fireclays and shales etc with carboniferous plants but no coal seams,
	(a) white and grey sandstones, dark shales, fireclays, ironstones and coals.
Carboniferous Limestone Series	sandstones, shales and limestones with seams of coal and ironstone;

an enthusiastic amateur geologist, made a very valuable contribution to our knowledge of the geology of the area by carefully observing and recording sections, many of which are now no longer available. Smith (1882) gave a comprehensive account of the geology of the Dalry area, and in 1898 he reported the presence of volcanic ash associated with the Dalry Blackband Ironstone in a railway cutting at Lissens, north-east of Kilwinning. He also made the first record in 1895 of the presence of bauxitic clays in the Passage Group.

The Revision Geological Survey

From 1911 to 1924 the Geological Survey revised the geological map Sheet 22. The value of fossils in correlation had by this time been clearly recognised though the interpretation of the results sometimes caused controversy.

A major advance in the correlation of the Carboniferous strata throughout the Midland Valley was made in 1929 when M Macgregor's presidential address to the Geological Society of Glasgow was published.

Wilson (1922) gave a detailed account of the Ayrshire Bauxitic Clay and Lapparent (1936) identified the minerals boehmite and diaspore for some of the samples.

During this revision survey other advances made in the stratigraphy of the sediments of the Dalry Basin and adjacent areas included the recognition that a major part of the Limestone Coal Group was absent south of the Inchgotrick Fault (Richey 1925) and that contemporaneous faults had a major effect on sedimentation (Anderson 1925).

Following observations made during the revision survey Richey

(1946) described features in the Dockra Limestone (see chapter 6).

Regional Studies

A number of authors have attempted to trace variation in individual stratigraphic units across the Midland Valley and these have become more detailed as time progressed and the volume of borehole data increased. Macgregor and Manson (1935) demonstrated thickness variation in the Upper Limestone Group and, with more success in the Limestone Coal Group. Richey (1937) related thickness variation to contemporaneous fault movement. More recently Goodlet (1957) presented an isopach map for the Lower Limestone Group with sandstone and limestone isolith maps and a lithofacies map.

These maps give a broad impression of sediment distribution in the Visean and Namurian of the Midland Valley.

Recent research

Recent work on the sediments of the Dalry area is somewhat limited. Burgess (1965) described two species of Calcifolium and proposed a correlation between the Dockra and the Blackhall Limestones. Shiells (1966) described a new productid brachiopod from the Dockra Limestone and the limestone lithologies in Trearne Quarry. Subsequently a more detailed account of the variation in the limestone facies was included with the publication of his notes (Shiells and Penn, 1971). The regional variation in the Dockra Limestone lithologies, its depositional and diagenetic history have been the subject of a post-graduate thesis (Brown 1975).

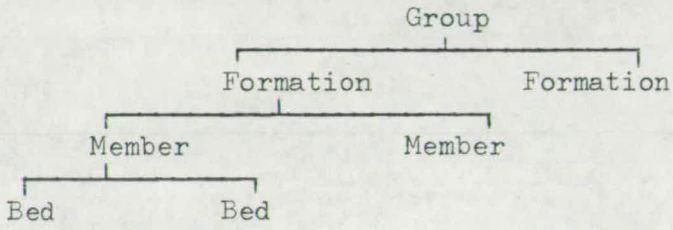
The most recent contribution to the geology of the Dalry Basin (Wilson 1979) attempts to settle the controversy of the Dockra

correlation presenting the palaeontological results of the drilling programme associated with this study.

The lithological succession with named marked horizons is shown in fig. 2.1.

2.4 Lithostratigraphy as a basis for division

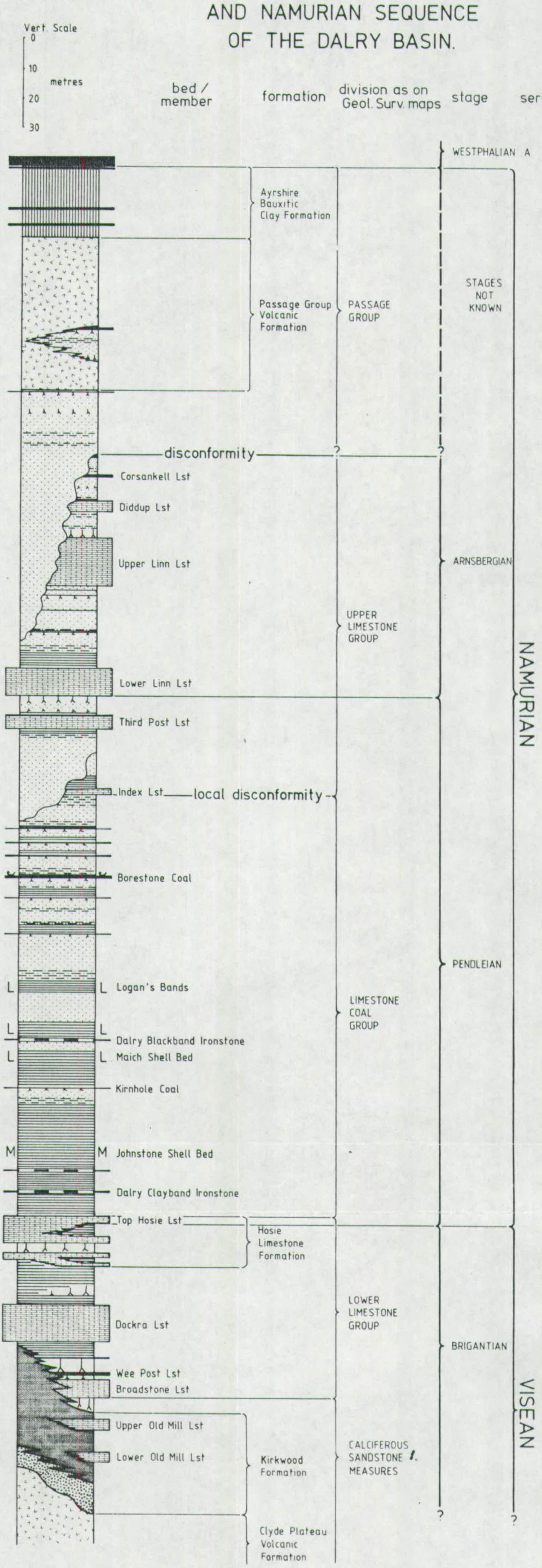
The rules related to lithostratigraphic procedure are set out and discussed by Harland et al (1972), Hedberg (1976) and Holland et al (1978). Each recommends a hierarchical system of litho-stratigraphic division as illustrated below.



The Formation is the primary unit of lithostratigraphic classification. It should possess some degree of internal homogeneity or distinctive lithological features that constitute a unity by comparison with adjacent strata. Practicality of mapping or delineating on cross sections is an important consideration in the establishment of formations. Thickness is not a determining feature and may vary from less than a metre to several thousand metres, depending on the size of units locally required to express best the lithological development of a region at the scale being used.

A Group consists of two or more adjacent and naturally related or associated formations with significant unifying lithological features in common. The aggregation of formations into groups should provide a means of simplifying and generalising stratigraphic classification without losing an appreciation of the overall

STRATIGRAPHY OF VISEAN AND NAMURIAN SEQUENCE OF THE DALRY BASIN.



lithological sequence.

A Member is recognised as a named entity within a formation possessing lithological characteristics distinguishing it from adjacent parts of the formation.

A Bed is the smallest unit in the hierarchy of litho-stratigraphic units. It is a unit layer in a stratified sequence of rocks which is lithologically distinguishable from other layers above and below.

The rock succession in the Dalry Basin could be divided up on this basis. However, by disregarding the fossils in the succession, correlation and comparison with successions developed elsewhere are precluded.

2.5 Bio/chronostratigraphy as a basis for division

Stratigraphic stages have been defined within the two sub-systems of the Carboniferous, the Silesian and the Dinantian on the basis of biostratigraphy (Ramsbottom et al 1978, George et al 1976). These stages are thought by the authors to approximate to time units. Stratotypes are described for each stage within the Dinantian but only biostratigraphic marker horizons have been defined within the Silesian.

Chronostratigraphic stages should be as widely applicable as possible, but difficulties arise when faunas are absent or are perhaps present only in the occasional band as a result of facies variation. Volcanism, active tectonism and sedimentary cycles mask and distort the record of the evolving faunas, fossils may be rare or limited to specific lithological horizons. These difficulties make identification of the stages imprecise in the Dalry Basin and

only a rough stratigraphic tool.

2.6 Major cycles as a basis for division

Major cycles have been used as a basis for stratigraphic division by a number of authors, principally Ramsbottom (1973, 1977) and Talbot (1973). These major cycles are thought to result from eustatic changes in sea level and are thus a close approximation to chronostratigraphic divisions. Talbot recognised four asymetric, upward-shallowing cycles in the Corallian rocks of England, each separated from the next by a non-sequence, usually an erosion surface, which marked a marine transgression.

A lithostratigraphic division of the same sequence was defined by Arkell (1947), the boundaries of which coincided with those of his ammonite zones. This correspondence has been demonstrated as invalid by Callomon (1969) who suggested that the biostratigraphic ammonite zones diverged radically from the lithostratigraphic units. Talbot's major cycles correspond exactly with three of Arkell's five lithostratigraphic divisions while the fourth major cycle includes both the remaining lithostratigraphic divisions.

These studies demonstrate that units which purport to be chronostratigraphic will have different boundaries depending on the criteria used to define the chronostratigraphic unit.

Ramsbottom (1973) has recognised four major cycles within the Carboniferous, Dinantian succession in the area between the Southern Uplands of Scotland and the Mendip Hills. Each is characterised by transgressive and regressive phases recognised by changes in lithology and fauna. Stratigraphical breaks and disconformities within the succession are regarded by Ramsbottom

as resulting from regressions. Each major transgression brings into the area distinctive faunas, the biostratigraphic classification of which define boundaries which differ from the coral/brachiopod zones of Smith et al (1967) and Green and Welsh (1965). Ramsbottom divided the Dinantian on the basis of these major cycles each of which has a faunal sequence which is distinctive and recognisable. The boundaries of the major cycles correspond with those of the chronostratigraphic stages (table 2.1).

Major cycles in the Namurian are discussed in a further paper by Ramsbottom (1977). Eleven major cycles are defined within conformable basinal sequences on the basis of significant faunal renewals and are traced on to shelf or 'block' areas where they are bounded by non-depositional unconformities or paraunconformities, with the basal faunas of each major cycle missing. Six of the major cycle and stage boundaries correspond (table 2.2).

The recognition of Ramsbottom's major cycles in the Scottish Carboniferous in general and in the Dalry Basin in particular is difficult requiring that a distinction be drawn between what is a major and what is a minor cycle. This difficult problem is further confused by the influences of local tectonism and the rapid variation in sediment type characteristic of periodic deltaic deposition. The faunas too are difficult to match across the Southern Uplands. Two of the Namurian major cycles or mesothems (N1 and N2) are defined by Ramsbottom (1978) as including, in Scotland, all strata from the Top Hosie Limestone to the top of the Upper Limestone Group (table 2.2). The remaining nine major cycles all lie within the Passage Group which, in the Dalry Basin, is composed largely of volcanic rocks.

TABLE 2.1

Comparison of divisions of the Dinantian

Series	Stages	Coral/Brachiopod Zones Smith et al (1967) and Green and Welsh (1965)	Major Cycles (mesothems) Ramsbottom 1973	Division on Geological Survey Maps (1928) and IGS maps (in preparation) - Dalry Basin	
		Upper Posidonia (P_2) Zone		Lower Limestone Group	
	Brigantian	Upper Dibunophylum (D_2) Zone	Sixth Group of Minor Cycles		Upper Sedimentary Group (1928)
	Asbian	Lower Dibunophylum (D_1) Zone	Fifth Group of Minor Cycles		
Visean	Holkerian	Seminula (S_2) Zone	Major Cycle 4		Clyde Plateau Volcanic Formation
	Arundian	Upper Caninia (C_2S_1 Zone)	Major Cycle 3	Calciferous Sandstone Measures	
	Chadian	Lower Caninia (C_1) Zone	Major Cycle 2		
Tournaisian	Courceyan	Zaphrentis (Z) Zone Cleistopora (K) Zone	Major Cycle 1		
		ORS facies			? ORS

Adapted from George et al (1976)

TABLE 2.2

Comparison of divisions of the Namurian

Series	Stages	Goniatite Zones Ramsbottom 1969	Major Cycles (mesothems) Ramsbottom 1977	Division on Geological Survey Maps (1928) and IGS maps (in preparation) - Dalry Basin
	Yeadonian	G_1	N11	Ayrshire Bauxitic Clay Formation — ? —
			N10	
	Marsdenian	R_2	N9	
			N8	Passage Group
	Kinderscoutian	R_1	N7	Passage Group Volcanic Formation
			N6	
Namurian	Alportian	H_2	N5	
	Chokierian	H_1	N4	
			N3	
	Arnsbergian	E_2	N2	Upper Limestone Group
	Pendleian	E_1	N1	Limestone Coal Group
				Lower Limestone Group

Adapted from Ramsbottom et al (1978)

Ramsbottom's mesothems may be a powerful chronostratigraphic tool in correlating sequences over a wide area, but, so far as the Dalry Basin is concerned, they offer too coarse a division within the fossiliferous strata and too fine a division within the volcanic succession.

2.7 Division as shown on Geological Survey maps

This has been reviewed in the light of recent stratigraphical research by Lumsden and Wilson (1979). The Carboniferous in the West of Scotland is divided into eight 'groups' which are not groups in the strict lithostratigraphic sense (see chapter 2.4). Each 'group' contains rocks or cycles of rocks with generally similar lithological characteristics, however, the 'group' boundaries are defined by marker horizons which are widespread within the Midland Valley of Scotland and are faunally distinctive.

Correlations can be readily made throughout the Midland Valley of Scotland using this system and comparisons made of different lithological sequences. The Geological Survey classification has evolved over many years and the 'group' names, Lower Limestone Group, Passage Group, Upper Limestone Group etc., are well established in the literature. There is room, however, for confusion if litho-stratigraphic groups are applied to a sequence divided on the basis of the Geological Survey classification. Henceforth, group is used meaning a lithostratigraphic group of Holland et al with 'group' meaning a group in the Geological Survey classification.

2.8 Stratigraphic division of the succession in the Dalry Basin

It is proposed in this thesis to adopt the 'groups' as used on Geological Survey maps as the basic descriptive units. These are established stratigraphic units whose boundaries are well defined in the literature. The basic lithological unity makes the 'group' a useful unit for description but where smaller units are required, formations can be defined. The aggregation of formations into groups is avoided, the only 'groups' referred to being those used on Geological Survey maps. The relationship between the lithological succession, formations, 'groups' and chronostratigraphic stages and series is shown in fig. 2.1.

2.9 Calciferous Sandstone Measures - definition and component units

The base of the Carboniferous has not been established in Scotland (Lumsden and Wilson 1979). The molasse type of deposit of red sandstones and siltstones called the Upper Old Red Sandstone can pass upwards into the grey sediments of the Calciferous Sandstone Measures with no apparent break in the sequence. Macro fossils from the lowest beds of the Calciferous Sandstone Measures are not the definitive zonal forms. A miospore zonation has been erected (Neves et al, 1973) in Scotland, but no evidence was found for the presence of the two lowest zones in the scheme proposed for the British Carboniferous as a whole (Neves et al, 1972). A horizon marked by the incoming of Lycospora has been suggested (Neves et al 1973, p 43) but this horizon is not corroborated by either lithological or macrofaunal evidence as the base of the Carboniferous system.

The base of the Carboniferous has, in practice, been drawn arbitrarily at the junction between the red sandstones of the Upper Old Red Sandstone and the grey sediments of the Calciferous Sandstone Measures. This thesis is concerned only with the sediments overlying the Clyde Plateau Volcanic Formation in the Dalry Basin which is itself of Carboniferous age and so the knotty problem of defining the base of the Calciferous Sandstone Measures is avoided.

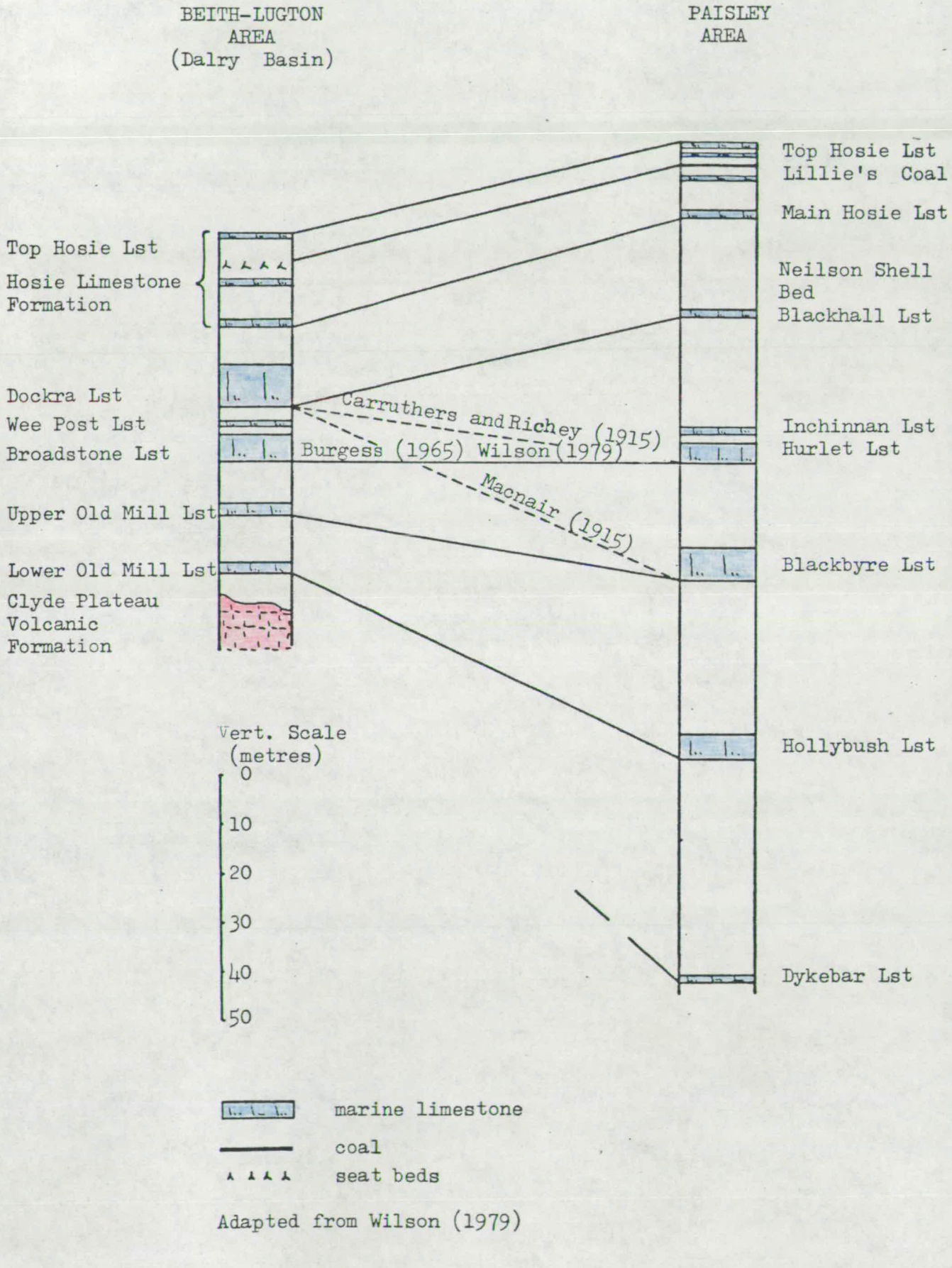
The junction between the Calciferous Sandstone Measures and the Lower Limestone Group is defined as the base of the Hurlet Limestone but the correlation of this horizon into the Dalry Basin has been disputed. Four correlations have been proposed, by Carruthers and Richey (1915), Macnair (1915), Burgess (1965) and Wilson (1979), and are shown in fig. 2.2.

Macnair correlated the Hurlet Limestone with the lowest limestone in the Hosie Limestone Formation, while Carruthers and Richey correlated it with the Dockra Limestone. Each correlation is based on a lithological comparison of the succession in the Dalry Basin with that in the Paisley area. Four species of marine bivalve* were recorded by Macnair from the mudstones below the Hurlet Limestone in several parts of the Midland Valley. He called this assemblage the Abden fauna (Macnair 1917). Although this fauna is present under the Hurlet Limestone at Howwood just north of the Dalry Basin (Macnair 1915), he could not find it in Ayrshire and concluded that the Hurlet Limestone was missing.

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* Abden fauna consists of Sanguinolites abdenensis, Streblopteria ornata, Actinopteria persulcata, and Myalina verneuili.

A COMPARISON OF STRATIGRAPHIC CORRELATION



Adapted from Wilson (1979)

Two of the four bivalves of Macnair's Abden fauna were found on the Rye Water at Cunningham-Baidland /NS 279 509/ by W Manson in mudstones beneath a quarried limestone which was considered to be the Dockra Limestone (Manson 1927). This discovery lent strong support to the Dockra-Hurlet correlation of Carruthers and Richey as it used Macnair's own line of evidence.

A third correlation, proposed by Burgess (1965) is based on the distribution of certain algal species of the genus Calcifolium within the succession. Burgess considered Calcifolium punctatum Maslov to be the characteristic form within the Hurlet Limestone while the overlying Blackhall Limestone was characterised by C. okense Shretzov and Binna. In the Dalry Basin only C. punctatum was found and that within the Broadstone Limestone, leading Burgess to correlate the Broadstone Limestone with the Hurlet Limestone and the Dockra Limestone with the Blackhall Limestone (fig. 2.2).

The re-examination of these strata by myself, and the examination of much new faunal evidence by Dr R B Wilson, particularly from boreholes, has led to a re-appraisal of the correlation of these strata (Wilson 1979). The Dockra-Hurlet correlation of Carruthers and Richey which, to date, has been that most widely accepted, has as its corner stone the presence of elements of the Abden fauna below the Dockra Limestone at the Rye Water near Cunningham-Baidland (Manson 1927). The area around Cunningham-Baidland has been recently re-mapped and a sketch map of the area is shown in fig. 2.3. The point marked x corresponds both geographically and geologically with that described by Manson, though no fossils were found. The point has been mapped as being at the base of the Broadstone Limestone and not the Dockra Limestone as assumed by

Manson. The arguments for this are as follows:

(1) the typical Dockra Limestone lithology in the area, light brownish-grey limestones with thin argillaceous partings, matches exposures in a quarry face to the west of the Manson locality but does not match with the dark grey argillaceous limestones and mudstones at the Manson locality which is more typical of the Broadstone Limestone;

(2) if these two exposures are the upper and lower parts of a single Dockra Limestone, then this limestone must here be about 40 m thick, much thicker than recorded anywhere else in the Dalry Basin;

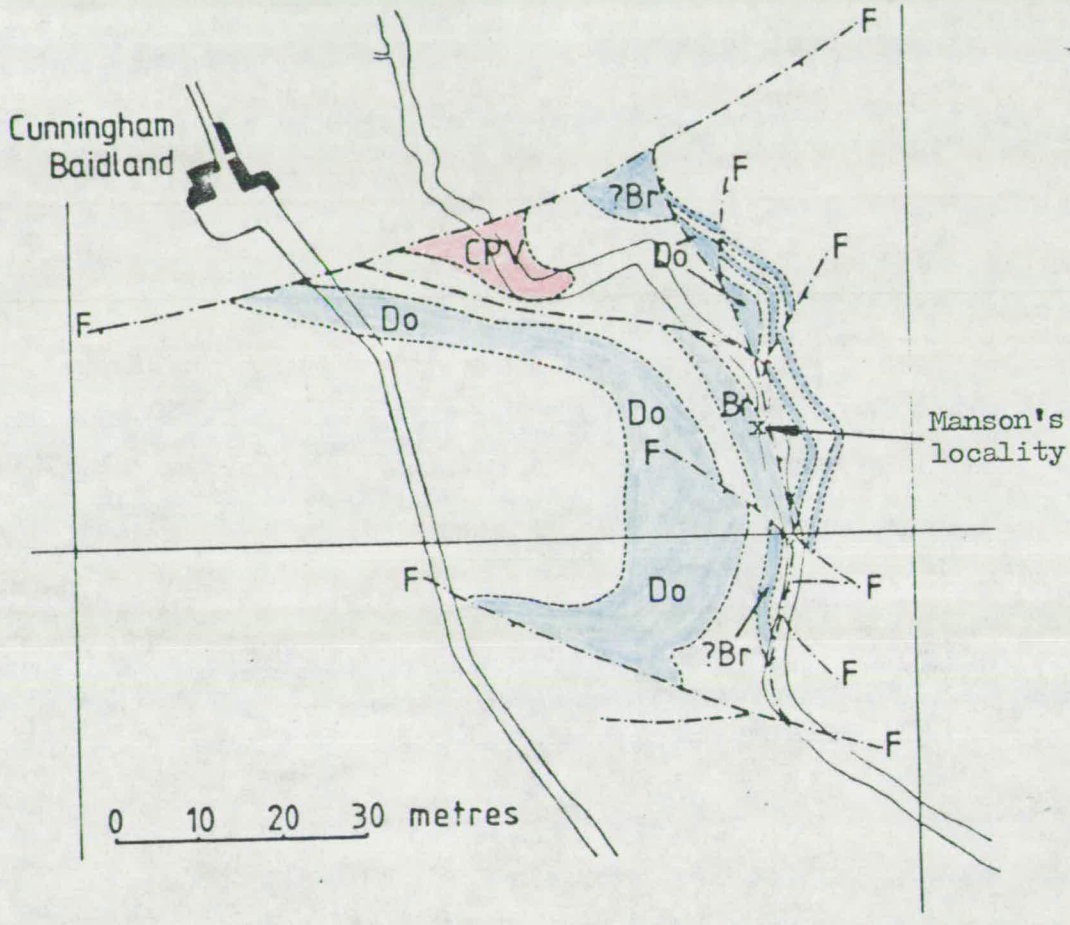
(3) Craig (1869) reported two major limestones as being present at Cunningham-Baidland quarry with coal developed between them.

A further line of evidence in the re-appraisal of the correlation comes from the recognition of Neilson Shell Bed faunas in the Dalry area for the first time. The Neilson Shell Bed is a marine band which can be traced from Paisley to Fife and East Lothian. In the Glasgow area it carries a rich and varied fauna and occurs in the mudstones overlying the Blackhall Limestone. The fauna is described by Wilson (1966) who shows that some of the species present are confined to this horizon in the Lower Carboniferous of central Scotland.

A few diagnostic species from the Neilson Shell Bed (Wilson 1979) occur within the calcareous mudstone intercalations in the upper part of the Dockra Limestone in the Ardrossan Borehole, the Coalhill No 2 Borehole and the Kirkwood Borehole. Typical Neilson Shell Bed faunas have also been collected by P J Brand (IGS) from

Fig. 2.3

GEOLOGICAL SKETCH MAP OF CUNNINGHAM-BAIDLAND AREA



Limestones are shown in blue

Do Dockra Limestone

Br Broadstone Limestone

CPV Clyde Plateau Volcanic Formation

F Fault

outcrops of Dockra Limestone from the shore north of Castle Craigs, Ardrossan /NS 2287 4266/.

The evidence thus points to a Broadstone-Hurlet correlation (fig. 2.2). In consequence the boundary between the Calciferous Sandstone Measures and the Lower Limestone Group will be taken at the base of the Broadstone Limestone within the Dalry Basin.

New names used in lithostratigraphic subdivision of the Calciferous Sandstone Measures are defined below:

Clyde Plateau Volcanic Formation: a formation wholly within the Calciferous Sandstone Measures consisting of mostly basaltic lavas erupted during the early Carboniferous and attaining a maximum thickness of about 1000 m. These rocks have been frequently referred to as the 'Clyde Plateau Lavas'.

Kirkwood Formation: a formation within the Calciferous Sandstone Measures and partly, in places, within the Lower Limestone Group consisting of tuffaceous mudstones and tuffs overlying the basaltic lavas of the Clyde Plateau Volcanic Formation. The formation is locally intercalated with non-tuffaceous sediments, sometimes with marine horizons developed. The Kirkwood Formation is typically developed in the Kirkwood Borehole (IGS Reg No NS 34 NE/11) /NS 3885 4716/ between 39.77 and 75.30 metres from surface.

Upper Old Mill Limestone: a member within the Kirkwood Formation, a marine limestone, 3.9 m thick, occurring in a non-tuffaceous intercalation within a tuffaceous sequence. It is known only from borehole evidence and is correlated with the Blackbyre Limestone of the Paisley area (fig. 2.2). The Upper Old Mill Limestone is typically developed in the Old Mill Borehole (IGS Reg No NS 35 SE/80) /NS 3897 5239/ between 40.40 and 44.30 metres from surface.

Lower Old Mill Limestone: a member within the Kirkwood Formation, a marine limestone 3.01 m thick occurring in a non-tuffaceous intercalation within a tuffaceous sequence. The presence of Semiplanus cf latissimus (J Sowerby) suggests correlation with the Hollybush Limestone of the Paisley area (Wilson 1979). The Lower Old Mill Limestone is typically developed in the Old Mill Borehole between 52.62 and 54.63 metres from surface.

2.10 Lower Limestone Group - definition and component units

The junction between the Lower Limestone Group and the underlying Calciferous Sandstone Measures is taken, as discussed previously, at the base of the Broadstone Limestone. Over a part of the area of the Dalry Basin, the Broadstone Limestone is unfortunately not present and the junction must be drawn either within or at the top of the underlying Kirkwood Formation. In places the top of the Kirkwood Formation may be within the Lower Limestone Group. (See discussion in chapter 4). The junction between the Lower Limestone Group and the Limestone Coal Group is taken at the top of the Top Hosie Limestone, the topmost of a group of generally thin limestones and is characterised by the presence of Posidonia corruguta.

One new name used in the lithostratigraphic subdivision of the Lower Limestone Group is defined below:

Hosie Limestone Formation: a formation wholly within the Lower Limestone Group, consisting of thin argillaceous limestones interbedded with mudstones and calcareous mudstones. Seatclays, sandstones and coals are occasionally developed within the formation. The limestone units have traditionally been referred to as Hosie

Limestones A, B, C and D but recent investigations show this classification to be inappropriate. The Hosie Limestone Formation is typically developed in the Paduff Burn /NS 3020 5490/.

2.11 Limestone Coal Group - definition and component units

The junction between the Limestone Coal Group and the underlying Lower Limestone Group is taken, as discussed previously, at the Top Hosie Limestone. The junction with the overlying Upper Limestone Group is taken at the base of the Index Limestone, a marker horizon present over a wide area within the Midland Valley of Scotland. Difficulties arise with this boundary in parts of the Dalry Basin when the Index Limestone is absent (see chapter 8).

Subdivision is not necessary within the thin successions of the Limestone Coal Group in the Dalry Basin, though a case can be made for describing the argillaceous strata at the base of the 'group' separately from the succeeding sandstones, siltstones and coals. The names of beds and members used in the descriptions are established names in the geological literature of the area.

2.12 Upper Limestone Group - definition and component units

The junction between the Upper Limestone Group and the underlying Limestone Coal Group is taken, as discussed previously, at the base of the Index Limestone. The junction with the overlying Passage Group is taken in the Midland Valley at the top of the Castlecary Limestone which is not known to be present in the Dalry Basin. A disconformity marks the top of the Upper Limestone Group throughout the area, though this is inferred rather than directly observed. The lower strata where limestone bands are present are included with the Upper Limestone Group while the strata above with Lingula sp. bands are included within the Passage Group.

New names used in the lithostratigraphic subdivision of the Upper Limestone Group are defined below:

Diddup Limestone: a member within the Upper Limestone Group, a marine limestone 2.90 m thick occurring above the Upper Linn Limestone and below the Corsankell Limestone in the Diddup Borehole, it crops out in only one locality 120 m south of Diddup Farm /NS 2657 4440/. Its correlative outside the Dalry Basin is not known. The Diddup Limestone is typically developed in the Diddup Borehole (IGS Reg No NS 24 SE/263) /NS 2651 4406/ between 64.70 and 67.60 metres from surface.

Corsankell Limestone: a member within the Upper Limestone Group, a marine limestone 0.71 m thick occurring only in the Diddup Borehole stratigraphically above the Diddup Limestone. Its correlative outside the Dalry Basin is not known. The Corsankell Limestone is typically developed in the Diddup Borehole between 55.85 and 56.56 metres from surface.

2.13 Passage Group - definition and component units

The junction of the Passage Group with the underlying Upper Limestone Group has been discussed previously. The junction with the overlying Lower Coal Measures is formally defined as being at the Gastrioceras subcrenatum Marine Band (Ramsbottom et al 1978). This horizon has not yet been discovered in Scotland and the junction is taken everywhere at an arbitrary line. In the Dalry Basin this is taken at the top of the Ayrshire Bauxitic Clay Formation.

New names used in the lithostratigraphic subdivision of the Passage Group are defined below:

Passage Group Volcanic Formation: a formation wholly within

the Passage Group consisting of extrusive basaltic rocks with some sedimentary intercalations. It is typically developed in the Lugton Water /NS 338 448/.

Ayrshire Bauxitic Clay Formation: a formation defined as being that sequence of strata immediately overlying fresh basaltic lavas of the Passage Group, characterised by the presence of bauxitic clay and related rock types. Interbedded sediments such as coals, seatclays and mudstones are also included within the formation. It is typically developed on the shore at Saltcoats /NS 2412 4150/.

Chapter 3 Calciferous Sandstone Measures

3.1 Introduction

This chapter seeks to describe the strata within the Calciferous Sandstone Measures in the Dalry Basin, to discuss the lateral variation in both thickness and lithology and to suggest factors which may have controlled this variation. The base of the 'group' (see chapter 2) is taken arbitarily at the base of the Clyde Plateau Volcanic Formation, the nearest mappable horizon to the base of the Carboniferous System in this area. The top of the 'group' is taken at the base of the Broadstone Limestone (see fig. 2.4). In areas where the Broadstone Limestone is absent, the topmost sediments of the Kirkwood Formation may, in part, belong to the Lower Limestone Group. For convenience all the strata of the Clyde Plateau Volcanic Formation and the Kirkwood Formation are described within this chapter.

3.2 Clyde Plateau Volcanic Formation - Lithologies and surface distribution

The Clyde Plateau Volcanic Formation has had a marked effect on subsequent sedimentation in the west of Scotland. The lavas, largely olivine-basalts with occasional trachytic members, crop out over a wide area of west central Scotland, from Ardrossan in the south-west, northwards to Greenock and east as far as Strathaven. Similar basaltic lavas form the Kilpatrick and the Campsie Hills north of the River Clyde. The pattern of outcrop (fig. 3.1) is dominated by large northwest trending folds cut by a series of north-east to south-west trending faults (see fig 9.3), but shows an apparent thinning of the lava pile south-westwards towards Ardrossan. The Inchgotrick Fault effectively masks the southern extent of these lavas.

Richey (1928) estimated the lavas to be at least 350 m thick west of Kilbirnie and 'greatly reduced' southwards towards Ardrossan.

3.3 Clyde Plateau Volcanic Formation - geophysical evidence

Recent geophysical work has provided a better understanding of the thickness and distribution of the Clyde Plateau Volcanic Formation, particularly where, as in the Dalry area, it is covered by younger sediments.

A gravity survey by McLean (1966) covered a wide area of what was then known as Ayrshire. He concluded that there were marked west-north-westerly changes in the Upper Old Red Sandstone - Clyde Plateau lava succession with thickening of the Upper Old Red Sandstone or thinning of the Clyde Plateau lavas or both, north-north-eastwards from Ardrossan with a marked change in thickness taking place across the fault running north-east from Ardrossan Harbour. McLean also recognised gradual changes in thickness of Carboniferous sediments across the Dusk Water Fault.

Hall (1974), using seismic techniques, showed that the lavas thinned south-eastwards towards the Dusk Water Fault, thickening again on the south-east side of the fault. A detailed seismic survey across the fault (seismic line 69/3 of Hall) suggested that the fault plane dips gently to the south-east. Hall concluded that the lavas originally formed a north-west to south-east trending outcrop, thinning to the north-east and south-west and truncated by major north-east to south-west trending faults.

3.4 Clyde Plateau Volcanic Formation - conclusions

The following conclusions may be drawn from the surface and sub-surface data available on the rocks of the Clyde Plateau

Volcanic Formation:

1. The Clyde Plateau Volcanic Formation is thickest beneath the northern part of the Dalry Basin, thinning south-eastwards towards the Dusk Water Fault.
2. The thickness of the Clyde Plateau Volcanic Formation changes abruptly across certain faults notably the Dusk Water Fault and the fault running north-east from Ardrossan Harbour; indicating movement along these faults during eruption of the lavas. In the case of the Dusk Water Fault, downthrow was apparently to the south-east.
3. The thickness of overlying Carboniferous sediments changes gradually across the Dusk Water Fault.

3.5 Kirkwood Formation - outcrop data

The Kirkwood Formation directly overlies the lavas of the Clyde Plateau Volcanic Formation and, by definition, is composed dominantly of tuffaceous mudstones and tuffs which vary in colour from dark reddish brown to greenish grey. Non-tuffaceous sediments, sandstones, siltstones and limestones generally grey in colour, occur in association within a restricted area in the Dalry Basin.

The stratigraphy of the Kirkwood Formation and the nature of the lithologies within this unit cannot be readily appreciated from the limited outcrop evidence. An exposure in the Dusk Water /NS 3124 4744/ shows grey and brown tuffaceous mudstones with bands containing igneous pebbles. While it can be demonstrated in outcrop that these rocks are overlain by the Broadstone Limestone, the relationship with the underlying lavas and the total thickness of the formation cannot be determined except by drilling. A further exposure on the eastern margin of the Dalry Basin at Carnals Castle

/NS 5687 4042/ shows at least 4 m of a light olive-grey, bedded, kaolinitic rock with sphaerosiderite. A few metres below is a conglomeratic band consisting of sub-angular pebbles of a light grey acid igneous rock. Both bands occur as isolated exposures within a succession of dark reddish-brown tuffaceous mudstones. The strata immediately overlying the Kirkwood Formation in this area belong to the Hosie Limestone Formation, the Dockra and Broadstone Limestones being absent.

3.6 Kirkwood Formation - borehole data

IGS drilling (1976-78) proved the thickness and nature of the Kirkwood Formation in six boreholes, the Kirkwood, Old Mill, Muirlaught, Ardrossan, Lora Burn and Dunniflat boreholes. The Coalhill No. 2 Borehole proved 41.39 m of strata belonging to the Kirkwood Formation, a minimum thickness, the borehole not having reached the lavas. The principal features of the sequences encountered can be seen from the following tables 3.1 to 3.4 in conjunction with the graphic plots of the borehole strata, shown in figures 3.2-3.8. Key to symbols and ornaments used is given in Appendix I.

The borehole sequences demonstrate that:

1. The Kirkwood Formation varies in thickness; the developments in the Lora Burn, Dunniflat and Ardrossan boreholes being markedly thinner than in the other boreholes.
2. The lithofacies within the Kirkwood Formation varies laterally; marine horizons are impersistent laterally or are contemporaneous laterally with other lithologies.
3. All the tuffs and some of the tuffaceous mudstones are graded.

TABLE 3.1

The Kirkwood Formation in the Kirkwood Borehole /NS 3885 4716/

	Depth (metres) from	to
Mudstones, tuffaceous, mottled dusky brown and light olive grey, fine clastic material, less than 0.5 mm, silty and rooty at top	38.90	48.15
Siltstones, greenish in colour, with basal unit of angular fragments and mudstone clasts up to 1 cm, erosive base	48.15	51.83
Mudstones, tuffaceous, mottled dusky brown and medium grey with poorly preserved brachiopods on seatclay	51.83	53.06
Siltstones and fine sandstones, greenish in colour with occasional roots and listric surfaces, basal unit of mudstone clasts in a muddy matrix	53.06	56.09
Mudstones, tuffaceous, mottled, dusky brown or light olive-grey with occasional roots and abundant sphaerosiderite in top 40 cm	56.09	60.65
Siltstones and fine sandstones, medium grey and greenish grey with some fine roots, basal unit of mudstone clasts	60.65	63.38
Mudstones, tuffaceous, mottled dusky brown and light olive grey, occasional mudstone clasts	63.38	69.50
Siltstones and fine sandstones, mottled greenish grey and olive grey, basal unit of mudstone clasts	69.50	70.26
Mudstones, tuffaceous, mottled dusky brown and olive-grey, frequent listric surfaces, occasional volcanic clasts, ostracods	70.26	73.97
Siltstones, greenish-grey, thin nodular limestone bands with dark grey algal patches	73.97	75.45

KIRKWOOD BOREHOLE

metres from surface

[NS 3885 4716]

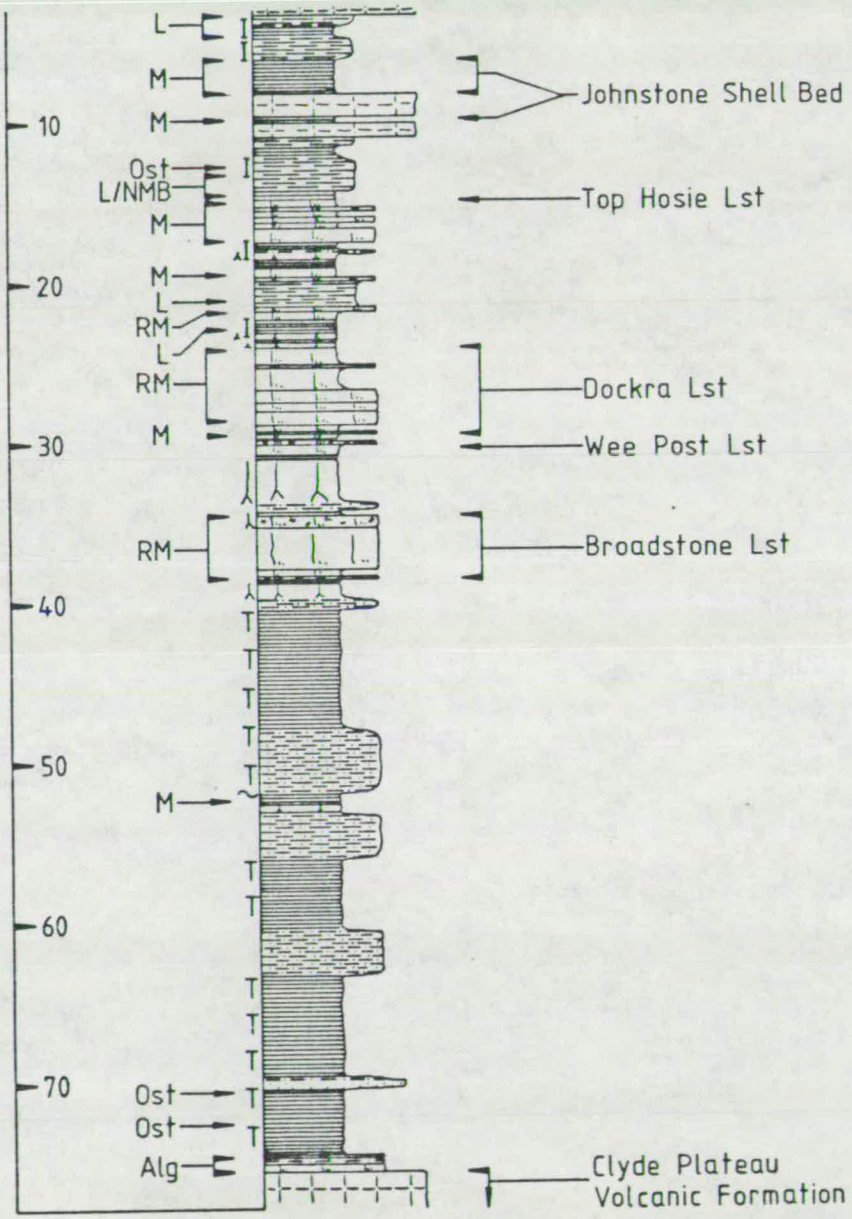


TABLE 3.2

The Kirkwood Formation in the Old Mill Borehole /NS 3897 5239/

	Depth (metres) from	to
Seatclay, light greenish-grey with carbonate concretions at base	33.52	37.81
Mudstone, tuffaceous, mottled dusky brown and greenish-grey, carbonate concretions below 38.95 m	37.81	40.40
Upper Old Mill Limestone: limestone, coarse grained and crinoidal at base becoming argillaceous with carbonate concretions, becoming a greenish-grey concretionary limestone at top	40.40	44.30
Mudstone, tuffaceous, with occasional silty band, mottled olive grey and dusky red, mottling associated with roots or former foot channels	44.30	51.62
Lower Old Mill Limestone: limestone, coarse grained, hard, compact, crinoidal limestone fining upwards to a medium to dark grey, bedded, calcareous mudstone	51.62	54.63
Sandstone, medium grained, greenish-grey with coalified plant fragments and small scale ripple lamination	54.63	55.93
Mudstones, tuffaceous, mottled dusky brown and greenish-grey with fine igneous clasts less than 1 mm	55.93	59.61
Mudstones, tuffaceous, mottled, dusky brown and greenish grey with bands containing igneous and 'sedimentary' clasts up to 2 cm, the sedimentary clasts being largely tuffaceous mudstones.	59.61	62.14

OLD MILL BOREHOLE

[NS 3897 5239]

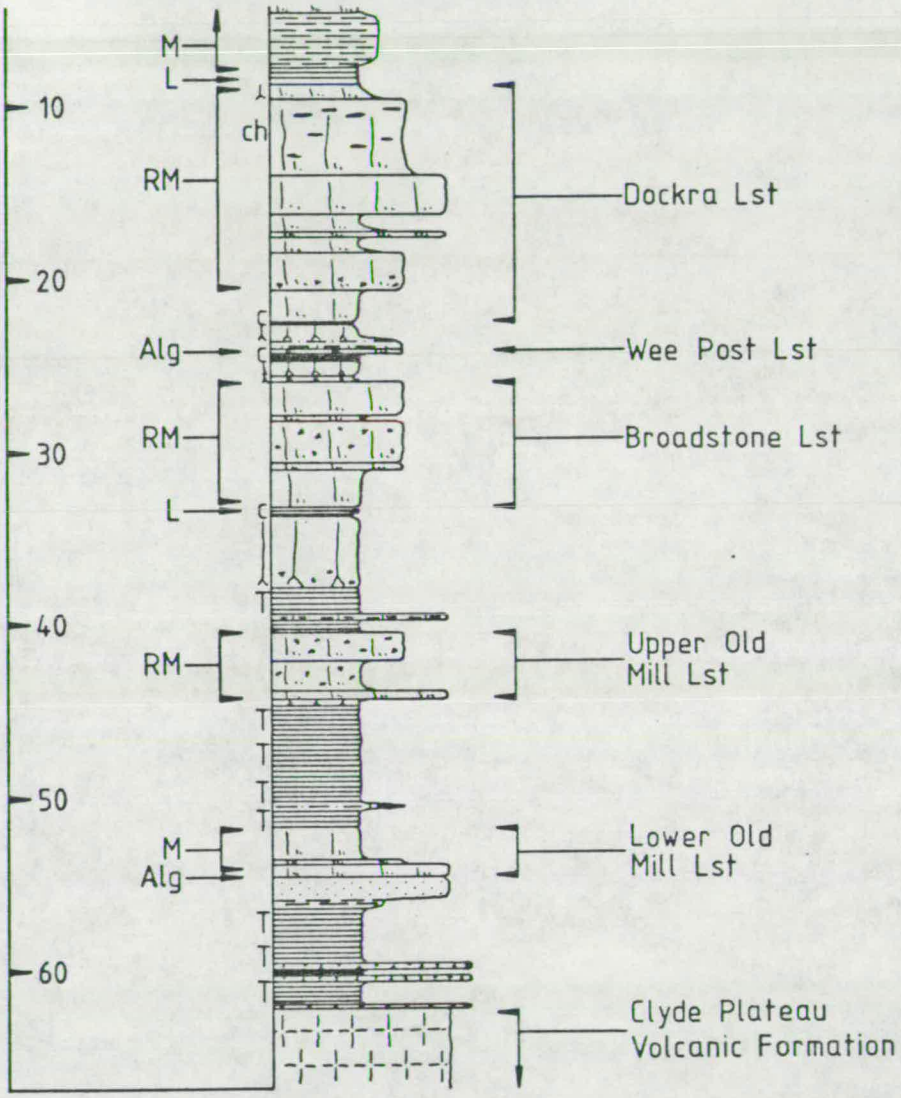


TABLE 3.3

The Kirkwood Formation in the Coalhill No 2 Borehole /NS 2432 4653/

	Depth (metres) from	to
Mudstones, tuffaceous, mottled brownish-grey and olive grey with occasional small igneous clasts up to 3 mm, some beds with coarser igneous clasts up to 2 cm, well rounded and well packed	98.53	118.54
Mudstones, tuffaceous, brownish-grey with bands up to 3.30 m thick of greenish-grey, well rounded and well packed igneous clasts up to 1 cm, light greenish grey, medium grained sandstone band	118.54	126.50
Mudstones, tuffaceous and tuffs, purplish grey with igneous clasts up to 1 cm at base fining upwards further band with igneous clasts up to 1 cm at top	126.50	133.00
Tuffs, dark greenish-grey, with igneous clasts up to 3 cm, well rounded and well packed in a silty matrix	133.00	137.24
Mudstone, tuffaceous, brownish grey with small igneous clasts up to 5 mm	137.24	139.92

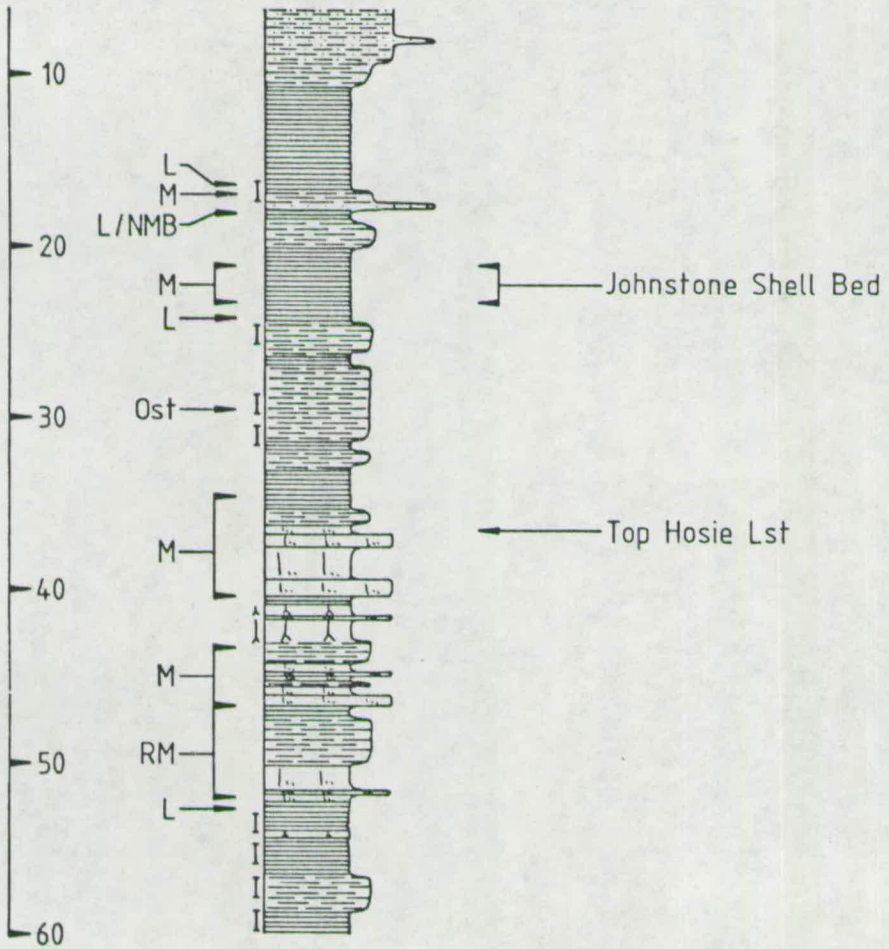
The Kirkwood Formation in the Muirlaught Borehole /NS 2604 4614/

Mudstones, tuffaceous, mottled greenish grey and brownish grey, small, well rounded, igneous clasts, particularly to base, becoming blocky upwards with steep joints	76.70	92.00
Tuffs, greenish-grey, well rounded, well packed igneous clasts up to 4 cm with a muddy matrix in units of variable thickness, tending to fine upwards, reddish brown tuffaceous mudstone band	92.00	98.62

MUIRLAUGHT BOREHOLE

metres from surface

[NS 2604 4614]



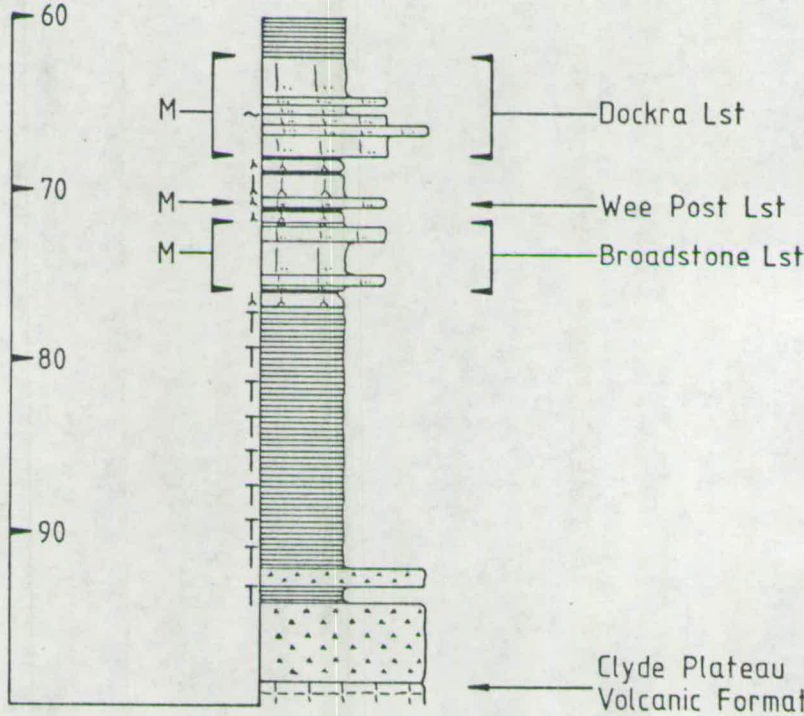


TABLE 3.4

The Kirkwood Formation in the Ardrossan Borehole /NS 2308 4191/

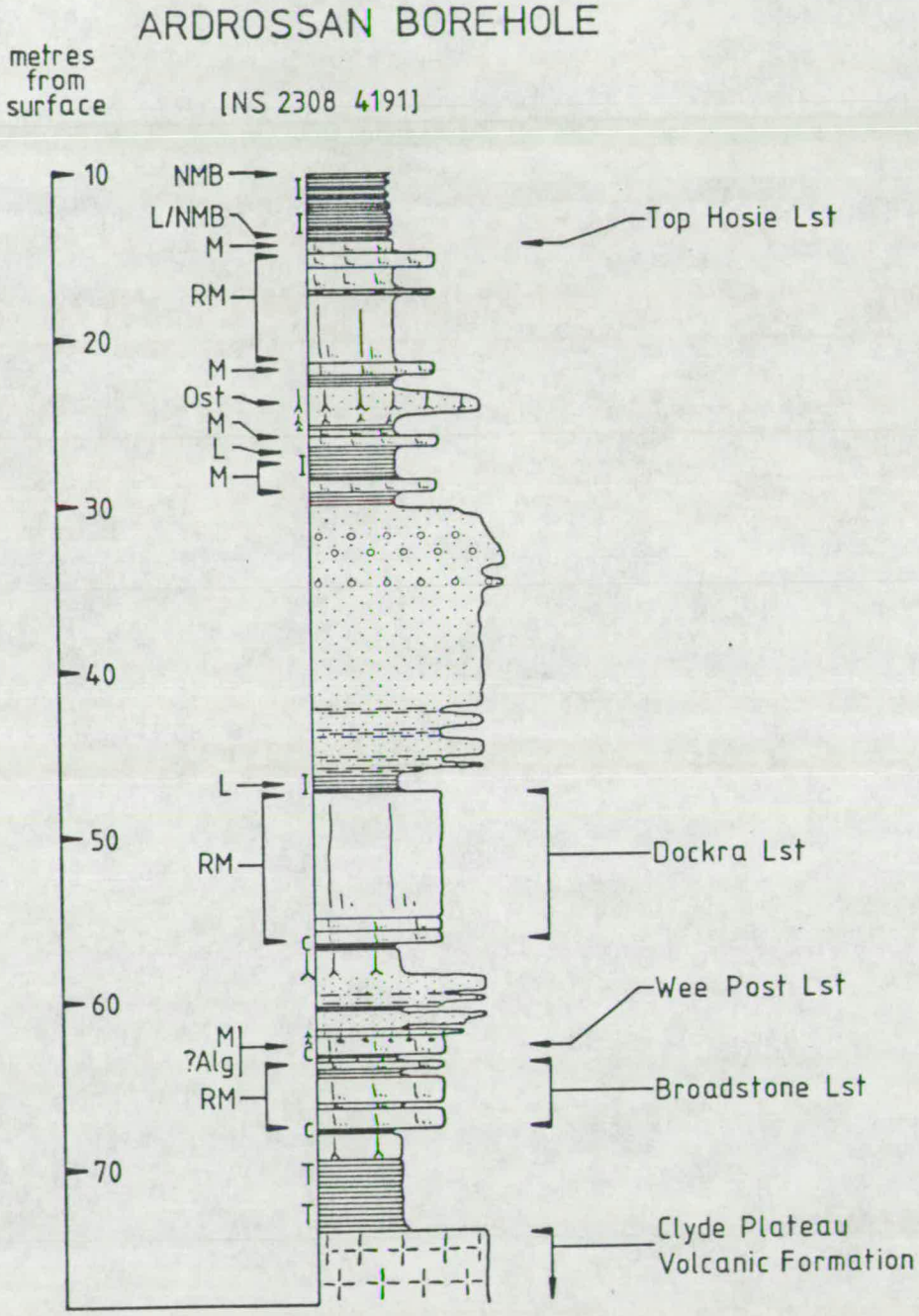
	Depth (metres) from	to
Mudstones, tuffaceous, mottled dusky brown and olive-grey with small rounded igneous clasts less than 1 mm, abundant sphaerosiderite in places	69.54	73.88

The Kirkwood Formation in the Lora Burn Borehole /NS 3336 5841/

Mudstones, ?tuffaceous, greenish-grey, blocky with clay coatings on joints, rooty particularly to top	39.00	44.55

The Kirkwood Formation in the Dunniflat Borehole /NS 4203 5314/

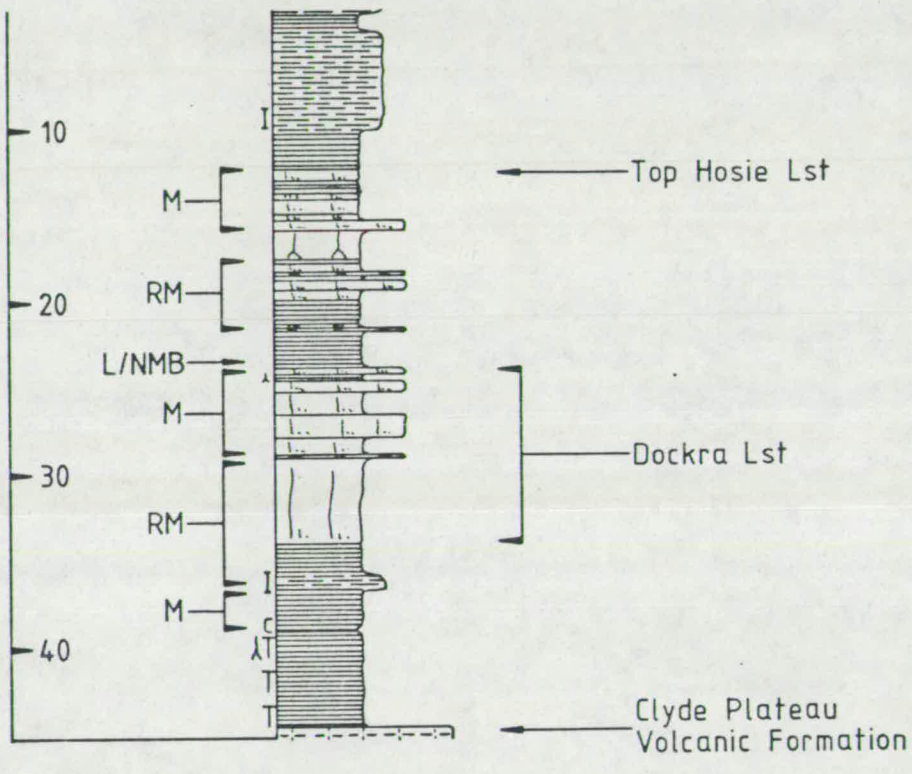
Mudstones, tuffaceous, greenish-grey with small igneous clasts less than 1 mm	43.03	44.28
Tuff, dark greenish-grey with well rounded igneous clasts up to 2 cm, frequently carbonate coated	44.28	45.90
Mudstone, tuffaceous, mottled dusky brown and greenish grey, frequent listric surfaces, bands with well rounded igneous clasts up to 1 cm in basal 3 m	45.90	50.03


ARDROSSAN BOREHOLE
metres from surface
[NS 2308 4191]
10
20
30
40
50
60
70
NMB
L/NMB
M
RM
M
Ost
M
L
M
L
RM
M
?Alg
RM
T
T
Top Hosie Lst
Dockra Lst
Wee Post Lst
Broadstone Lst
Clyde Plateau Volcanic Formation

LORA BURN BOREHOLE

metres from surface

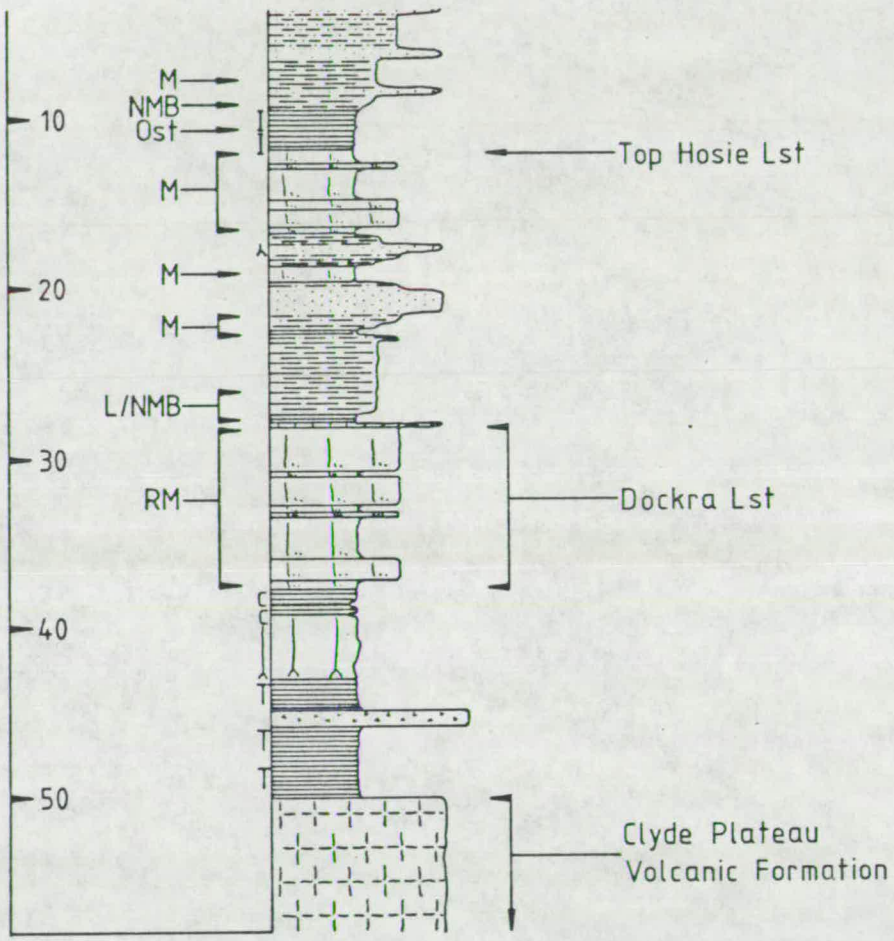
[NS 3336 5841]



DUNNIFLAT BOREHOLE

metres from surface

[NS 4203 5314]



3.7 Kirkwood Formation - definition of lithofacies

The Kirkwood Formation contains two lithofacies, a 'marine' and a 'non-marine'. The 'marine' lithofacies can be defined as those successions within the Kirkwood Formation which contain marine horizons. The area where the 'marine' lithofacies is preserved is shown (fig. 3.9)as the area where Dockra, Broadstone and Old Mill limestones are present. Outwith this area is the 'non-marine' lithofacies of the Kirkwood Formation.

3.8 Kirkwood Formation - 'marine' lithofacies

The characteristics of this lithofacies are apparent from a comparison of the Kirkwood Formation in the Old Mill and Kirkwood boreholes, the only two boreholes examined which have marine horizons in the Kirkwood Formation.

a. Old Mill succession: Two marine horizons, the Upper and the Lower Old Mill limestones, have been recognised in the Old Mill Borehole (table 3.2 and fig. 3.3). The basal beds of the Lower Old Mill Limestone are coarse-grained, medium to brownish grey limestones composed almost entirely of crinoid columnals with little argillaceous matrix material. The limestones become well bedded and more argillaceous upwards, the topmost beds being calcareous mudstones varying in colour between dark and medium grey. The Upper Old Mill Limestone also has coarse-grained basal beds of limestone composed largely of crinoid columnals and shell fragments with little argillaceous matrix material. The upper beds of this limestone are nodular with greenish grey carbonate concretions in an argillaceous matrix. The remaining strata within the Kirkwood Formation are composed of tuffaceous mudstone but with a greenish grey sandstone

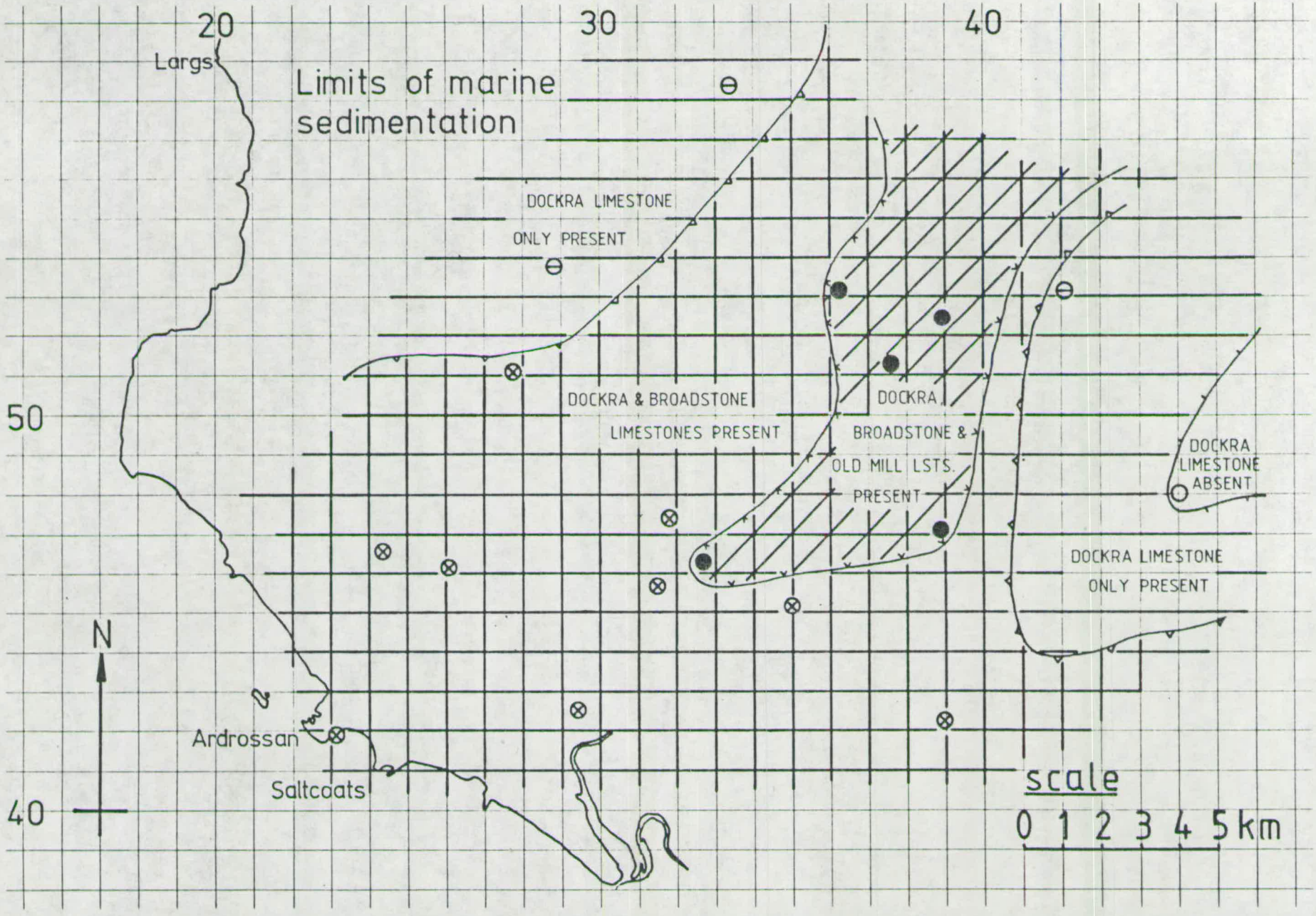

20
30
40
Largs
Limits of marine sedimentation
DOCKRA LIMESTONE ONLY PRESENT
DOCKRA & BROADSTONE LIMESTONES PRESENT
DOCKRA BROADSTONE & OLD MILL LSTS. PRESENT
DOCKRA LIMESTONE ABSENT
DOCKRA LIMESTONE ONLY PRESENT
50
40
N
Ardrossan
Saltcoats
scale
0 1 2 3 4 5 km

Fig. 2.9

band beneath the Lower Old Mill Limestone. In situ root developments are recorded from the sediments immediately beneath the Upper Old Mill Limestone.

b. Kirkwood succession: Two marine horizons have been recognised in the Kirkwood Borehole (table 3.1 and fig. 3.2). The lower marine horizon consists of greenish grey siltstones with thin concretionary limestone bands containing black algal patches. Poorly preserved crinoid columnals have been recorded from the siltstones, and ostracods from the overlying tuffaceous mudstones. The upper marine horizon is a band of dusky brown, tuffaceous mudstone containing rare, poorly preserved brachiopod moulds.

The remaining strata within the Kirkwood Formation generally consist of tuffaceous mudstones with frequent bands of greenish grey siltstone and fine sandstone. In situ root developments are recorded from the top of the formation, from immediately below the upper marine horizon and from various horizons, in both tuffaceous mudstones and siltstones, between the two marine horizons.

c. Comparison and correlation: In both successions two marine horizons have been recognised though the lithologies and the faunas of these two horizons differ. These differences are more probably facies controlled. In both successions the topmost marine horizon overlies a root-bed. The marine horizons in each borehole are correlated.

Within the remaining strata of the Kirkwood Formation, thicker developments of siltstones and sandstones and of tuffaceous mudstones are present in the Kirkwood Borehole than in the Old Mill Borehole, contributing to a greater overall thickness at Kirkwood. Roots, though recorded in both boreholes immediately beneath the lower marine

horizon, occur throughout the lower part of the Kirkwood Formation at Kirkwood.

3.9 Kirkwood Formation - 'non-marine' lithofacies

The characteristics of this lithofacies are apparent from the successions in the Lora Burn, Dunniflat, Ardrossan, Muirlaught and Coalhill No 2 Boreholes (tables 3.4-3.4 and figs. 3.4-3.8).

a. Lithology: The 'non-marine' lithofacies of the Kirkwood Formation is composed almost exclusively of mottled tuffaceous mudstones with occasional coarse tuff bands. The coarse tuffs invariably grade upwards into tuffaceous mudstones. In hand specimen the coarse tuffs are seen to be composed of pebbles with a generally discoid shape. They are greenish grey in colour and are poorly bedded. In thin section the pebbles are seen to be highly altered to clay minerals and in some cases are barely distinguishable from the matrix. Less altered pebbles are basaltic with relatively fresh ferromagnesian minerals preserved.

Tuffaceous mudstone is the more common lithology in the non-marine lithofacies but also occurs in the 'marine' lithofacies. It is a blocky mudstone, generally mottled dusky red and greenish grey in colour. Small, rounded, altered clasts of reworked tuffaceous mudstone or of volcanic material may be present though these tend to be scattered and are usually less than 5 mm across. Some of the mottling has been recorded as being associated with roots, however actual root casts are seldom preserved.

Kaolinite is the dominant clay mineral produced by the alteration of these tuffs and tuffaceous mudstones (XRD determination). Montmorillonite is also present in some of the tuffaceous mudstones

(XRD determination), which can be seen to swell in water.

b. Thickness: The 'non-marine' lithofacies of the Kirkwood Formation wedges out eastwards and north-westwards (figs. 3.10 and 3.11). Thin successions with only thin beds of tuff are recorded in the Lora Burn and Dunniflat boreholes. A thin succession is also recorded at Ardrossan from a position immediately to the north of the line of the Dusk Water Fault. Thicker successions with thick bands of tuff occur in the Muirlaught and Coalhill No 2 boreholes. Both of these boreholes lie to the north of the fault running north-east from Ardrossan Harbour which from geophysical evidence (see chapter 3.4) is interpreted as having been active prior to eruption of the lavas of the Clyde Plateau Volcanic Formation. Further contemporaneous movements may account for the variations in the thickness of these deposits across the north-easterly faults.

3.10 Environment of deposition of Kirkwood Formation - an introduction

'A conformable vertical sequence of facies is generated by a lateral sequence of environments' (Middleton 1973). This is a more succinct expression of Walther's Law (Walther 1894) and is the basic assumption in facies analysis. Two lithofacies have already been defined within the Kirkwood Formation on the basis of lithological sequence and geographical distribution, a 'marine' lithofacies and a 'non-marine' lithofacies. The 'non-marine' lithofacies consists of a single suite of related rock types, tuffs and tuffaceous mudstones which grade from tuff to tuffaceous mudstone and are interpreted as the products of a single depositional environment. The 'marine' lithofacies contain a conformable sequence of differing sediment types and must be interpreted as a lateral sequence of environments

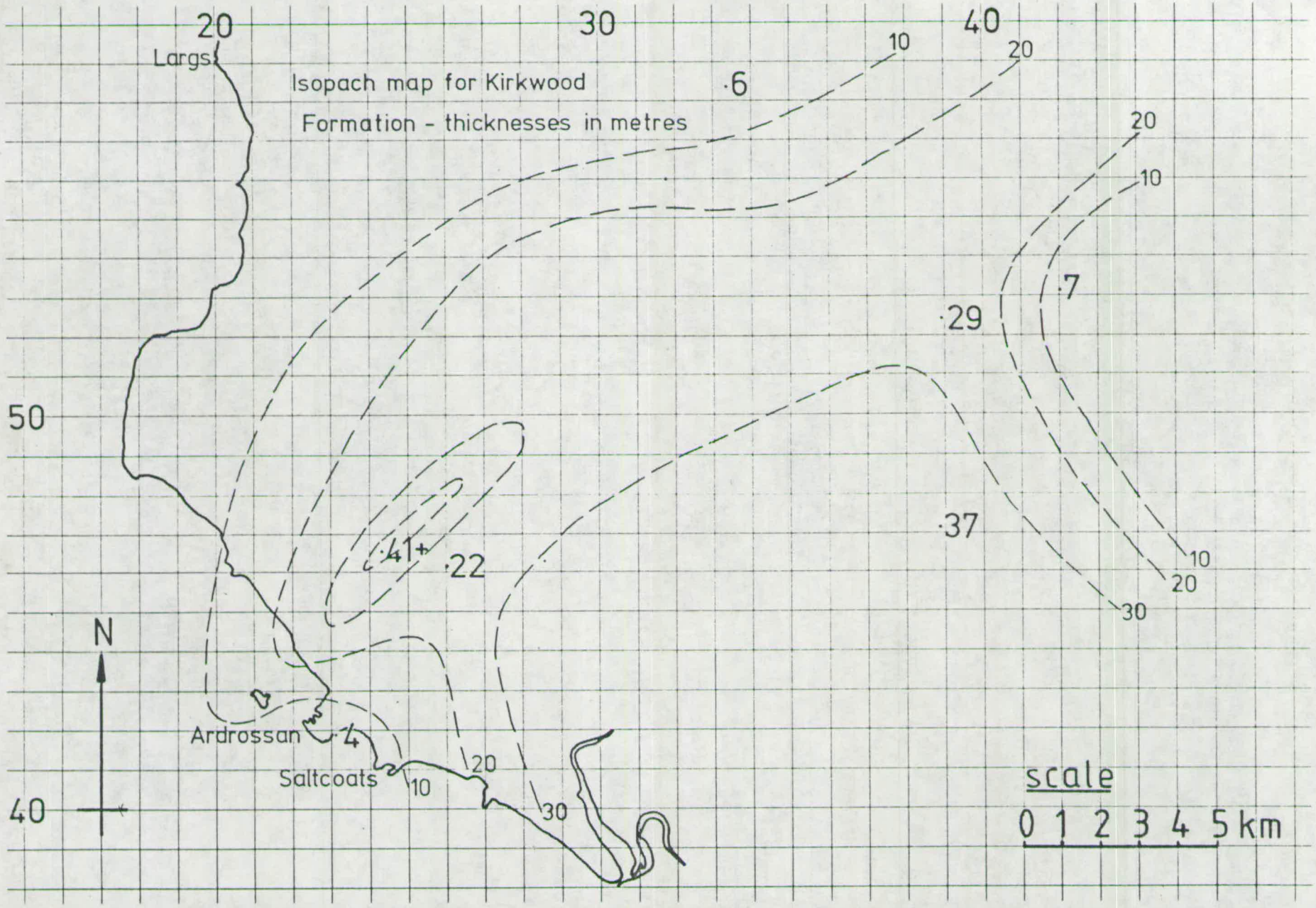
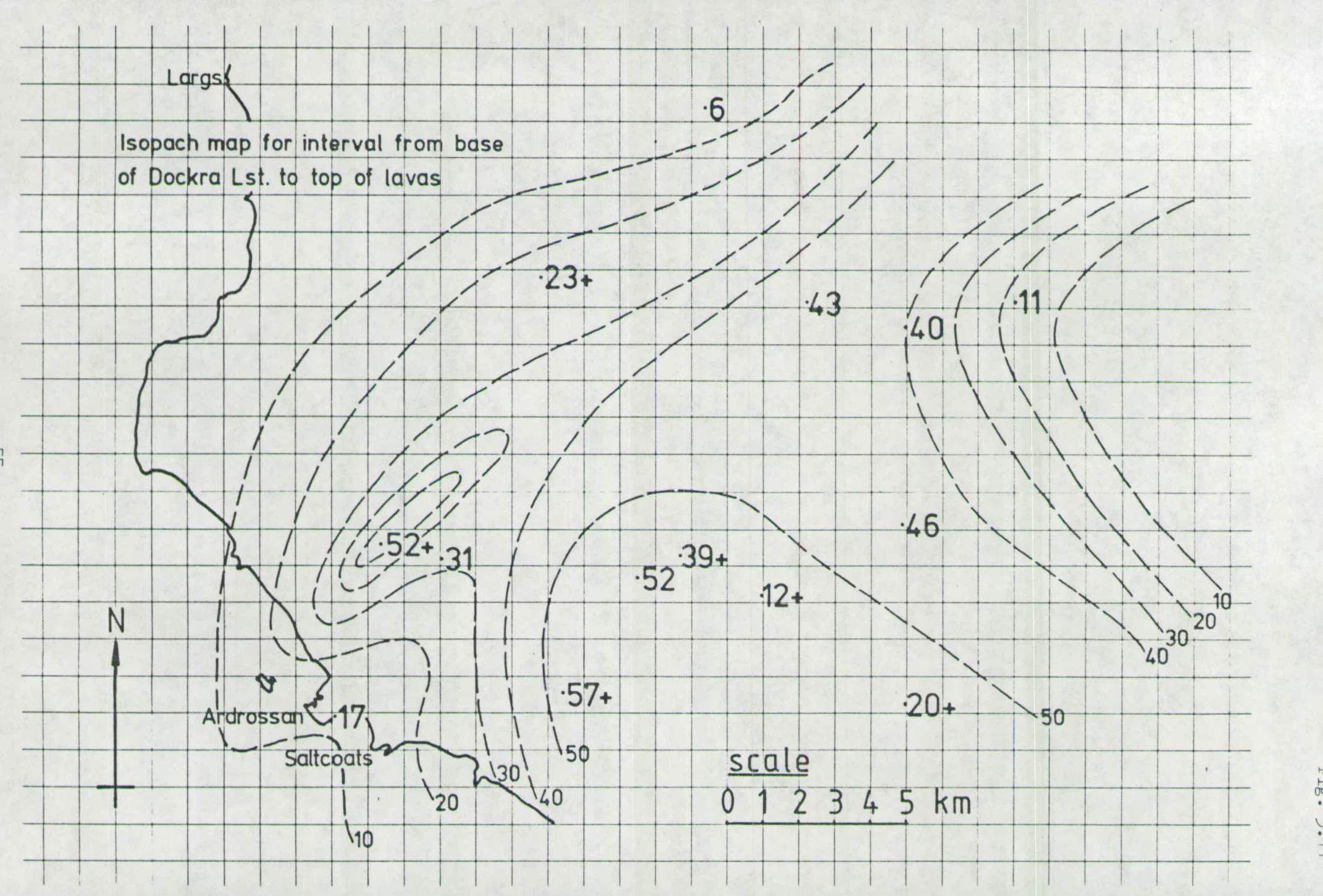

20
30
40
Largs
Isopach map for Kirkwood
Formation - thicknesses in metres
·6
10
20
20
10
·7
·29
·37
·41+
·22
10
20
30
50
N
Ardrossan
·4
Saltcoats
10
20
30
40
scale
0 1 2 3 4 5 km

Fig. 7.10


Largs
Isopach map for interval from base
of Dockra Lst. to top of lavas
·6
·23+
·43
·40
·11
·46
·52+
·31
·52
·39+
·12+
·57+
·20+
·17
Ardrossan
Saltcoats
10
20
30
40
50
N
scale
0 1 2 3 4 5 km

indicating marine transgression.

3.11 'Non-marine' lithofacies - environment of deposition

This lithofacies is composed of a single suite of related lithologies, tuffs and tuffaceous mudstones.

a) Accumulation: The tuffs and tuffaceous mudstones may have accumulated in any one of three ways:

i) by direct ash falls, either sub-aerially or into water

ii) by reworking of weathered igneous material and consolidated volcanic ash

iii) by both processes i) and ii) together.

Of the characteristics of these rocks described in chapter 3.9, the presence of montmorillonite-rich bands and the presence of quite large clasts within a tuffaceous mudstone would indicate direct ash falls as the method of accumulation. Rounded discoid-shaped clasts within the tuffs, well sorted and graded, could result from reworking of igneous material and consolidated volcanic ash. All the other characteristics may result from either mode of origin. The evidence from the lithologies themselves is inconclusive.

IGS drilling (1976-78) has, for the first time, shown the geometry of these deposits. Local basins, probably fault controlled, contain considerable thicknesses of tuffs and tuffaceous mudstones and there is a wedging out of these lithologies against positive areas in the lava topography.

The volcanic source or sources for any ash fall tuffs which overly the lavas must be a vent which penetrates the lavas. The most prominent of these is Misty Law vent to the north of the Dalry Basin. This vent is situated in an area where the lavas are thickest

and which must have been a positive area in the lava topography. The geometry of any ash-fall deposit from this vent would be lobate in plan in a direction indicating the prevailing wind direction and, in section, would thin away from the volcanic source. This geometry does not fit with that observed for these lithologies.

It is concluded that the strata were formed largely by the reworking of weathered igneous material and consolidated ash, infilling basins and wedging out against positive areas in the lava topography.

b) In situ weathering: There is some evidence to suggest that the sediments were subjected to considerable in situ weathering following deposition. Rounded clasts of volcanic or tuffaceous origin, capable of withstanding abrasion during transportation (by whatever means) are now altered and in a soft, highly weathered state. Kaolinite has been produced in the alteration of the tuffs and tuffaceous mudstones. This clay mineral is produced in considerable quantities in bauxitic clays and flint clays by weathering under tropical or sub-tropical conditions. The kaolinite is also shown to pseudomorph feldspar grains in altered igneous clasts.

Time is an important factor in the development of deep weathering and therefore, climatic factors remaining constant, the areas exposed for longest should show the most mature weathering profile. At Carnals Castle (see chapter 3.5), where the Dockra and Broadstone Limestones are absent, the Kirkwood Formation contains bands which, in hand specimen, appear rich in kaolinite with aggregations infilling cavities. This would be a more mature development of the weathering of tuffaceous mudstones.

3.12 'Marine' lithofacies - environment of deposition

The sediments of the 'marine' lithofacies contain, by definition, bands of sediment of marine origin. Sediments which may not be marine in origin are present also. Three sub-facies can be defined

a) tuffaceous mudstone sub-facies

b) sandstone-siltstone sub-facies

c) limestone sub-facies - including all sediments of marine origin.

Each of these sub-facies is present as a group of lithologies within the vertical sequences of the Kirkwood and Old Mill boreholes.

a) Tuffaceous mudstone sub-facies: The environment of deposition of these sediments is thought to be similar to those of the 'non-marine' lithofacies, with almost identical lithologies. These are sediments derived by the reworking and *in situ* weathering of igneous and tuffaceous material. Accumulations presumably developed in basins and banked against positive areas of the underlying lava topography. Roots are quite well preserved in some of the tuffaceous mudstones which must have been exposed or under very shallow water for some time.

b) Sandstone-siltstone sub-facies: These lithologies are coarser in grain size than the tuffaceous mudstones. They are generally greenish-grey in colour and contain some volcanically derived material. Plant fragments, commonly coalified, are preserved in places. Sedimentary structures are not generally apparent in the borehole cores though small scale ripple lamination has been noted in the sandstone in the Old Mill Borehole. Other sandstones and siltstones may be poorly to well-bedded with parallel lamination.

Mudstone clasts are common in the basal beds of the siltstone and sandstone units of the Kirkwood Borehole with some units having a marked erosive base.

Rocks of the sandstone-siltstone sub-facies may have been deposited in more than one depositional environment. Sandstone-siltstone units in the Kirkwood Borehole with erosive lower junctions and with mudstone clasts in the basal beds suggest deposition infilling channels. The sandstone in the Old Mill Borehole is coarser and better sorted than those at Kirkwood and also displays ripple lamination. It immediately precedes a marine limestone and, although coalified plant fragments are present, may represent a deposit marginal to the marine environment, such as a beach. Such a supposition can be tentative only and it should be noted that no organic skeletal remains have been recorded from this sandstone. It is also unlikely that such a body of sandstone could have been derived from a local hinterland composed largely of lavas, tuffs and tuffaceous mudstones. Long shore drift may be a mechanism for bringing mature sandstones into the area.

c) Limestone sub-facies: The limestone sub-facies has been described in chapter 3.8. The beds are marine in origin and have been correlated between the Old Mill and Kirkwood boreholes.

Lower Old Mill Limestone : The Lower Old Mill Limestone in the Old Mill Borehole shows a sequence of coarse grained limestones, poor in mud and rich in bioclastic fragments, mostly crinoid columnals, becoming progressively more muddy upwards. Deposition was initially in clear water or, more probably, in water with currents agitating the sediment, removing the fines. Progressive upward increase in the mud content of the sediment shows that the area of

deposition was silting up. The lateral equivalent of this horizon at Kirkwood is a sequence of fine grained nodular limestones interbedded with siltstones containing some volcanically derived material but also occasional marine fossils. Here the environment of deposition must have been close to the shore. A restricted marine environment subject to some wave or current action is envisaged where algae can flourish and be broken up to form patches.

Upper Old Mill Limestone: The Upper Old Mill Limestone in the Old Mill Borehole has a similar development to the Lower Old Mill Limestone at the same locality. The interpretation of environment of deposition is similar though the top of the Upper Old Mill Limestone is concretionary, a feature most probably post-depositional in origin. The lateral equivalent of this horizon in the Kirkwood Borehole is a thin band of tuffaceous mudstone with a poorly preserved marine fauna. This development represents the interface between the environments of the tuffaceous mudstone sub-facies and of the limestone sub-facies - a shoreline.

3.13 Kirkwood Formation - a depositional model

The various lithologies within the Kirkwood Formation have been described and grouped into lithofacies and sub-facies. An interpretation of the depositional environments associated with each of these facies is suggested. A depositional model which fits laterally with the vertical succession of facies inferred from the boreholes is represented in diagramatic sections at two periods; at the maximum developments of the Upper and Lower Old Mill Limestones (figs. 3.12 and 3.13). The sections highlight the differences in the nature of the transgressive surface. The Lower Old Mill Limestone was deposited on to tuffaceous mudstones

infilling lava basins; the Upper Old Mill Limestone on to a more mature surface penetrated by roots.

In plan the extent of the two marine transgressions is interpreted as being close to the geographical extent of deposition of the Old Mill Limestones as shown in fig. 3.9, shore-line sedimentation being inferred. In a wider context it is noted that the Upper and Lower Old Mill Limestones correlate with the Blackbyre and Hollybush limestones of the Paisley area and the v-shaped inlet into the area of the Dalry Basin presumably opened northwards towards the Glasgow-Paisley area.

Chapter 4 Lower Limestone Group to base of the Dockra Limestone

4.1 Introduction

This chapter seeks to describe the strata within the Lower Limestone Group up to the base of the Dockra Limestone in the Dalry Basin. Principal marker horizons are correlated and lateral variations in both thickness and lithology are studied. Cyclicity within the strata is discussed and a model postulated for the environment of deposition.

4.2 Lower Limestone Group to base of Dockra Limestone-outcrop data

The principal sections in the Lower Limestone Group to the base of the Dockra Limestone which crop out within the Dalry Basin are given in the following tables 4.1 to 4.3.

The outcrops at Horse Isle /NS 2141 4256/ and at Cleeves Cove /NS 3178 4745/ (see Table 4.1) show the Broadstone Limestone resting directly on tuffaceous mudstones of the Kirkwood Formation. The Wee Post Limestone is not visible on Horse Isle and at Cleeves Cove it is either lost by faulting or else passes laterally into mudstones with sandstone bands. A similar succession to that exposed on Horse Isle can be seen at low tide on the foreshore at Ardrossan /NS 2288 4168/ where the Broadstone Limestone again rests directly on tuffaceous mudstones of the Kirkwood Formation. The thickness of individual units is complicated by faulting but the Broadstone Limestone is seen to be overlain by about 4.0 m of massive quartzose sandstone with no development of a Wee Post Limestone.

A comparison of the sections above the Broadstone Limestone at Broadstone /NS 3624 5404/, in the Langside Mine and in the sections north and south of the Roebank Bridge /NS 3490 5580 and NS 3493 5570/

TABLE 4.1

The strata between the Kirkwood Formation and the base of the Dockra Limestone - in outcrop

Horse Isle /NS 2141 4256/

	Thickness (metres)
Dockra Limestone: limestone, dark grey, argillaceous, crinoidal	6.00+
GAP	
Broadstone Limestone: limestone, light grey, crinoidal passing down into dark grey argillaceous limestone with calcareous mudstone bands	5.7
Mudstones, dark grey, coaly with pyrite patches passing down into seatclay on	0.39
Kirkwood Formation: mudstones tuffaceous reddish brown	

Cleeves Cove /NS 3178 4745/

Dockra Limestone: limestone, dark grey, argillaceous with calcareous mudstone bands	6.40+
Mudstones, dark grey to black, well bedded with marine fauna to top	0.50+
Fault	
Mudstones, dark grey, well bedded with medium to fine grained sandstone bands	1.70+
Broadstone Limestone: limestone, dark grey, argillaceous with calcareous mudstone bands and laminae, concretionary in places	4.90
Mudstones, dark grey, well bedded with thin basaltic intrusion 0.7-1.3 m thick on	1.85+
Kirkwood Formation: mudstones, tuffaceous, reddish brown with bands containing well rounded igneous pebbles	

+ full thickness not seen

TABLE 4.2

The strata between the Kirkwood Formation and the base of the Dockra Limestone - in outcrop

Broadstone /NS 3624 53047

	Thickness (metres)
Sandstones and siltstones, grey, poorly bedded	1.00+
Wee Post Limestone: limestone, dark grey argillaceous, bedded to base	0.50
Coal, bright	0.20
Seatclay, dark grey, some bedding	0.70
Broadstone Limestone: limestone, dark grey becoming brownish grey, bedded with argillaceous bands and laminae	5.20+

Langside Mine /NS 3702 53727

Siltstones, dark grey, sandy to top with some bedding	0.70+
Mudstones, dark grey, bedded with occasional pebbles at top	1.10
Broadstone Limestone: limestone, brownish-grey becoming dark grey, calcareous mudstone bands near top with frequent *Lithostrotion sp.* colonies	3.60+

North of Roebank Bridge /NS 3490 55807

Sandstones, medium-grained, brownish-grey with dark grey roots unbedded	0.60+
Mudstones, silty medium grey with irony sandy bands and ribs	0.90
Mudstones, dark grey, bedded with marine fauna	0.70
Coal, dull	0.15
Seatclay on	0.20
Broadstone Limestone, dark grey, hard	

TABLE 4.3

The strata between the Kirkwood Formation and the base of the Dockra Limestone - in outcrop

Dusk Water at Hessilhead /NS 3835 52857

	Thickness (metres)
Dockra Limestone: limestones and calcareous mudstones, light to medium grey, muddy laminae and limy nodules	1.40+
Mudstones, dark grey, well bedded	1.10+
GAP	
Siltstones and silty sandstones, light grey, rather hard	0.90+
GAP	
Wee Post Limestone: limestone, dark grey, hard	0.50+
Siltstones, dark grey with carbonate patches and sulphide stringers on	0.85
Broadstone Limestone: limestone, grey, argillaceous, crinoidal	

Auchenmade Quarry /NS 3372 48487

Dockra Limestone: limestone, dark grey, nodular with calcareous mudstone bands, stylolitic surfaces	0.40+
Mudstones, dark grey, calcareous at top, well bedded, poorly preserved brachiopods	0.75
Coal, dull with bright patches	0.20
Seatclay, light olive-grey, structureless	1.30
Wee Post Limestone: limestone, dark grey, argillaceous, hard, compact with sphaerosiderite	0.70
Coal, dull and rather muddy	0.12
Seatclay, dark grey, some bedding	0.60
Mudstones, dark grey, argillaceous, bedded	1.30+

+ full thickness not seen

(table 4.2), demonstrates lateral variation within the sediments around the stratigraphic position of the Wee Post Limestone. The Wee Post Limestone, well developed at Broadstone, passes laterally into siltstones and mudstones at the Langside Mine, one kilometre to the east. Richey (1930) recorded a fine shelly laminae from the siltstones above the Broadstone Limestone at the Langside Mine which may be the equivalent of the Wee Post Limestone.

The two localities north and south of the Roebank Bridge are only 100 m apart and demonstrate the replacement of the Wee Post Limestone northwards by sandstone and silty mudstone.

The outcrop sections also show the Broadstone Limestone as being generally dark grey and argillaceous and commonly succeeded by seatclays. The Wee Post Limestone commonly occurs immediately above a coal. This cyclicity in the conditions of sedimentation will be analysed in greater detail and more objectively in chapter 4.4.

4.3 Lower Limestone Group to base of Dockra Limestone - borehole data

The strata of the Lower Limestone Group below the Dockra Limestone was penetrated in six of the IGS boreholes (1976-78), viz. Muirlaught, Coalhill No. 2, Ardrossan, Montgreenan, Kirkwood and Old Mill. Also in the Dunniflat and Lora Burn boreholes the Dockra Limestone was seen to rest directly on sediments of the Kirkwood Formation. In all other boreholes, with the exception of the Montgreenan Borehole, the Broadstone Limestone was also drilled through prior to penetrating sediments of the Kirkwood Formation. In the Montgreenan Borehole the Broadstone Limestone rests on 2.30 m+ of medium to coarse-grained sandstone. Drilling at Montgreenan stopped in coarse-grained sandstones at 161.35 m.

The principal features of the sequences encountered can be seen

from the following tables 4.4-4.6 in conjunction with the graphic plots of the borehole strata shown in figs. 3.2-3.6 and in fig. 4.1, and can be summarised as follows:-

Limestone Lithologies: Though of differing thickness the Wee Post and Broadstone limestones have similar lithologies which are maintained laterally. Generally dark or medium grey in colour, they are both argillaceous with bands of calcareous mudstone. Root structures are commonly preserved in the topmost beds of these limestones. The beds commonly show a nodular development which distorts original bedding in the limestone indicating a post-depositional origin. Both limestones carry a marine fauna with a rich variety of species in places but in the Wee Post Limestone in the Old Mill Borehole only algal structures were seen.

Cyclicity: The cyclical nature of sedimentation is most apparent from the borehole data as these sections are complete. Roots from overlying seatclays frequently penetrate carbonate sediments and the limestones themselves frequently rest directly on coal. This cyclicity in sedimentation pattern is discussed in chapter 4.4.

Sandstones within the sequence: The outcrop data suggests local lateral variation from marine limestones into sandstones and siltstones at around the Wee Post Limestone position. The Wee Post Limestone is missing only in the Montgreenan Borehole (table 4.6 and fig. 4.1) where the entire Wee Post Limestone cycle is absent. There is no suggestion of lateral lithological variation into sandstones and siltstones and it is assumed that locally the Wee Post Limestone was not deposited, coal or seatclays forming instead. Sandstones are recorded immediately above the Wee Post Limestone in the Ardrossan and Coalhill No. 2 boreholes.

TABLE 4.4

The strata between the Kirkwood Formation and the base of the Dockra Limestone in boreholes

	Depth (metres) from	to
Ardrossan Borehole /NS 2308 4191/		
Coal, bright, broken, pyrite in patches	56.55	56.96
Seatclay, light grey, structureless, silty to base	56.96	58.65
Sandstones, medium grained, medium grey with siltstone and mudstone bands, mud cracks and silt pellets, rooty to base	58.65	62.10
Wee Post Limestone: limestone, medium grey becoming dark grey, nodular and rooty at top, *Lithostrotion sp.* colonies	62.10	63.33
Coal, bright with dull bands	63.33	63.47
Seatclay, medium grey, bedded, pyrite patches	63.47	63.69
Broadstone Limestone: limestone, dark grey, argillaceous with calcareous mudstone bands, rooty and nodular at top	63.69	67.76
Coal, dull, broken	67.76	68.04
Seatclay, light olive-grey	68.04	69.54
Kirkwood Borehole /NS 3885 4716/		
Coal, rather burnt	29.70	29.81
Wee Post Limestone: limestone and calcareous mudstones, medium dark to dark grey, nodular in places	29.81	30.75
Coal and mudstone, canneloid in places with coal stringers	30.75	31.17
Seatclay, light olive-grey	31.17	33.80
Siltstones and mudstones, light greenish grey, bedded with roots to base	33.80	34.56
Broadstone Limestone: limestone, light olive grey and light grey, nodular with roots at top, dark grey to base with calcareous mudstone bands	34.56	38.60

TABLE 4.4 (cont'd)

	Depth (metres)	
	from	to
Coal, bright with dull bands	38.60	38.70
Seatclay, dark grey with olive-grey	38.70	39.77

TABLE 4.5

The strata between the Kirkwood Formation and the base of the Dockra Limestone in boreholes

	Depth (metres) from	to
Muirlaught Borehole /NS 2604 4614/		
Coal, bright with dull bands	68.01	68.18
Seatclay, light olive grey, carbonaceous to base	68.18	68.87
Coal, bright with dull bands, thin carbonate stringers	68.87	69.13
Seatclay, light olive-grey, carbonaceous top	69.13	70.45
Wee Post Limestone: limestone, medium grey, argillaceous, some bedding, some roots	70.45	71.06
Coal, dull, bright bands to base	71.06	71.30
Seatclay, light olive-grey, structureless	71.30	71.49
Broadstone Limestone: limestones, dark grey, argillaceous, rooty with calcareous mudstone bands in top 60 cm, frequent colonies of *Lithostrotion* sp.	71.49	75.78
Coal, bright with carbonate veinlets	75.78	75.86
Seatclay, light brownish grey	75.86	76.70
Coalhill No 2 Borehole /NS 2432 4653/		
Coal, dull with bright patches	87.00	87.63
Seatclay, light olive-grey becoming brownish grey, abundant finely disseminated pyrite, coaly streaks	87.63	93.30
Sandstones, fine grained, medium dark grey, carbonate veinlets	93.30	93.86
Wee Post Limestone: limestone, medium grey, nodular	93.86	94.32
Coal, dull and carbonaceous mudstone	94.32	94.47
Seatclay, light olive-grey, structureless	94.47	96.28
Broadstone Limestone: limestone, medium grey, fine grained	96.28	97.80
Seatclay, brownish grey, calcareous at top	97.80	98.53

TABLE 4.6

The strata between the Kirkwood Formation and the base of the Dockra Limestone in boreholes

	Depth (metres) from	to
Old Mill Borehole /NS 3897 5239/		
Coal, dull with bright patches	22.47	22.59
Seatclay, medium grey, structureless, becoming silty and bedded to base	22.59	24.13
Wee Post Limestone: limestone, dark grey, brecciated with concretionary algal growths, fine carbonate veining, medium to dark grey mudstone to base	24.13	24.53
Coal, dull with bright patches	24.53	24.72
Seatclay, medium to olive grey, structureless	24.72	25.60
Broadstone Limestone: limestones, dark grey, argillaceous, nodular in places, calcareous mudstone bands to base	25.60	33.30
Coal, dull with bright ribs	33.30	33.52
Seatclay, light greenish grey, carbonate concretions to base	33.52	37.81
Montgreenan Borehole /NS 3503 4523/		
Coal, dull with bright patches	149.57	149.77
Seatclay, dark brownish grey becoming medium grey	149.77	151.74
Igneous rock, brownish grey, porphyritic, altered	151.74	151.88
Mudstones, dark grey, rooty	151.88	151.97
Broadstone Limestone: limestone, dark grey, argillaceous, bedded, carbonate veining	151.97	153.60
Dolerite, fine grained, dark grey	153.60	155.36
Broadstone Limestone, limestones, dark grey, argillaceous, bedded, carbonate veinlets, *Lithostrotion sp.* colonies, calcareous mudstone bands to base with limy nodules	155.36	158.24
Seatclay, dark grey	158.24	159.05

TABLE 4.6 (cont'd)

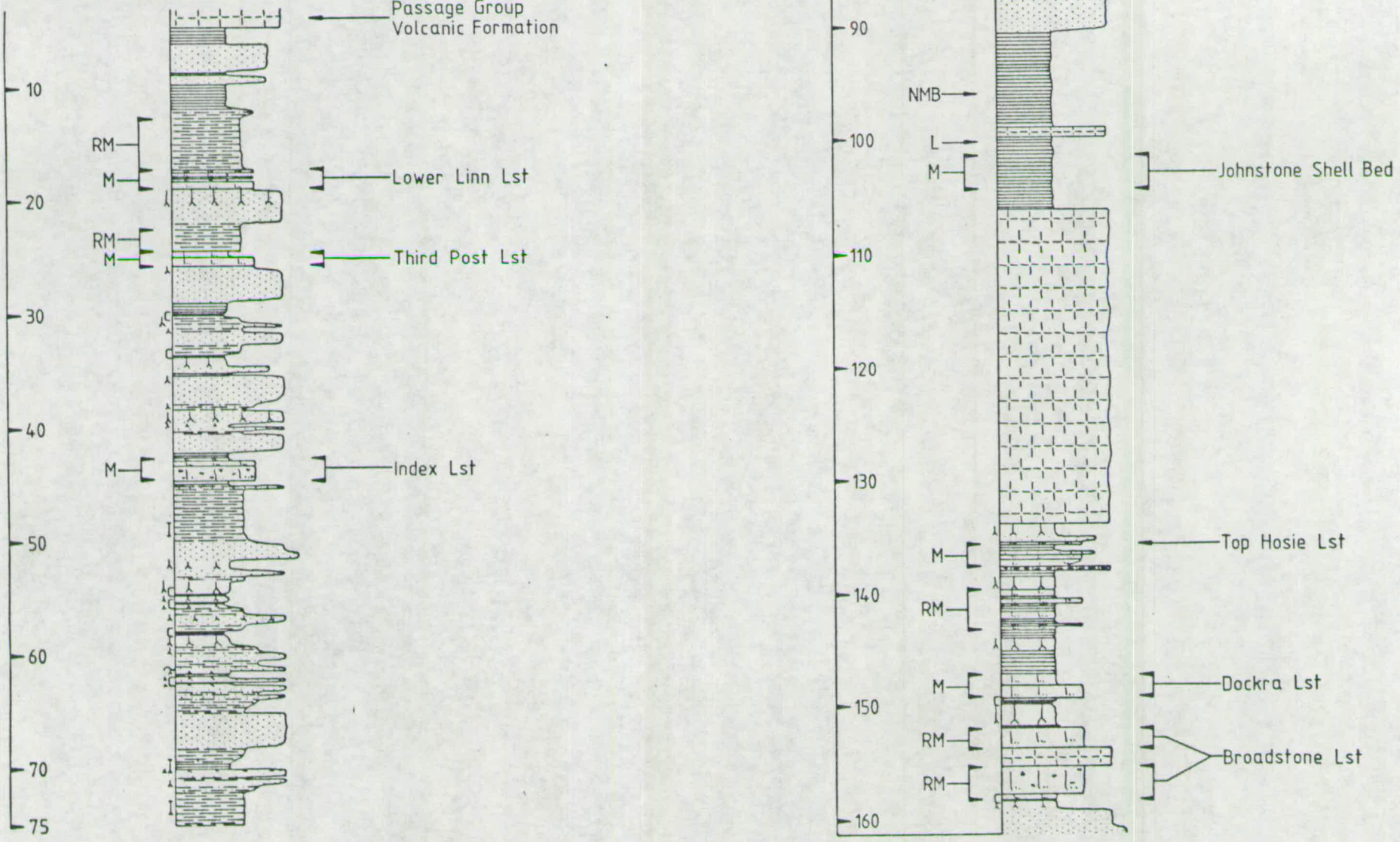
	Depth (metres)	
	from	to
Sandstones, medium grey, medium grained becoming coarse grained, quartzose, siltstone pellets	159.05	161.35+

+ following an item indicates full thickness not proved

MONTGREENAN BOREHOLE

metres from surface

[NS 3503 4523]



4.4 Lower Limestone Group to base of Dockra Limestone - cyclicity

The cyclicity which is apparent in the borehole and outcrop sections can be examined in a more objective way using a simple mathematical device (Selley 1970) which does not require the use of a computer. The relatively few data available within the Dalry Basin make such manual methods attractive.

The method detailed by Selley involves the construction of a matrix showing the number of observed upward and downward transitions from one lithology to another. A diagram can be drawn from this matrix which shows the most common upward and downward transitions. A further matrix may be constructed giving the numbers of transitions to be expected if these transitions were random. This is calculated by cross multiplying row and column totals and dividing by the grand total. This matrix can then be compared with the matrix constructed from observed transitions and a third matrix produced showing the difference between the numbers of observed transitions and the numbers predicted assuming a random relationship between lithologies. A diagram may then be drawn showing the upward and downward transitions which are more common than would be expected had the relationship between lithologies been random.

Transitions may be recorded in two ways, either by fixed interval sampling, or else by noting each change in lithology regardless of thickness. The first method has the distinct disadvantage that thin horizons, critical to the cycle, for example coals, may be missed. Each change in lithology is used to construct the matrix including 'multi-storey' transitions. These are transitions from one lithology into the same lithology, the distinction between the two being based on some other criteria.

The borehole data for the Lower Limestone Group sequence to

the base of the Dockra Limestone from the Muirlaught, Coalhill No. 2, Ardrossan, Montgreenan, Kirkwood and Old Mill boreholes are examined using this technique. These boreholes drilled recently have been described in a consistent way and all the cores were examined by myself.

The analysis of the sequences and the diagrams generated are given in tables 4.7-4.12. In the case of the sequences in the Ardrossan and Kirkwood boreholes (tables 4.9-4.11) the analysis based on number of transitions did not show the clear, simple relationship between lithologies which is necessary before a diagram can be constructed. But the diagrams based on the difference between the observed number of transitions and the predicted number assuming a random arrangement show a clear, simple relationship between lithologies and these were constructed for each sequence. In the Ardrossan Borehole the limestones have a random relationship with other lithologies. In the Muirlaught Borehole the same applied to the relationship between the sandstones, siltstones and mudstones and the other lithologies.

The principal points which are illustrated by the diagrams can be summarised as follows:-

(1) Marine limestones and calcareous mudstones have a good 'memory' for coal and coal has a good 'memory' for seat clay. Seatclay commonly passes up into coal which passes up into limestone or calcareous mudstone.

(2) Where siltstones and sandstones occur they commonly pass up into seatclay.

(3) The clastic sediments, mudstone, siltstone and sandstone do not show a clear transition neither coarsening nor fining upwards.

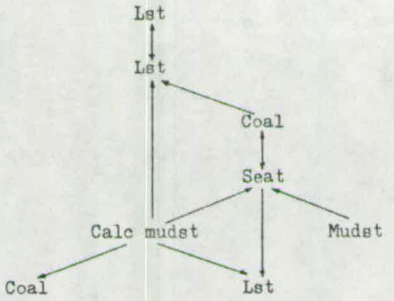
Analysis of sequences - Muirlaught Borehole

Lower Limestone Group to base of Dockra Limestone

	Lst	Seat	Coal	Calc mudst	Mudst	
Lst	4	2	0	1	0	7
Seat	1	0	4	0	0	5
Coal	2	1	0	1	0	4
Calc mudst	1	1	0	0	0	2
Mudst	0	1	0	0	0	1
	8	5	4	2	0	19

(a) data array of bed transitions

(b) facies relationship diagram showing the most common upward and downward transition for each lithology



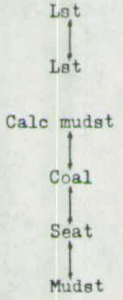
	Lst	Seat	Coal	Calc mudst	Mudst
Lst	3	2	1	1	0
Seat	2	1	1	1	0
Coal	2	1	1	0	0
Calc mudst	1	1	0	0	0
Mudst	0	0	0	0	0

(c) predicted data array assuming random arrangement of lithologies (calculated to nearest whole number)

	Lst	Seat	Coal	Calc mudst	Mudst
Lst	+1	0	-1	0	0
Seat	-1	-1	+3	-1	0
Coal	0	0	-1	+1	0
Calc mudst	0	0	0	0	0
Mudst	0	+1	0	0	0

(d) table showing the difference between the observed number of transitions and the predicted number assuming a random arrangement

(e) facies relationship diagram showing the largest number of upward and downward transitions that occur for each lithology after subtracting those predicted if the beds were arranged randomly



Analysis of sequences - Coalhill No 2 Borehole

Lower Limestone Group to base of Dockra Limestone

	Seat	Lst	Mudst	Coal	Sst	
Seat	0	1	1	1	0	3
Lst	1	0	0	0	1	2
Mudst	1	0	0	1	0	2
Coal	0	2	0	0	0	2
Sst	1	0	0	0	0	1
	3	3	1	2	1	10

(a) data array of bed transitions

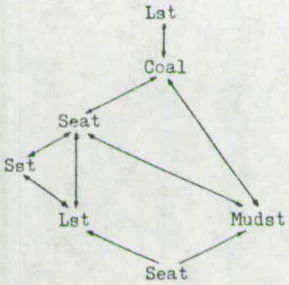
	Seat	Lst	Mudst	Coal	Sst
Seat	1	1	0	1	0
Lst	1	1	0	0	0
Mudst	1	1	0	0	0
Coal	1	1	0	0	0
Sst	0	0	0	0	0

(c) predicted data array assuming a random arrangement of lithologies (calculated to nearest whole number)

	Seat	Lst	Mudst	Coal	Sst
Seat	-1	0	+1	0	0
Lst	0	-1	0	0	+1
Mudst	0	-1	0	+1	0
Coal	-1	+1	0	0	0
Sst	+1	-1	0	0	0

(d) table showing the difference between the observed number of transitions and the predicted number assuming a random arrangement

(b) facies relationship diagram showing the most common upward and downward transition for each lithology



(e) facies relationship diagram showing the largest number of upward and downward transitions that occur for each lithology after subtracting those predicted if the beds were arranged randomly

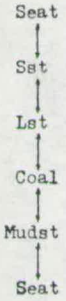


TABLE 4.9

Analysis of sequences - Ardrossan Borehole

Lower Limestone Group to base of Dockra Limestone

	Lst	Sst	Seat	Mudst	Coal	Siltst	Calc mudst	
Lst	1	1	1	1	0	0	1	5
Sst	0	1	1	2	0	1	0	5
Seat	0	0	1	0	3	0	0	4
Mudst	1	1	1	0	0	1	0	4
Coal	3	0	0	0	0	0	0	3
Siltst	0	1	0	0	0	1	0	2
Calc mudst	1	0	0	0	0	0	0	1
	6	4	4	3	3	3	1	24

(a) data array of bed transitions

	Lst	Sst	Seat	Mudst	Coal	Siltst	Calc mudst
Lst	1	1	1	1	1	1	0
Sst	1	1	1	1	1	1	0
Seat	1	1	1	1	1	1	0
Mudst	1	1	1	1	1	1	0
Coal	1	1	1	0	0	0	0
Siltst	1	0	0	0	0	0	0
Calc mudst	0	0	0	0	0	0	0

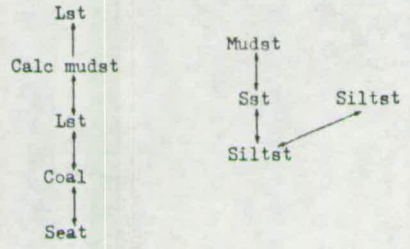
(c) predicted data array assuming random arrangement of lithologies (calculated to nearest whole number)

	Lst	Sst	Seat	Mudst	Coal	Siltst	Calc mudst
Lst	0	0	0	0	-1	-1	+1
Sst	-1	0	0	+1	-1	0	0
Seat	-1	-1	0	-1	+2	-1	0
Mudst	0	0	0	-1	-1	0	0
Coal	+2	-1	-1	0	0	0	0
Siltst	-1	+1	0	0	0	+1	0
Calc mudst	+1	0	0	0	0	0	0

(d) table showing the difference between the observed number of transitions and the predicted number assuming a random arrangement

(b) no clear facies relationship emerges from the most common upward and downward transitions for each lithology

(e) facies relationship diagram showing the largest number of upward and downward transitions that occur for each lithology after subtracting those predicted if the beds were arranged randomly. Note uncertainty of relationship between Mudst/Siltst/Sst and Lst/Calc mudst/Coal/Seat lithologies



Analysis of sequences - Montgreenan Borehole

Lower Limestone group to base of Dockra Limestone

	Seat	Coal	Calc mudst	Lst	Mudst	Sst	
Seat	0	2	0	0	0	0	2
Coal	0	0	2	0	0	0	2
Calc Mudst	0	0	0	1	0	0	1
Lst	0	0	0	0	1	0	1
Mudst	1	0	0	0	0	0	1
Sst	1	0	0	0	0	0	1
	2	2	2	1	1	0	8

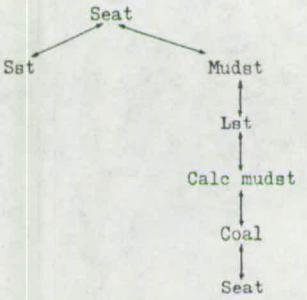
(a) data array of bed transitions

	Seat	Coal	Calc mudst	Lst	Mudst	Sst
Seat	1	1	1	0	0	0
Coal	1	1	1	0	0	0
Calc mudst	0	0	0	0	0	0
Lst	0	0	0	0	0	0
Mudst	0	0	0	0	0	0
Sst	0	0	0	0	0	0

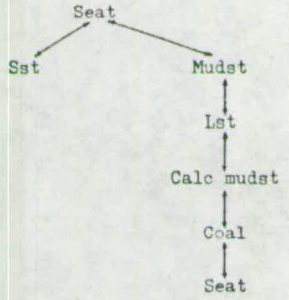
(c) predicted data array assuming a random arrangement of lithologies (calculated to nearest whole number)

	Seat	Coal	Calc mudst	Lst	Mudst	Sst
Seat	-1	+1	-1	0	0	0
Coal	-1	-1	+1	0	0	0
Calc mudst	0	0	0	+1	0	0
Lst	0	0	0	0	+1	0
Mudst	+1	0	0	0	0	0
Sst	+1	0	0	0	0	0

(d) table showing the difference between the observed number of transitions and the predicted number assuming a random arrangement



(b) facies relationship diagram showing the most common upward and downward transition for each lithology



(e) facies relationship diagram showing the largest number of upward and downward transitions that occur for each lithology after subtracting those predicted if the beds were arranged randomly

Analysis of sequences in Kirkwood Borehole

Lower Limestone Group to base of Dockra Limestone

	Mudst	Lst	Coal	Seat	Calc mudst	Siltst	
Mudst	0	1	1	0	1	1	4
Lst	1	1	1	0	1	0	4
Coal	3	0	0	0	0	0	3
Seat	0	0	2	1	0	0	3
Calc mudst	0	2	0	0	0	0	2
Siltst	0	0	0	2	0	0	2
	4	4	4	3	2	1	18

(a) data array of bed transitions

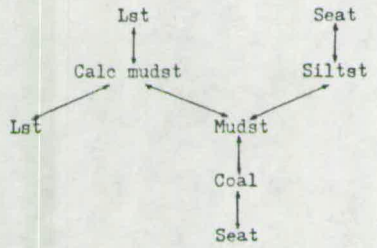
	Mudst	Lst	Coal	Seat	Calc mudst	Siltst
Mudst	1	1	1	1	0	0
Lst	1	1	1	1	0	0
Coal	1	1	1	1	0	0
Seat	1	1	1	1	0	0
Calc mudst	0	0	0	0	0	0
Siltst	0	0	0	0	0	0

(c) predicted data array assuming random arrangement of lithologies (calculated to nearest whole number)

	Mudst	Lst	Coal	Seat	Calc mudst	Siltst
Mudst	-1	0	0	-1	+1	+1
Lst	0	0	0	-1	+1	0
Coal	+2	-1	-1	-1	0	0
Seat	-1	-1	+1	0	0	0
Calc mudst	0	+2	0	0	0	0
Siltst	0	0	0	+2	0	0

(d) table showing the difference between the observed number of transitions and the predicted number assuming a random arrangement

(b) no clear facies relationship emerges from the most common upward and downward transitions for each lithology



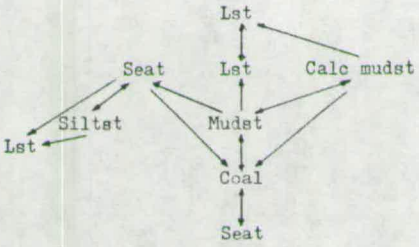
(e) facies relationship diagram showing the largest number of upward and downward transitions that occur for each lithology after subtracting those predicted if the beds were arranged randomly

Analysis of sequences - Old Mill Borehole

Lower Limestone Group to base of Dockra Limestone

	Lst	Seat	Coal	Mudst	Calc mudst	Siltst	
Lst	4	1	0	0	0	1	6
Seat	0	0	4	0	0	0	4
Coal	0	1	0	2	1	0	4
Mudst	1	1	0	0	1	0	3
Calc mudst	1	0	0	0	0	0	1
Siltst	0	1	0	0	0	0	1
	6	4	4	2	2	1	19

(a) data array of bed transitions



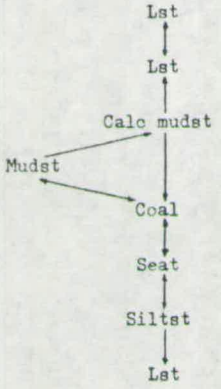
(b) facies relationship diagram showing the most common upward and downward transition for each lithology

	Lst	Seat	Coal	Mudst	Calc mudst	Siltst
Lst	2	1	1	1	1	0
Seat	1	1	1	0	0	0
Coal	1	1	1	0	0	0
Mudst	1	1	1	0	0	0
Calc mudst	0	0	0	0	0	0
Siltst	0	0	0	0	0	0

(c) predicted data array assuming a random arrangement of lithologies (calculated to nearest whole number)

	Lst	Seat	Coal	Mudst	Calc mudst	Siltst
Lst	+2	0	-1	-1	-1	+1
Seat	-1	-1	+3	0	0	0
Coal	-1	0	-1	+2	+1	0
Mudst	0	0	-1	0	+1	0
Calc mudst	+1	0	0	0	0	0
Siltst	0	+1	0	0	0	0

(d) table showing the difference between the observed number of transitions and the predicted number assuming a random arrangement



(e) facies relationship diagram showing the largest number of upward and downward transitions that occur for each lithology after subtracting those predicted if the beds were arranged randomly

4.5 Lower Limestone Group to base of Dockra Limestone - environment of deposition

An interpretation of the environment of deposition of the Lower Limestone Group strata below the Dockra Limestone may be suggested following an examination of the observations under the following headings:-

1. Correlation and thickness variation
2. Variation in limestone lithologies
3. Nature of any cyclicity
4. Local sediment variation.

Each of these points has been referred to in either outcrop or borehole observations and can now be interpreted in terms of a depositional environment.

1. Correlation and thickness variation: The strata within the Lower Limestone Group up to the base of the Dockra Limestone can be correlated on a lithological basis across the Dalry Basin. Though bed-for-bed correlation is seldom achieved, correlation based on observed lithological cycles is always possible. These correlations have been confirmed by faunal evidence (Wilson pers. comm.). The correlation of the borehole sequences is given in fig. 4.2 with lines drawn at the base of the cycle including the Dockra Limestone and at that which includes the Broadstone Limestone. The limited area of development of the Broadstone Limestone is shown in fig. 3.9.

In the areas where the Dockra Limestone rests directly on the Kirkwood Formation the nature of the junction is problematical. It may be a disconformity representing a break in sedimentation or it may be a conformable sequence, in which case the topmost strata may, in part, belong to the Lower Limestone Group. A third possibility

is that although disconformities may be present, sediments typical of the Kirkwood Formation may be lateral equivalents of 'normal' Lower Limestone Group strata.

In the previous chapter kaolinisation of sediments at the top of the Kirkwood Formation is described. The presence of such sediments suggest a period of in situ weathering with little sediment accumulation. The length of such a period of weathering is conjectural, but a period or periods of non-deposition probably occurred. The age of these strata at the top of the Kirkwood Formation remains problematical but the junction with the succeeding strata must be disconformable in part at least.

In the areas where the Broadstone Limestone is present, the Broadstone, Wee Post and Dockra Limestones can generally be correlated with certainty. These correlations can also be made across such major structures as the Dusk Water Fault (see fig. 4.2).

The area within which the Broadstone Limestone is developed straddles the line of the Dusk Water Fault and the thickness variation of the Lower Limestone Group up to the base of the Dockra Limestone can be determined from the borehole data. The thickest development (15.34 m) is present in the Old Mill Borehole and similar thicknesses are present in the Ardrossan (12.99 m), Kirkwood (10.07 m), Muirlaught (8.69 m), Coalhill No. 2 (11.53 m) and Montgreenan (9.48 m) boreholes. The thicknesses are all of the same order of magnitude and show no systematic change across the Dusk Water Fault.

From the evidence of correlation and thickness variation it may be concluded that during the deposition of the strata of the Lower Limestone Group up to the base of the Dockra Limestone, topography maintained its influence on marine transgression. The enclosed gulf

feature which defined the extent of transgression of the Upper and Lower Old Mill Limestones is now less well defined (fig. 3.9), a phenomenon which may result either from a lack of relief or else a greater net sea-level rise than those associated with the Upper and Lower Old Mill transgressions.

It may also be suggested from comparisons of sequences of strata that the area was tectonically inactive with respect to contemporaneous fault movements.

2. Variation in limestone lithologies: In an assessment of limestone lithologies in relation to depositional environment, features are looked for which may indicate transgressive sequences, marginal marine developments or water depth. The limestones developed in the Lower Limestone Group below the Dockra Limestone have a restricted lateral development and show none of the transgressive sequences displayed within the carbonate sediments of the Upper and Lower Old Mill Limestones. Both the Wee Post and the Broadstone Limestones are remarkable for their uniformity. They are generally both dark grey and argillaceous throughout with a marine fauna commonly with a rich variety of species. It may be inferred that these limestones were formed in a sea into which mud was being continuously deposited and that very little winnowing took place.

An exception to the uniform appearance of these limestones is the brecciated character of the Wee Post Limestone in the Old Mill Borehole. The Wee Post Limestone is thinly developed (0.40 m) there and contains algal structures and no other fauna. The Old Mill Borehole is situated close to the limit of deposition of the Broadstone Limestone. The Wee Post Limestone has a similar distribution and it may be that this development is the marginal

facies of the Wee Post Limestone, possibly deposited in part in an intertidal environment where only algae could survive and where periods of dessication brecciated a partly consolidated sediment. Insufficient data preclude a firm conclusion.

Roots are frequently observed penetrating the topmost beds of the limestones and are commonly associated with nodular developments. This association may reflect the effect of roots on the carbon dioxide concentration within the unconsolidated carbonate rock. Carbon dioxide released by roots during respiration and decay increases the partial pressure of CO_2 and the solubility of calcium carbonate. Calcium carbonate may then be dissolved, moved in solution and reprecipitated in areas where the partial pressure of carbon dioxide is lower. Reprecipitated material may nucleate around grains, etc., building up to form nodules.

In terms of a depositional environment the limestone lithologies suggest that the area was close enough to shore to have an abundant supply of fine-grained detritus. Winnowing action either did not take place, the sediment accumulating below wave base, or the process failed to have any effect on the sediment because of the abundant supply of fine-grained detritus. The final accumulations of marine sediments were in water shallow enough to sustain plant life with roots penetrating the unconsolidated marine sediments.

3. Nature of cyclicity: The cycles developed in the Lower Limestone Group up to the base of the Dockra Limestone show alternation between marine and terrestrial conditions. The nature of the transitions, as shown through the cycles, gives evidence of the depositional environment. Marine sediments invariably succeed coal. Swamp conditions starved of clastic detritus and accumulating organic

material give way to marine conditions with limestones and calcareous mudstones being deposited. Geographically this can be interpreted as a swamp area marginal to a sea being inundated with a relative rise in sea level.

Where sandstones and siltstones occur they commonly pass up into seatclays. These clastic sediments appear to be associated with the silting up of marine areas prior to the establishment of vegetation. Though not apparent from the analysis of cycles, the observed phenomena of roots penetrating limestones indicates that clastic sedimentation is not always a factor in raising the sediment-water interface. There is no clear pattern in the sequence of lithologies within the clastic sediments to indicate their mode of formation but in an environment changing from marine to terrestrial conditions, deltaic conditions are likely to be present.

In terms of the depositional environment the cycles suggest a swamp area marginal to a sea with clastic sediments forming small local deltas.

4. Local sediment variations: The outcrop evidence highlights an example at Roebank Bridge (see chapter 4.2) where part of the Wee Post Limestone passes laterally into sandstones and siltstones, the lower mudstones with their marine fauna being present at both localities. While it may be that the limestone sediments of the Wee Post Limestone in an area north of the Roebank Bridge were removed by erosion there is no evidence of a scour surface nor that the succeeding clastic sediments were deposited in an eroded channel. There is no coarse-grained basal unit to the clastic sediments nor is there any indication of an upward fining sequence.

At the Langside Mine pebbles are found in mudstones above the

Broadstone Limestone but there is no pebbly base nor upward fining sequence within the sandstones and siltstones to indicate a channel fill deposit.

It seems that, in these examples, limestones are laterally replaced by clastic sediments, which show neither the coarse-grained base and fining upwards sequence of a channel-fill deposit nor the cross-bedded, coarsening upwards sequence of a deltaic deposit. These clastic sediments are only locally developed and are generally poorly bedded (table 4.2). While they may represent small local deltas whose sedimentary structures have been subsequently destroyed by pedogenesis, they may also represent small off-shore sand bar deposits.

Chapter 5 Lower Limestone Group - Dockra Limestone

5.1 Introduction

This chapter seeks to re-examine the Dockra Limestone in the light of recent palaeontological work (Shiells and Penn, 1971) and petrographic work (Brown, 1978). Their work is examined from a regional and stratigraphical context incorporating the data from the IGS drilling and mapping programme. Lateral variation in lithology is discussed and the concepts of a 'Trearne' facies and 'Lugton' facies (Richey, 1946) are revised. Features in the topmost part of the Dockra Limestone are described and their geological significance discussed.

5.2 Dockra Limestone - lithologies in outcrop

The principal outcrops of the Dockra Limestone with details of lithology and thickness are listed in table 5.1. From these descriptions it is possible to split the Dockra Limestone into two facies. The first consists of limestones, light to medium grey or brownish grey in colour with argillaceous material confined to fine laminae and corresponds to the 'Trearne' facies described by Richey (1946) as "consisting of dominantly white or cream coloured limestones (though usually containing small dark patches) often in massive beds. It is also characterised by an abundance of well-preserved fossils, especially large encrinite stalks, many of them an inch in width and medium-sized Productid shells." The second facies consists of dark grey argillaceous limestones, more variable in bioclastic content and containing bands of calcareous mudstone, and corresponds with the 'Lugton' facies which Richey (1946) describes as being "marked by a succession consisting of dark grey

TABLE 5.1

Dockra Limestone - outcrop data

Locality and Grid Ref	Lithological Description	Thickness (metres)	Litho-facies
Geirston /NS 2991 5519/	Limestone, dark grey with calcareous mudstone bands, top 1.10-1.60 light grey patchy, wedging into underlying limestone	6.00+	'Lugton'
Auchencloigh /NS 2980 3492/	Limestone, dark grey, argillaceous, posts up to 0.15 m with thin calcareous mudstone partings	4.00+	'Lugton'
Hourat Cottage /NS 2850 5410/	Limestone, dark grey, massive	2.50+	'Lugton'
300 m south of Hourat Quarry /NS 2870 5325/	Limestone, dark brownish grey with beds of brachiopod shells, corals and crinoid stems, little mud	4.00+	'Trearne'
Newside /NS 2886 5198/	Limestone, medium grey with discontinuous argillaceous laminae, colonial and solitary corals in patches	4.00+	'Trearne'
Cunningham-Baidland /NS 2884 5094/	Limestone, brownish grey, rather massive but with few argillaceous bands, abundant crinoids and shell fragments	10.00+	'Trearne'
Auldmuir /NS 2661 5044/	Limestone, brownish grey with fine argillaceous laminae, abundant crinoid and shell fragments	3.00+	'Trearne'
Glen Lora /NS 3304 5855/	Calcareous mudstone, medium grey passing up into limestone, dark grey (see Lora Burn Borehole)	3.00+	'Lugton'
150 m south of Holehouse /NS 3090 5608/	Limestone, dark grey with argillaceous bands	5.00+	'Lugton'

TABLE 5.1 (cont'd)

Locality and Grid Ref	Lithological Description	Thickness (metres)	Litho-facies
Dykes Quarry /NS 3004 5522/	Limestone, dark grey with thin argillaceous laminae	3.00+	'Lugton'
Trearne Quarry (north) /NS 3727 5352/	Limestone, light brownish grey to dark grey in posts up to 1.0 m thick inter-bedded with calcareous mudstone, medium grey in beds up to 1.0 m thick, reddened top	7.47+	'Lugton'
Trearne Quarry (south) /NS 3729 5314/	Limestone, brownish grey with fine argillaceous laminae, abundant shell and crinoid fragments, calcareous mudstone bands to base, reddened top	8.30+	'Trearne'
Hessilhead Quarry /NS 3780 5315/	Limestone, medium to light grey with fine argillaceous laminae, abundant crinoid and shell debris, reddened top with lenticular chert nodules 1 m below	9.00+	'Trearne'
Old Mill Quarry (north) /NS 3964 5277/	Limestone, medium grey, argillaceous with scattered crinoid and shell debris, reddened top with lenticular chert nodules about 1 m below	10.00+	'Lugton'
Old Mill Quarry (south) /NS 3928 5258/	Limestone, medium to light grey with fine argillaceous laminae, abundant crinoid and shell debris (see Old Mill Borehole)	8.00+	'Trearne'
Lugton /NS 4108 5268/	Limestone, dark grey, argillaceous in posts about 1.0 m thick with calcareous mudstone bands	2.40+	'Lugton'
Middleton Quarry /NS 4027 5268/	Limestone, medium grey with dark grey calcareous mudstone laminae, algel ancolites on top surface with some reddening	3.00+	'Lugton'

TABLE 5.1 (cont'd)

Locality and Grid Ref	Lithological Description	Thickness (metres)	Litho-facies
Shaw's Rock Horse Isle /NS 2141 4256/	Limestone, dark grey, argillaceous with crinoid and coral fragments	6.00+	'Lugton'
Ardrossan Shore /NS 2288 4168/	Limestone, dark grey, argillaceous	4.00	'Lugton'
250 m south of Birkhead /NS 2580 4962/	Limestone, light grey to brownish grey with calcareous mudstone bands	5.30+	'Trearne'
Blackstone /NS 2575 4918/	Limestone, dark grey, argillaceous	2.00+	'Lugton'
Auchenmade /NS 3392 4853/	Limestone, medium grey with fine argillaceous laminae, abundant shell and crinoid debris	4.00+	'Trearne'
Cleeves Cove /NS 3127 4744/	Limestone, dark grey, argillaceous with thin calcareous mudstone bands	6.90+	'Lugton'
Auchenskeith /NS 3145 4680/	Limestone, dark grey, argillaceous with calcareous mudstone bands	3.00+	'Lugton'
Low Gameshill /NS 4066 4773/	Limestone, dark grey, argillaceous with calcareous mudstone laminae, (see Kirkwood Borehole)	1.30+	'Lugton'

limestone beds interleaved with dark grey calcareous shale".

A 'White Post' as described by Richey (1946) has been recorded from Geirston and again from the Trearne, Hessilhead, Middleton and Old Mill quarries. The detail and significance of this profile is discussed later.

5.3 Dockra Limestone - lithologies in boreholes

The Dockra Limestone was penetrated in eight of the recent IGS boreholes, the Lora Burn, Dunniflat, Ardrossan, Coalhill No 2, Montgreenan, Muirlaught, Kirkwood and Old Mill boreholes. Descriptions of the lithologies of the Dockra Limestone in each of these boreholes, with the exception of the Old Mill Borehole, are given in tables 6.3 -6.9. In the Old Mill Borehole the Dockra Limestone is 13.7 metres thick consisting of light to dark brownish-grey limestone with abundant fossils. Calcareous mudstones are confined to the basal 1.84 metres. These lithologies match those included in Richey's 'Trearne' facies.

The top 0.87 metres of the Dockra Limestone in the Old Mill Borehole consists of a brownish-grey fine grained limestone with dark grey root structures preserved. This is similar to the 'White Post' at Geirston (above). Chert nodules occur between 2 and 5 metres from the top of the limestone. A bed of similar lithology to the 'White Post' is present within the Dockra Limestone in the Muirlaught Borehole. The bed has a sharp base and is capped by some 2.80 metres of calcareous mudstone. No bed of 'White Post' type limestone is recorded from the Kirkwood Borehole but the 0.85 metres of strata above the limestone consists of seatclays and seaty calcareous mudstones with marine shells. A bed

of light grey, mottled limestone 0.45 metres thick and similar to the 'White Post' occurs within the Dockra Limestone in the Lora Burn Borehole. It lies between 1.19 and 1.64 metres from the top of the Dockra Limestone with a series of limestones and calcareous mudstones above, occasionally with roots recorded. No evidence of 'White Post' type beds were recorded from the Dunniflat, Montgreenan, Ardrossan or Coalhill No 2 boreholes.

5.4 Distribution of facies within Dockra Limestone

Richey's (1946, fig. 1) map showing the geographical distribution of the 'Trearne' and 'Lugton' facies can now be revised (fig. 5.1). At Auchenskeith the Dockra Limestone is dark grey and argillaceous and has been referred to the 'Lugton' facies and not the 'Trearne' facies to which it was assigned by Richey. The area of dark limestone of 'Lugton' facies shown by Richey as occurring around Barrmill has been omitted from the revised map. Detailed field observations have shown that these dark grey limestones are in fault contact with a small outcrop of Dockra Limestone of 'Trearne' facies. The dark grey limestones are now considered to be Broadstone Limestone.

5.5 Transition from 'Trearne' to 'Lugton' facies

The transition from the 'Trearne' to the 'Lugton' facies of the Dockra Limestone can be examined in the faces in Trearne Quarry and less well in the Old Mill Quarry. The north end of Trearne Quarry (point A in fig 5.2) consists of a series of posts of dark grey argillaceous limestone interbedded with bands of calcareous mudstone (Plate 5.1a). Some of the limestone posts are light grey

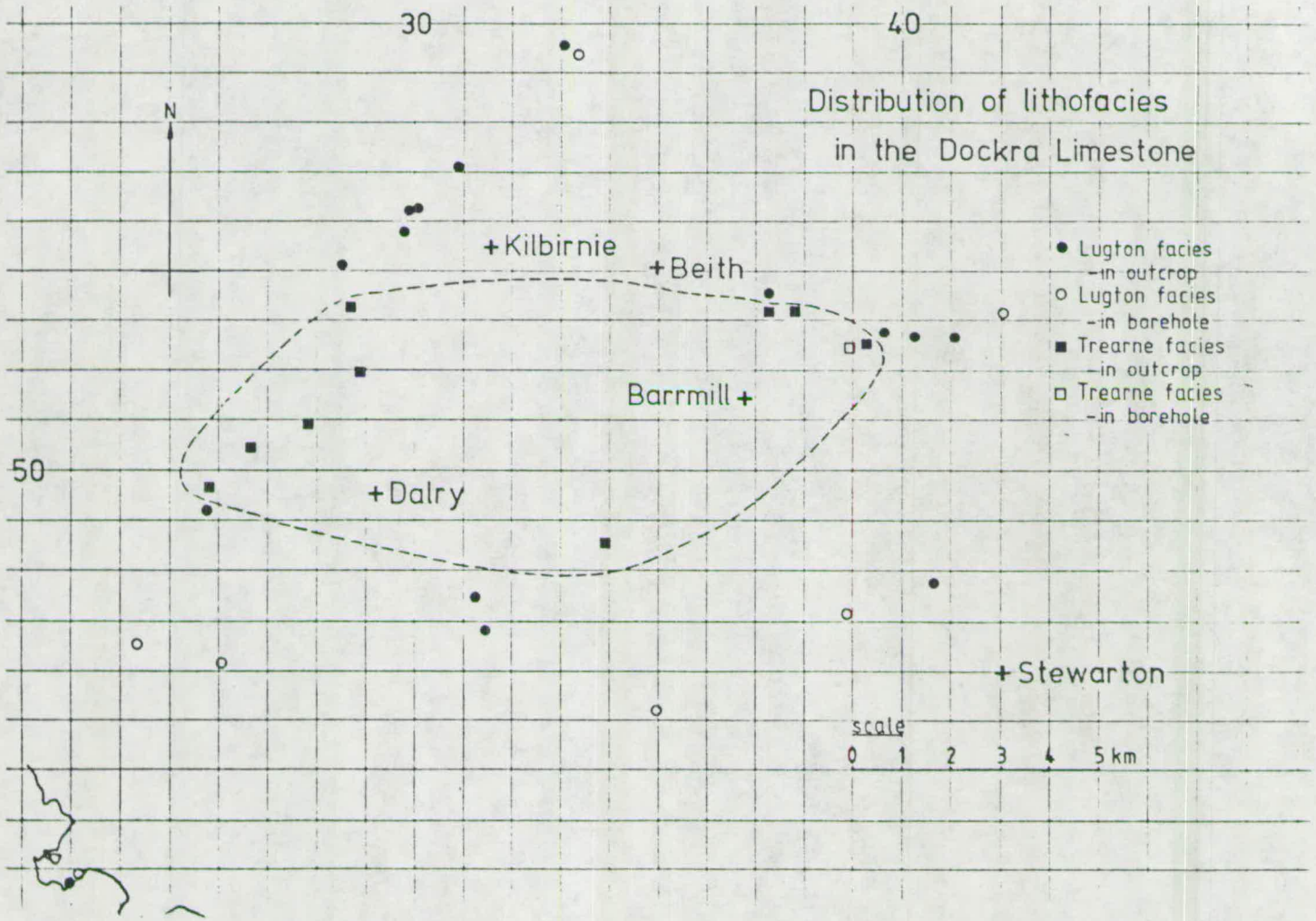
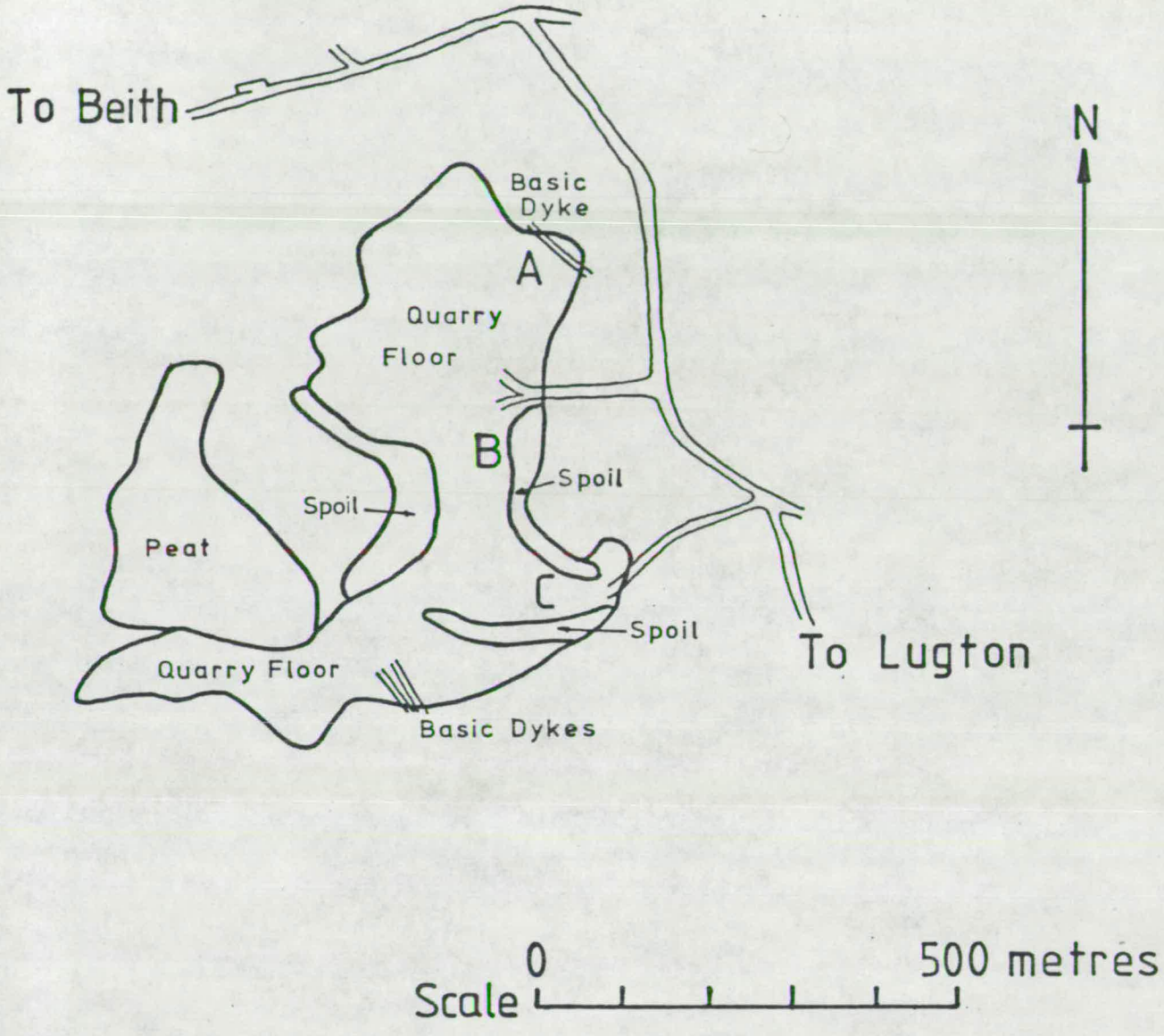

30
40
50
N
Distribution of lithofacies
in the Dockra Limestone
+Kilbirnie
+Beith
Barrmill+
+Dalry
+Stewarton
Lugton facies
-in outcrop
Lugton facies
-in borehole
Trearne facies
-in outcrop
Trearne facies
-in borehole
scale
0 1 2 3 4 5 km

Fig. 5.1



SKETCH MAP OF TREARNE QUARRY

PLATE 5.1

PLATE 5.1

a. Section of the argillaceous, 'Lugton' facies, of the Dockra Limestone at the north end of Trearne Quarry /ÑS 3727 5352/

b. Section of the bioclastic, 'Trearne' facies of the Dockra Limestone at the south end of Trearne Quarry /ÑS 3729 5314/





in colour and mottled, a lithology referred to by Shiells (1971) as 'multicomponent mudstones' and by Brown as 'mottled limestones'.

Southwards the bands of calcareous mudstone thin until they become fine argillaceous laminae. The limestone lithologies also change southwards. Midway along the quarry (Point B in fig 5.2) coarser bioclastic limestones appear resting on beds of a fine-grained, light grey mottled limestone, the 'multicomponent mudstones' of Shiells and the 'mottled limestones' of Brown. At the southernmost point in the quarry (Point C in fig 5.2) the 'multicomponent mudstones' or 'mottled limestones' have disappeared, passing laterally into a succession of beds of light brownish grey, bioclastic limestone with fine argillaceous laminae (Plate 5.1b and 5.2b). Low mounds or thickets of Lithostrotion junceum usually 20-30 cm high are common (Plate 5.2a).

The 'reef limestone' shown by Shiells and Penn (1971 fig 1A) has not been recognised in this present study and at the southern end in the floor of the quarry beds of calcareous mudstone are exposed which borehole data confirm as being the basal beds of the Dockra Limestone. A diagramatic representation of the transition from 'Lugton' to 'Trearne' facies is given in fig 5.3. The important features are summarised as follows:

1. An increase in mud content from 'Trearne' to 'Lugton' facies, both within the limestone beds and as separate beds of calcareous mudstone.
2. Light coloured bioclastic limestones in 'Trearne' facies.
3. Presence of 'mottled limestone' or 'multicomponent mudstone' lithologies within a transition zone.

PLATE 5.2

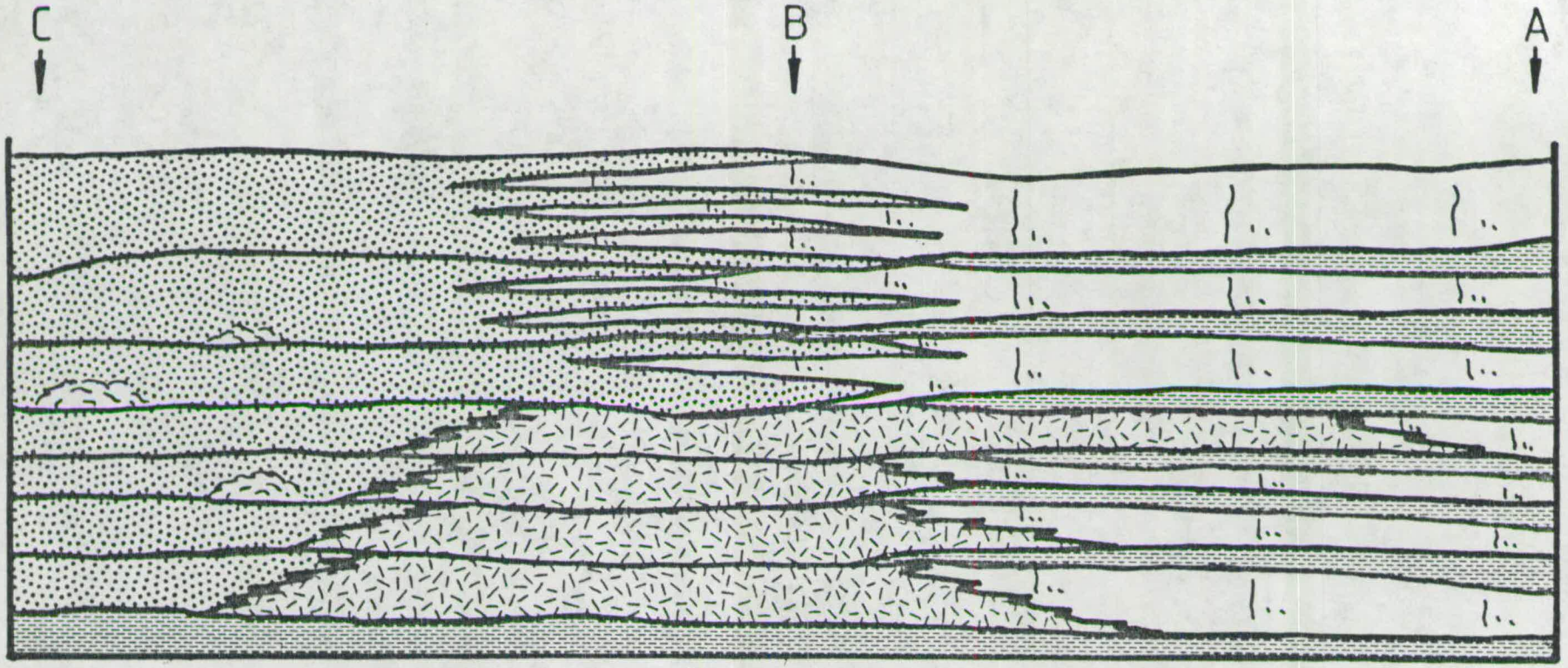
a. Development of colony of Lithostrotion sp. within the bioclastic, 'Trearne' facies of the Dockra Limestone at the south end of Trearne Quarry /NS 3729 5314/

b. Bioclastic, 'Trearne' facies of the Dockra Limestone composed almost entirely of crinoid columnals and brachiopod shell fragments. South end of Trearne Quarry /NS 3729 5314/





Trearne Quarry - facies transition diagram



Argillaceous Limestone

Bioclastic Limestone

Calcareous Mudstone

Mottled Limestone

Lithostrotion Mound

Fig. 5.3

5.6 Thickness of Dockra Limestone

An isopach map for the Dockra Limestone has been constructed using the IGS borehole data, other borehole data and outcrop sections where these give a complete or nearly complete section. The resulting map (fig 5.4) can be compared with the facies distribution map (fig 5.1). The areas of thickest development of Dockra Limestone correspond with the areas of 'Trearne' facies.

5.7 Upper surface of the Dockra Limestone - in outcrop and boreholes

The lithology of the upper part of the Dockra Limestone has been modified, in some places, to a depth of between one and two metres. A distinctive bed of fine-grained, light grey limestone is formed called the 'White Post'. Reddening may occur in the top few centimetres of the limestone and lenticular chert nodules may be present at around two metres below the surface. The 'White Post' is well exposed in the Paduff Burn 150 metres north-east of Geirston Farm /NS 2991 5519/ and in the Trearne, Hessilhead and Old Mill quarries in the area 3 to 4 kilometres east of Beith. A 'White Post' lithology has also been recorded from the top or near the top of the Dockra Limestone in the Old Mill, Muirlaught and Lora Burn boreholes.

The occurrence of the 'White Post' in the Paduff Burn at Geirston was recorded and commented on by Richey (1946). It consists of 1.20-1.60 metres of fine-grained, light grey limestone resting on dark grey, bedded, argillaceous limestone of the Lugton facies. The junction between the 'White Post' bed and the underlying limestones is irregular with wedges of the 'White Post'

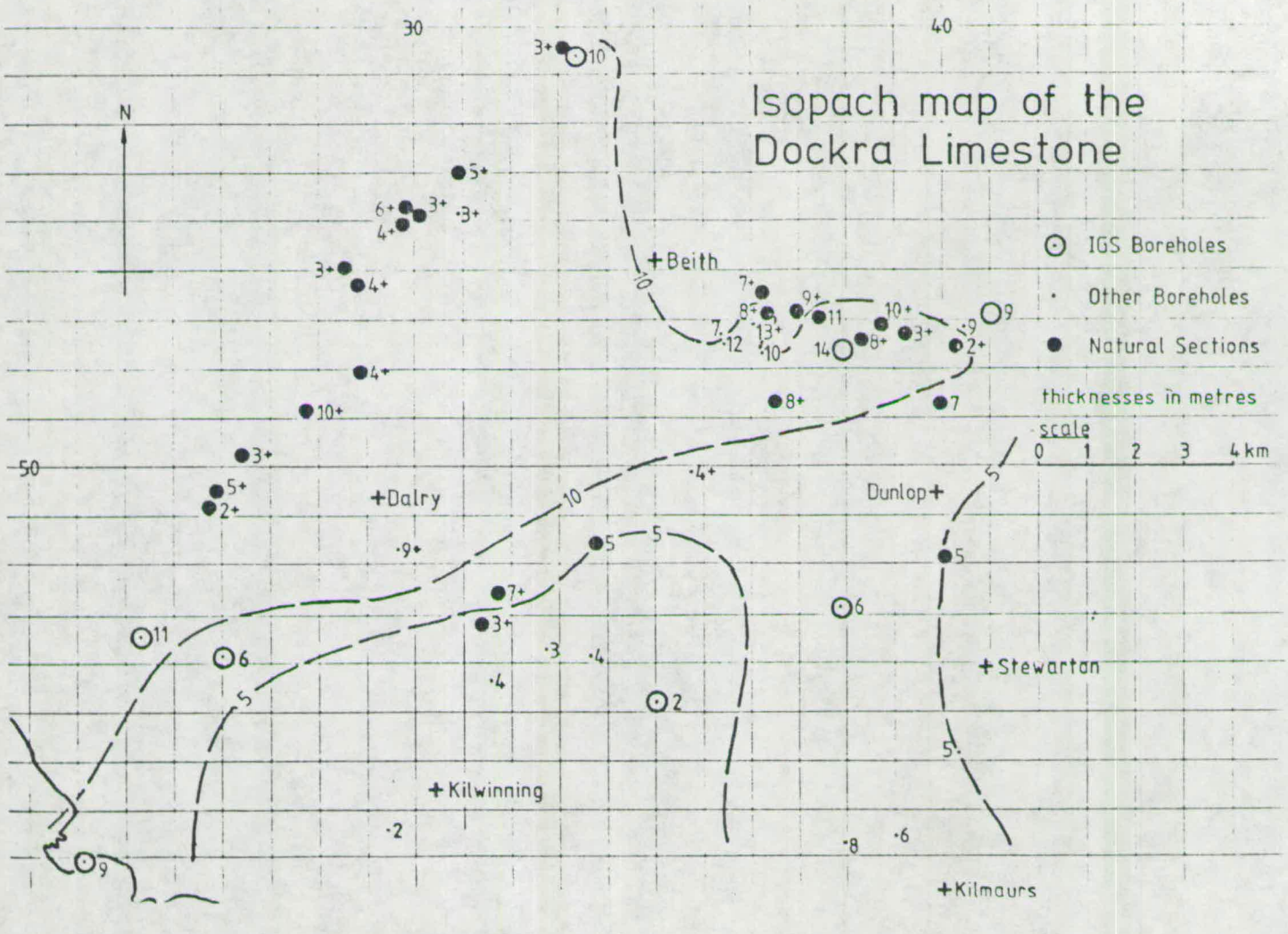

Isopach map of the
Dockra Limestone
N
30
40
50
IGS Boreholes
Other Boreholes
Natural Sections
thicknesses in metres
scale
0 1 2 3 4 km
+Beith
+Dalry
Dunlop+
+Stewarton
+Kilwinning
+Kilmaurs

Fig. 5.4

penetrating the underlying beds. These wedges have distorted the bedding in the underlying argillaceous limestone (Plate 5.3).

In thin section the top surface to a depth of around 4 cm consists of brownish-grey, low birefringent clay mineral, often as discrete bands or laminae. Carbonate grains are present, scattered throughout the clay matrix and increasing in proportion downwards becoming a dominantly carbonate rock below 4 cm. The carbonate grains are shown by staining with Alizarin Red to be calcite and have grown as euhedral crystals around a core of clay mineral (Plates 5.4a and 5.5). Reddish-brown coatings of haemitite occur round grains in top 5 mm. Pyrite is scattered throughout. Quartz grains, of detrital origin, are present throughout. An XRD scan of a bulk sample of this rock confirms a quartz-calcite mineralogy and shows the dominant clay mineral to be kaolinite. The rock has been extensively bioturbated either by roots or burrowing organisms. Foraminifera and other shell fragments indicate a marine origin for the sediment.

Below the top 4 cm the 'White Post' consists of a light brownish grey micrite with scattered shell fragments. In thin section the bulk of the rock is seen to consist of fine-grained calcite with sparry calcite infilling open joints in the structure. Extensive bioturbation has occurred either by roots or burrowing organisms (Plate 5.5b).

At the Old Mill Quarry /NS 3964 5277/ and in the Trearne and Hessilhead quarries nearby the 'White Post' is also developed. It is here characterised by a reddened crust at the top around 5 cm thick and by black lenticular chert nodules in the limestones below the 'White Post'. The 'White Post' as developed in the Old Mill

PLATE 5.3

a. Base of the 'White Post' at the top of the Dockra Limestone in the Paduff Burn, /NS 2990 5529/

b. Base of the 'White Post' at the top of the Dockra Limestone in the Paduff Burn /NS 2990 5529/ showing disturbance of underlying argillaceous laminae


'WHITE POST'

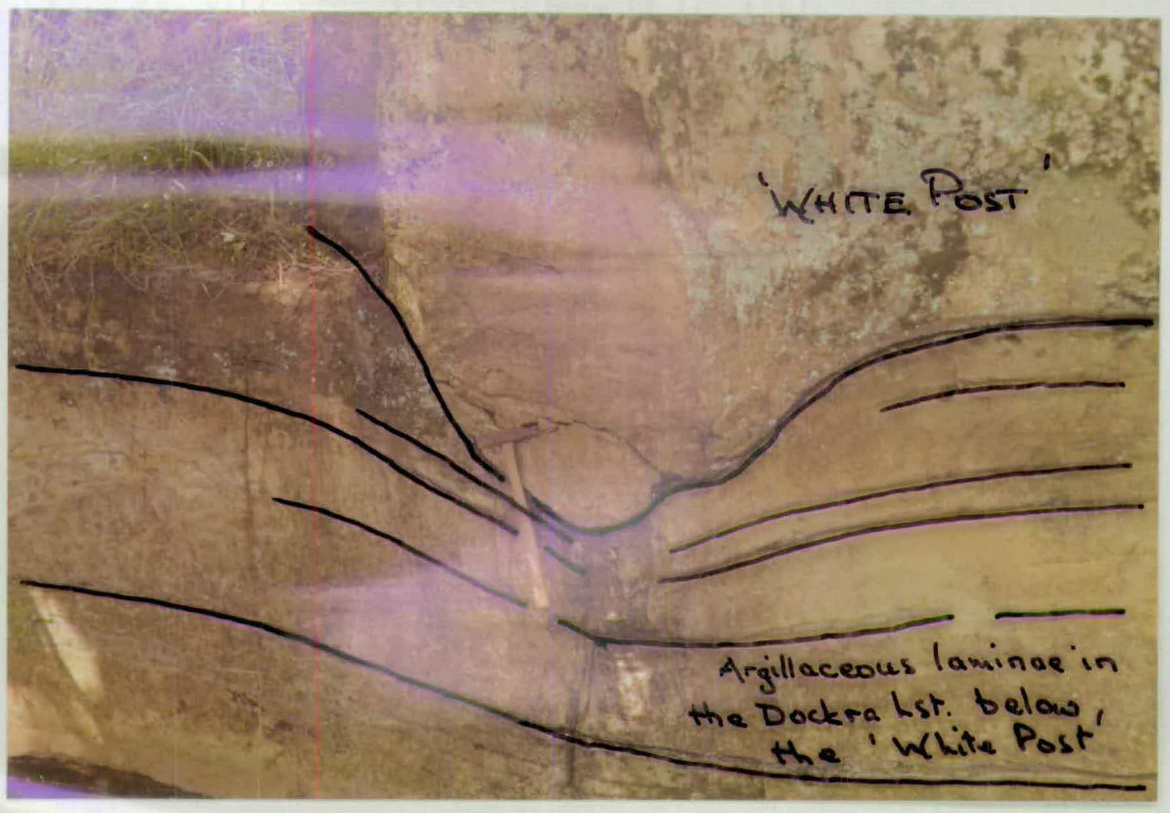
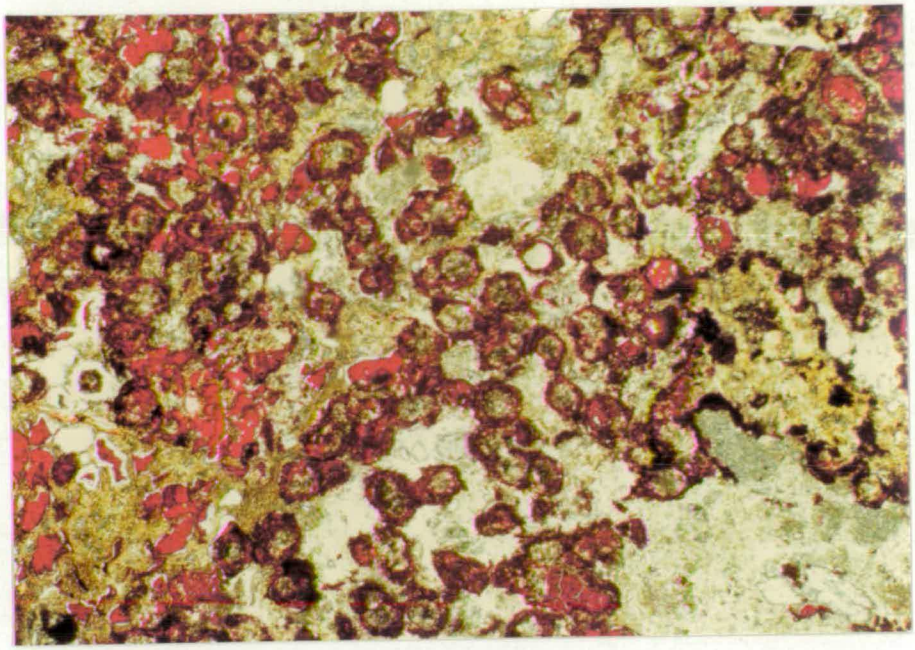

'WHITE POST'
Argillaceous laminae in the Dockra Lst. below the 'White Post'

PLATE 5.4

a. Photo micrograph of the top of the 'White Post' at Geirston /NS 2991 5519/ showing calcite, stained red with alizarin red growing round a clay core within a clay matrix (ppl - mag x 50)

b. Photo micrograph of the top of 'White Post' at the Old Mill Quarry /NS 3947 5277/ showing the bioclastic fragments composed of calcite, stained red with aluzarin red, small rhombs of dolomite with a calcite or clay mineral core and a matrix of greenish clay mineral (ppl - mag x 50)



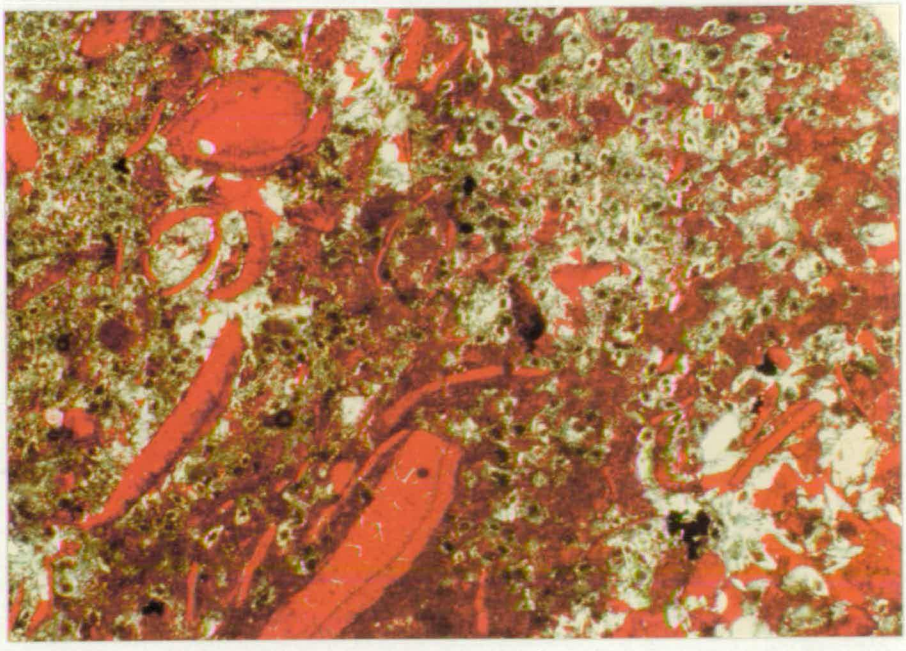
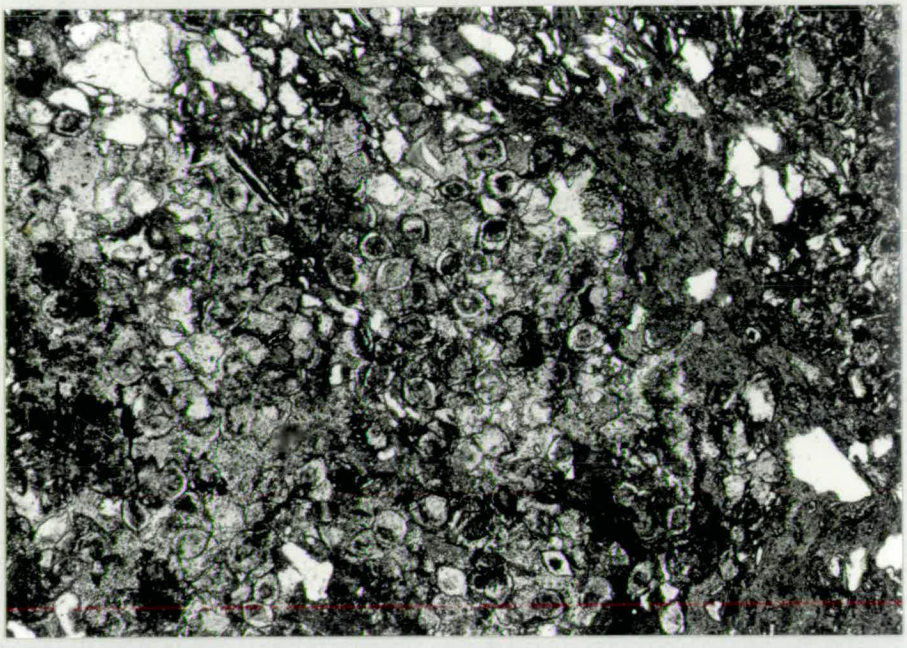
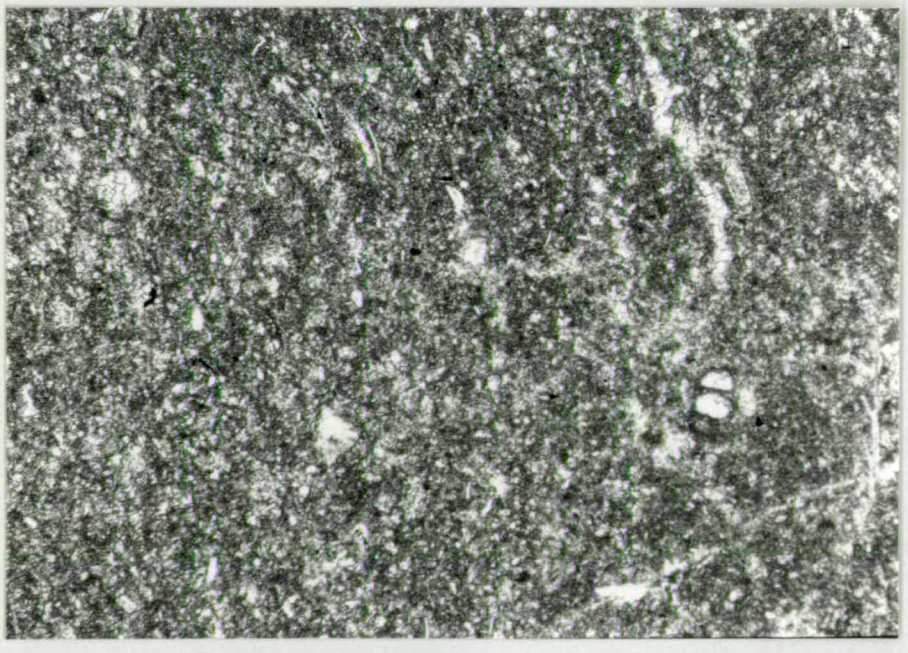


PLATE 5.5

a. Photo micrograph of the top of the 'White Post' at Geirston /NS 2991 5519/ showing calcite overgrowths and discrete patches of clay mineral (ppl - mag x 50)

b. Photo micrograph of the lower part of the 'White Post' at Geirston /NS 2991 5519/ showing fine-grained micrite with occasional shell fragments, extensively bioturbated (ppl - mag x 50)





Quarry is shown in Plate 5.6 and is typical of the development in this area. A reddened crust around 5 cm thick marks the top of the 'White Post' which is here a bed of light grey, fine-grained limestone around 0.75 metres thick. Beneath the 'White Post' are a series of dark grey, argillaceous limestone beds with bands of calcareous mudstone. Within the top metre of these beds black, lenticular chert nodules are developed. Similar profiles to this are developed at the top of the Dockra Limestone in the Trearne, Hessilhead and Old Mill quarries with Stigmaria also present within the reddened crust at Hessilhead and Old Mill.

The relationship between the 'White Post' and the rest of the Lower Limestone Group succession can be deduced from the exposures in the Old Mill Quarry in association with the Old Mill Borehole. In the Old Mill Borehole the Dockra Limestone is 13.7 m thick, the top 0.87 m being of the typical 'White Post' lithology. This is overlain by 0.37 m of dark grey to black carbonaceous mudstone, passing upwards into mudstones with Lingula sp. and limestones and calcareous mudstones of the Hosie Limestone Formation.

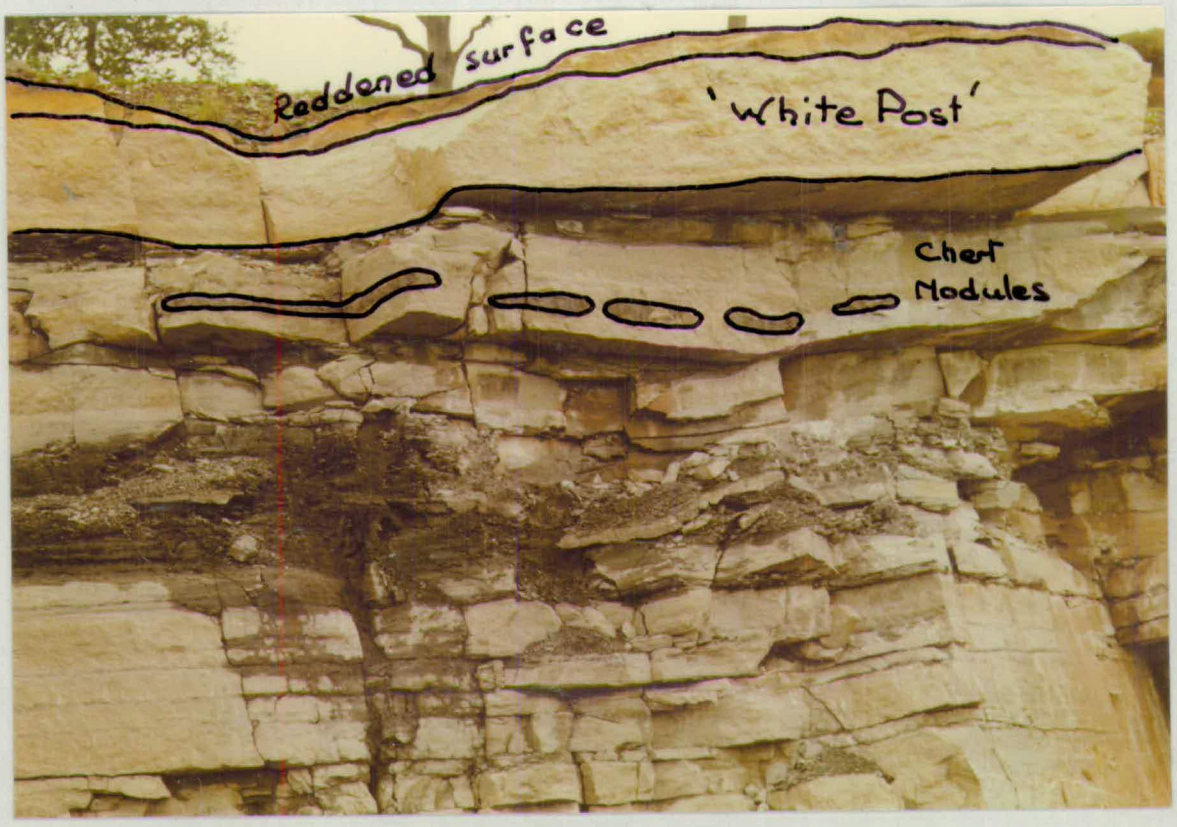
The western face in the northern part of the Old Mill Quarry shows the relationship between the 'White Post' and the rest of the Dockra Limestone (Plate 5.6). The 'White Post', and its reddened crust, is present at both the north and south ends of the face. The 'White Post' bed at the north end of the face can be traced laterally and passes southwards into a bed of dark grey limestone within the Dockra Limestone with a 'White Post' bed developed again at the top. There is a local unconformity displayed in this face with the 'White Post' representing processes that have taken place after some erosion of the limestone.

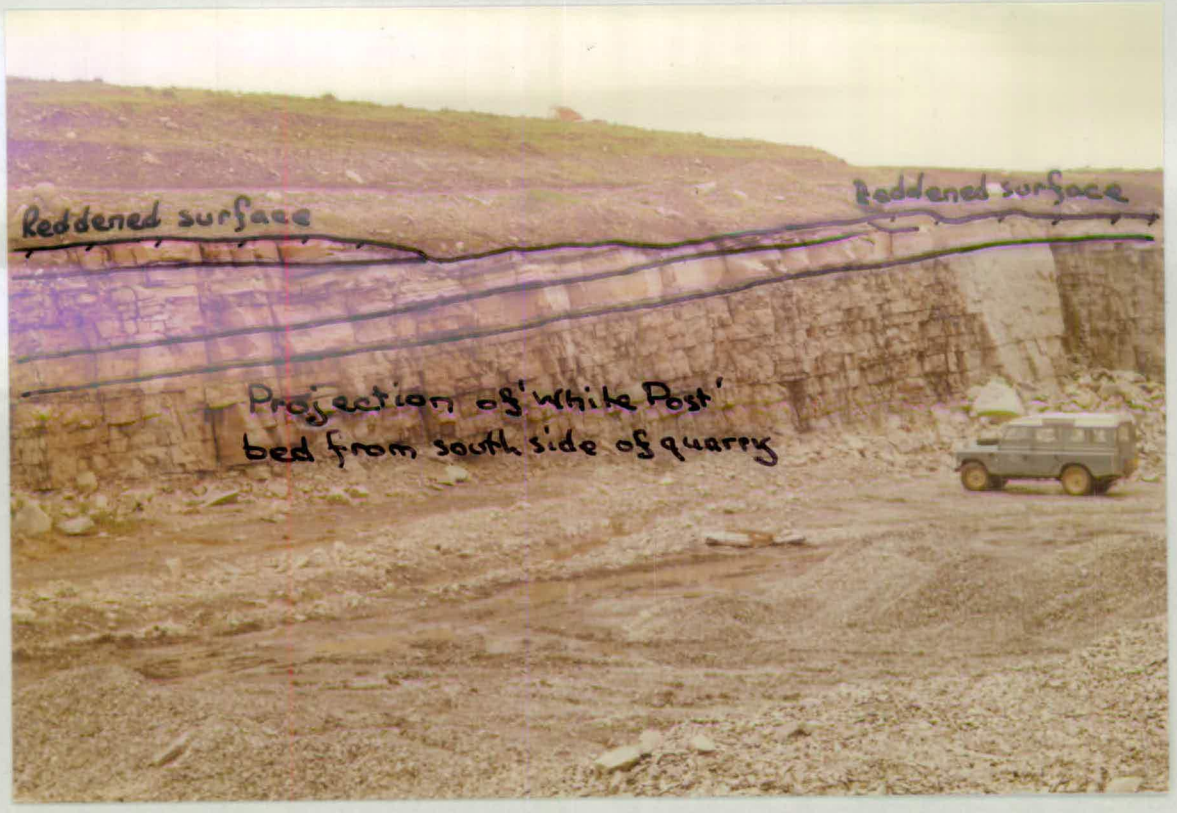
PLATE 5.6

PLATE 5.6

a. Top of the Dockra Limestone in the Old Mill Quarry /NS 3964 5277/ showing reddened crust and the 'White Post' bed with lenticular chert nodules below

b. Dockra Limestone in the Old Mill Quarry /NS 3964 5277/ showing the relationship between the 'White Post' bed with the reddened crust and the bedding in the limestone


Reddened surface
'White Post'
Chert Nodules


Reddened surface
Reddened surface
Projection of 'White Post' bed from south side of quarry

In thin section the reddened top of the Dockra Limestone can be seen to contain abundant rhombs of dolomite (Plate 5.4b) and patches of kaolinite (Plates 5.7 and 5.8) which XRD determinations show to be well-ordered. In addition the fauna is characterised by the presence of ostracods and occasional algal structures, some of which form oncolites (Plates 5.9 and 5.10). The transition from the reddened crust to the 'White Post' is irregular and frequently disrupted by roots (Plate 5.8).

5.8 Genesis of the 'White Post'

The key to the origin of the 'White Post' lies in the recognition that there is a) an erosive surface at the top of the Dockra Limestone and b) an accumulation of an iron-rich residue as a result of chemical weathering forming the reddened crust. If erosion has taken place by sub-areal exposure then chemical weathering should form a residual deposit rich in iron. In addition there should be rapid colonisation by plants and in the then prevailing climate some evidence of lateritic weathering. Stigmaria roots are found with the 'White Post' and cavities occur within the reddened crust filled with well-ordered kaolinite (Plates 5.7 and 5.8). The suggestion is that the 'White Post' is formed by pedogenesis on an uplifted area of Dockra Limestone. This process may also explain the occurrence of lenticular silica someway down the profile. If silica were dissolved in ground water in an uplifted area of limestone the dissolved silica would move down the profile until it reached the watertable where it would be re-precipitated. The level of the silica nodules may represent the site of the then water table. The source of the silica may either be siliceous sponges

PLATE 5.7



PLATE 5.8

a. Polished and etched slab from the top of the Dockra Limestone in the Old Mill Quarry /NS 3947 5277/ showing reddened crust with abundant ostracods and kaolinite patches and the top of the bioturbated 'White Post' bed

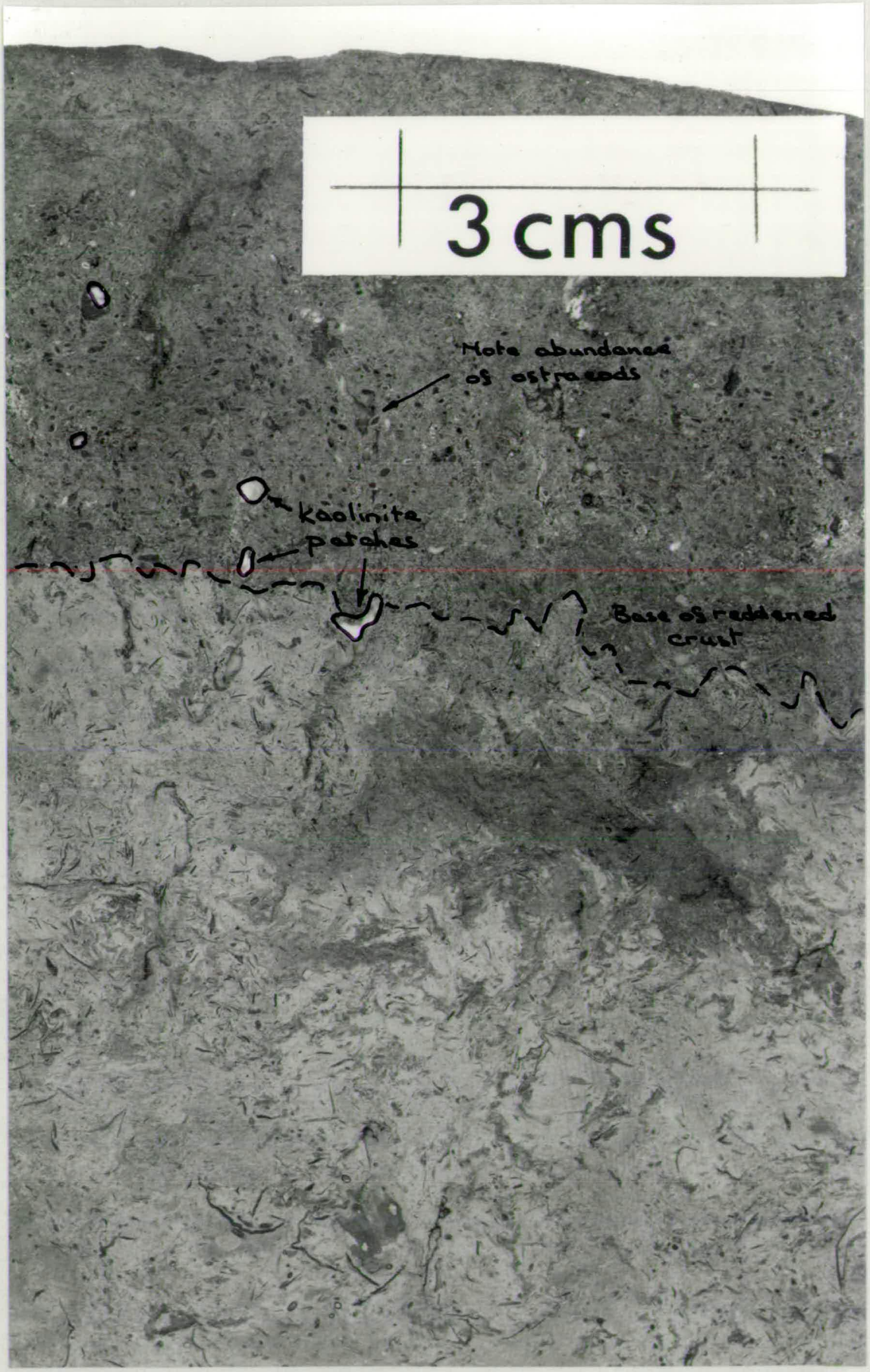
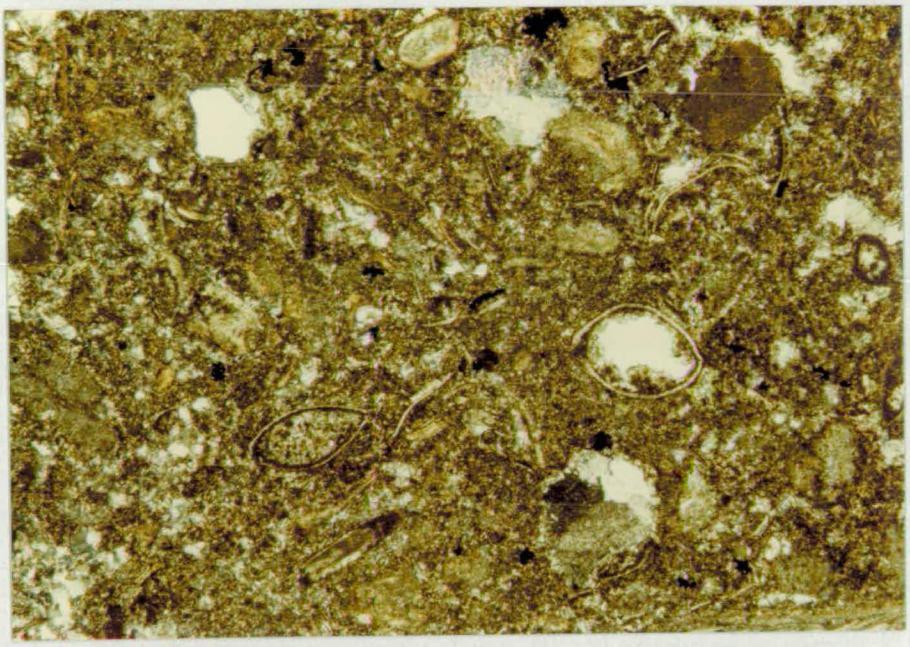

3 cms
Note abundance of ostracods
kaolinite patches
Base of reddened crust

PLATE 5.9

PLATE 5.9

a. Photo micrograph of the top of the Dockra Limestone in the Old Mill Quarry /NS 3947 5277/ with abundant ostracods (x pol - mag x 20)

b. Photo micrograph of algal structures in the top of the Dockra Limestone in the Old Mill Quarry /NS 3947 5277/ (ppl - mag x 20)



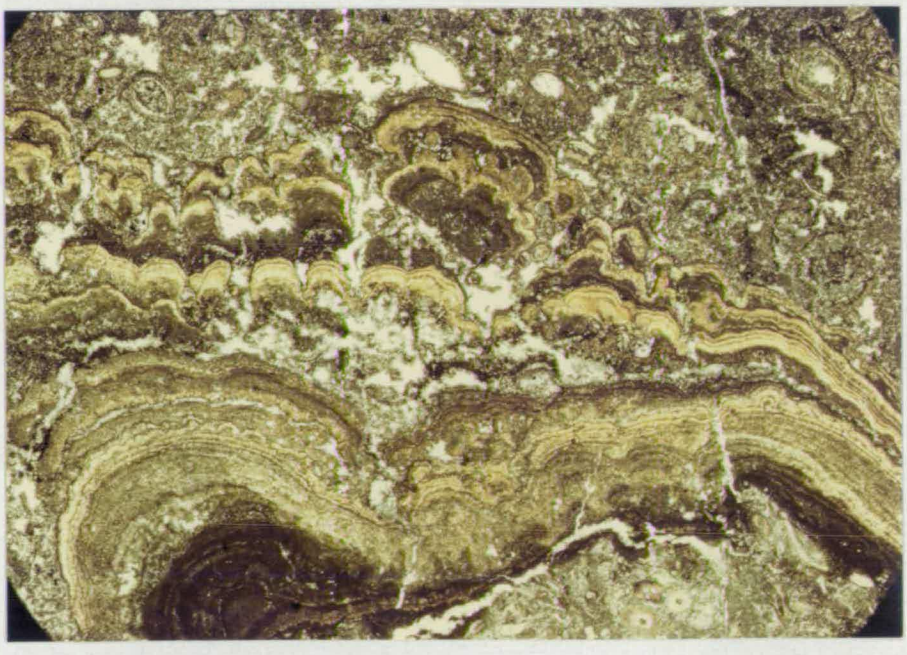


PLATE 5.10



which are known to be present or else as a result of the lateritic weathering of kaolinite. If this area of limestone had been exposed and subjected to sub-areal weathering then there should be some evidence in the topmost beds of the limestone of a transition from marine to terrestial conditions. Faunal changes are seen in the top few centimetres of the Dockra Limestone at Old Mill. From a marine fauna rich in brachiopods, crinoids and corals, the fauna alters to one dominated by ostracods and with algal oncolites (Plates 5.9 and 5.10). This faunal change may represent a change in environment induced by either uplift of the limestone or else by a net lowering of sea level. Certainly the algal oncolites have formed in agitated waters possibly close in-shore.

5.9 Environment of deposition of Dockra Limestone

With the exception of the few centimetres at the top of the Dockra Limestone in the Old Mill Quarry, the fauna is characteristic of an open marine environment. Fig 3.9 shows that the Dockra Limestone was deposited over a wide area. Fine-grained detritus was being supplied and was deposited within the areas of the 'Lugton' facies. On the other hand mud is not so common within the 'Trearne' facies and a model for impeding the distribution of this sediment is required.

Brown (1978) discussed two alternative models, a carbonate shoal model and a biotic barrier model. The first model envisages a shoal developing on a site rich in organisms which builds on itself by being more attractive to organisms with more light, better circulation and a freedom from terrigenous sediment. The end-product would be a buildup of mud-free limestone within a central area. The

second model is one where the abundance of crinoids stabilises the in-coming sediment leaving areas starved of clastic detritus.

The area of 'Trearne' facies corresponds to the thickest development of Dockra Limestone but by tracing an individual calcareous mudstone band in the 'Lugton' facies into a muddy laminae and thence into a bedding plane in the 'Trearne' facies it becomes apparent that at any time the topographical difference was not more than 1-2 metres. An organic build-up or reef structure may be present in the Dockra Limestone at Dockra Quarry /NS 3615 5279/. This is the only place where such structures are seen and one which, due to flooding, is inaccessible for detailed study.

Overall, the Dockra Limestone of 'Trearne' facies is thicker than that of 'Lugton' facies. There is also considerably more mud within the 'Lugton' facies the compaction of which following deposition would be greater than within the 'Trearne' facies. Crinoid 'forests' may have an influence in stabalising in-coming sediment but while richly crinoidal limestones occur at the transition between 'Trearne' and 'Lugton' facies in the Trearne quarry, crinoids are not so abundant at Old Mill. Their influence may therefore be local. Neither model previously suggested fully satisfies the facts.

Following deposition of the Dockra Limestone part of the area became land with pedogenic processes forming the 'White Post' and reddened top. The structures seen in the Paduff Burn at the base of the 'White Post' (Plate 5.3) are enigmatic. It might be suggested that they are structures related to the former tap roots of plants and may be, in cross section, structures similar to those seen in the Middle Long Craig Limestone at Catcraig in East Lothian (Craig, 1975).

In summary the Dockra Limestones were deposited in an open marine shelf area which was supplied with an abundance of mud grade detritus. The development of bioclastic limestones define areas where this mud did not penetrate due either to topography or a 'crinoid forest' barrier. A period of local emergence immediately after deposition of the Dockra Limestone is indicated by the development of the 'White Post'.

Chapter 6 Lower Limestone Group between the Dockra and the Top Hosie Limestones

6.1 Introduction

This chapter describes the strata of the Lower Limestone Group between the Dockra and the Top Hosie limestones in the Dalry Basin. The basis of correlation is considered as are lateral variations in both thickness and lithology. Cyclicity within the strata is discussed and a model postulated for the environment of deposition.

6.2 Lower Limestone Group between the Dockra and the Top Hosie Limestones - outcrop data

The principal sections in the Lower Limestone Group between the Dockra and the Top Hosie limestones which crop out within the Dalry Basin are given in tables 6.1 and 6.2.

At Cunningham-Baidland and in the Gurdie railway cutting the strata consist of limestones, calcareous mudstones and mudstones with a sandstone band approximately midway between the Top Hosie and Dockra Limestones. At the Blair Mill Bridge and Paduff Burn localities similar limestones are present with a rooty bed developed midway between the Top Hosie and Dockra limestones.

6.3 Lower Limestone Group between the Dockra and Top Hosie Limestones - borehole data

The strata between the Dockra and Top Hosie limestones were encountered in seven of the IGS boreholes, the Kirkwood, Coalhill No 2, Muirlaught, Montgreenan, Ardrossan, Lora Burn and Dunniflat boreholes. The principal features of the sequences encountered can

TABLE 6.1

Lower Limestone Group between the Dockra and Top Hosie Limestones - outcrop data

Paduff Burn /NS 3020 5490/

	Thickness (metres)
Top Hosie Limestone: limestone and calcareous mudstones	1.40
Mudstone with seatclay bands	4.00
Limestone, dark grey, argillaceous, crinoidal	0.65
Mudstones, dark grey with irony weathering	1.80
Limestone, dark grey, crinoidal	0.20
Mudstone, dark grey, broken	2.00
GAP about on	0.40
Dockra Limestone: limestone, light grey with irregular top	

Cunningham-Baidland /NS 288 509/ composite section

Top Hosie Limestone: limestones and calcareous mudstones, dark grey with frequent brachiopods and crinoids	2.55
Mudstones, dark grey	0.20
Sandstones, medium grained, light grey, cross bedded	2.10
Mudstones, dark grey	4.00
Limestones and calcareous mudstones, dark grey with small brachiopods and crinoids	0.65
Mudstones, dark grey	3.90
Limestone and calcareous mudstone, dark grey	0.25
Mudstone, dark grey	0.40
Dockra Limestone: limestones, dark grey with irregular argillaceous partings	4.00+

TABLE 6.2

Lower Limestone Group between the Dockra and Top Hosie Limestones - outcrop data

Blair Mill Bridge /NS 3210 4752/

	Thickness (metres)
Top Hosie Limestone: limestone and calcareous mudstones, dark grey with brachiopods and crinoids	1.02
Mudstones, calcareous at top	1.16
Mudstones, calcareous and limestones, dark grey, crinoidal	1.04
Mudstones, dark grey, irony weathering, rooty and calcareous in places	1.24
Mudstones, calcareous, limestone band at top, dark grey, crinoidal	0.61
Mudstone, dark grey, irony weathering	2.16
Limestone and calcareous mudstones, dark grey with crinoids and bryozoa	0.36+
GAP	
Dockra Limestone: limestones, dark grey,argillaceous	

Gurdie Railway Cutting /NS 334 524/

Top Hosie Limestone: limestone, dark grey, argillaceous	0.20
Mudstones, dark grey with marine fauna at top, becoming silty	2.00
Limestone, dark grey, argillaceous with brachiopods and crinoids	0.65
Mudstones, dark grey	1.20
Sandstones, light brownish grey, medium grained with silty laminae to base	1.00
Mudstones, dark grey with frequent ironstone nodules	4.00
Limestones, dark grey, argillaceous	0.70
Mudstones, dark grey, irony weathering, poorly preserved goniatites and other shells to base	4.11+

+ following an item indicates full thickness not seen

be seen from tables 6.3 to 6.9 together with the graphic plots given in figs 3.2, 3.4 to 3.8, and in fig 4.1.

6.4 Lower Limestone Group between the Dockra and Top Hosie Limestones - correlation

In both borehole sections and in outcrop, strict bed-for-bed correlations are not possible. The Top Hosie and Dockra limestones can be recognised by their place in the sequence and by their fossil content, but between these two horizons it is not possible to distinguish with certainty the four Hosie Limestones recognised elsewhere (Richey 1930). For this reason it has been proposed (chapter 2.10) that the strata at the top of the Lower Limestone Group characterised by the presence of these thin Hosie Limestones be treated as a single lithostratigraphic formation, the Hosie Limestone Formation.

Local criteria for finer correlation within the Dalry Basin are required and the use of local lithological variations is considered here. The borehole and outcrop sections indicate that the sequence between the Top Hosie and Dockra limestones is mostly a succession of limestones, calcareous mudstones and mudstones. Sandstones, siltstones and rooty beds are less typical.

Both sandstones and rooty beds are seen in outcrop between the Top Hosie and Dockra limestones. Rooty beds have also been recorded at a similar stratigraphic position in the borehole sections, at 18.00 m in the Kirkwood Borehole, at 60.35 m in the Coalhill No 2 Borehole, at 40.78 m in the Muirlaught Borehole, at 138.60 m in the Montgreenan Borehole, at 22.92 m in the Ardrossan Borehole and at 15.80 m in the Lora Burn Borehole. This position is

TABLE 6.3

The strata from the base of the Dockra Limestone to the Top Hosie Limestone - in boreholes

	Depth (metres) from	to
Kirkwood Borehole /NS 3885 4716/		
Top Hosie Limestone: limestones and calcareous mudstones, dark grey and argillaceous with brachiopods, crinoids and bivalves, *Lingula sp.* at top	14.75	17.51
Mudstone, dark grey, carbonaceous with *Lingula sp.*, some ironstone bands	17.51	17.85
Siltstone, grey and greenish grey with ironstone band bearing ostracods	17.85	18.00
Seatclay, dark grey	18.00	18.40
Mudstones, dark grey with *Lingula sp.* and marine shells to base	18.40	19.05
Mudstones, calcareous, medium to dark grey with limestone bands, brachiopods, crinoids and gastropods	19.05	19.94
Mudstones, silty, dark grey	19.94	21.47
Limestones and calcareous mudstones, medium to dark grey, brachiopods and crinoids	21.47	22.20
Mudstones, dark grey and black, carbonaceous in places, ironstone bands	22.20	23.15
Seatclays, light olive-grey, calcareous in places	23.15	24.00
Dockra Limestone: limestones and calcareous mudstones, dark grey, argillaceous, nodular bands, abundant brachiopods	24.00	29.70

TABLE 6.4

The strata from the base of the Dockra Limestone to the Top Hosie Limestone - in boreholes

	Depth (metres) from	to
Coalhill No 2 Borehole /NS 2432 4653/		
Top Hosie Limestone: limestones and calcareous mudstones, dark grey, argillaceous with varied marine fauna	58.47	60.35
Seatclays, dark grey and light olive-grey, with ostracods and Lingula sp.	60.35	60.75
Mudstone, dark grey, silty, Lingula sp. and bivalves in patches	60.75	63.00
Limestones and calcareous mudstones, dark grey, argillaceous with varied marine fauna	63.00	64.92
Mudstones, dark grey, silty with ironstone bands and Lingula sp.	64.92	67.33
Seatclays and seatearths, light olive-grey and greenish grey	67.33	70.86
Sandstones and siltstones, light and dark grey	70.86	73.62
Mudstones, dark grey, silty at top, carbonaceous bands	73.62	75.82
Dockra Limestone, limestone, dark grey, argillaceous with varied marine fauna	75.82	87.00

TABLE 6.5

The strata from the base of the Dockra Limestone to the Top Hosie Limestone - in boreholes

	Depth (metres) from	to
Muirlaught Borehole /NS 2604 4614/		
Top Hosie Limestone: limestones and calcareous mudstones, dark grey, argillaceous, frequent brachiopod fragments	36.26	40.58
Mudstones, silty, dark grey	40.58	40.78
Seatclays, medium to dark grey with limestone bands	40.78	43.00
Mudstones, silty, dark grey with some brachiopod and *Lingula* fragments	43.00	44.15
Mudstones, calcareous, dark grey with fine grained limestone bands	44.15	45.20
Mudstones, silty, dark grey, goniatite and brachiopod fragments	45.20	45.45
Mudstones, calcareous and limestones, medium dark grey to dark grey with brachiopod and crinoid fragments	45.45	46.76
Mudstones, becoming silty, dark grey with crinoids, *Lingula sp.* and brachiopod and bivalve shells	46.76	50.10
Mudstones, calcareous with limestone bands, dark grey with goniatite and brachiopod fragments	50.10	52.15
Mudstones, dark grey, *Lingula sp.* at top, ironstone bands	52.15	53.98
Seatclays, dark grey with ironstone bands	53.98	55.00
Mudstones, dark grey, carbonaceous in places with ironstone bands	55.00	62.41
Dockra Limestone: limestone, dark grey, argillaceous but with coarser bands, calcareous mudstone bands at top	62.41	68.01

TABLE 6.6

The strata from the base of the Dockra Limestone to the Top Hosie Limestone - in boreholes

	Depth (metres) from	to
Montgreenan Borehole /NS 3503 4523/		
Top Hosie Limestone: limestone, fine grained, medium grey	135.52	135.60
Mudstones, medium grey with marine fauna	135.60	136.30
Sandstone, fine grained, greenish grey	136.30	136.66
Limestone, dark grey, argillaceous	136.66	137.00
Sandstone, fine grained, medium grey	137.00	137.11
Limestones, fine and medium grained	137.11	137.63
Igneous rock, highly altered feldspathic veins	137.63	138.00
Mudstones, medium grey, baked	138.00	138.60
Seatclays, dark grey with pyrite nodules	138.60	139.60
Mudstones, calcareous, medium grey with brachiopods, crinoids and goniatites	139.60	140.20
Mudstones, dark grey with pyrite stringers	140.20	140.40
Limestones, dark grey, argillaceous, calcareous mudstone to base	140.40	141.00
Mudstones, dark grey, with brachiopods and bivalves at top and Lingula sp. to base	141.00	141.54
Mudstones, calcareous, medium to dark grey, abundant brachiopods and gastropods	141.54	142.20
Mudstones, dark grey, Lingula sp. at top, bivalves and gastrapods to base	142.20	142.68
Mudstones, calcareous, dark grey, medium grey limestone at top	142.68	143.24
Mudstones, dark grey, pyrite at top	143.24	144.04
Seatclays, dark grey	144.04	145.10

TABLE 6.6 (cont'd)

	Depth (metres) from	to
Mudstones, dark grey, carbonaceous with fish scales to base	145.10	147.15
Dockra Limestone: mudstones, calcareous and limestone, medium and dark grey, *Lingula sp.* at top, brachiopod and crinoid debris	147.15	149.57

TABLE 6.7

The strata from the base of the Dockra Limestone to the Top Hosie Limestone - in boreholes

	Depth (metres) from	to
Ardrossan Borehole /NS 2308 4191/		
Top Hosie Limestone: limestones and calcareous mudstones, dark grey, argillaceous, frequent bivalves and brachiopods	14.09	22.35
Mudstones, black carbonaceous	22.35	22.92
Seatearths and seatclays, brownish grey to dark grey with pyrite and sphaerosiderite	22.92	25.25
Mudstones, dark grey with pyritous roots	25.25	25.63
Limestones and calcareous mudstones, dark grey with brachiopods	25.63	26.54
Mudstones, dark grey with ironstone bands, marine fauna	26.54	28.96
Limestone, dark grey, argillaceous	28.96	29.34
Mudstones, dark grey, marine fauna near top	29.34	30.10
Sandstones, medium and coarse grained with fine grained, pebbly and silty bands, light grey	30.10	45.88
Mudstones, dark grey to black, carbonaceous ironstone bands, fish scales, coprolites and Lingula sp.	45.88	47.42
Dockra Limestone: limestones, dark grey, argillaceous with varied marine fauna	47.42	56.55

TABLE 6.8

The strata from the base of the Dockra Limestone to the Top Hosie Limestone - in boreholes

	Depth (metres) from	to
Lora Burn Borehole /NS 3336 5841/		
Top Hosie Limestone: mudstones, calcareous, medium dark grey	12.25	12.90
Mudstones, dark grey	12.90	13.60
Mudstones, calcareous with limestone bands, medium dark grey, brachiopods, crinoids and goniatite scraps	13.60	15.80
Seatclays, dark grey	15.80	17.50
Mudstones, dark grey	17.50	17.80
Mudstones, calcareous with limestone bands, dark grey, brachiopod and crinoid fragments	17.80	18.52
Mudstones, dark grey	18.52	18.70
Mudstones, calcareous and limestones with brachiopod shells and spines and bryozoa	18.70	19.90
Mudstones, dark grey with *Lingula sp.* and goniatite fragments	19.90	21.25
Mudstone, calcareous, dark grey, argillaceous limestone to base	21.25	21.63
Mudstones, medium dark grey with ostracods and *Lingula sp.*	21.63	23.56
Dockra Limestone: limestone, light and dark grey, mottled top with calcareous mudstone and mudstone, becoming calcareous mudstone, medium grey	23.56	34.00
Mudstone, silty, medium grey, with ironstone bands, brachiopods and bivalves at top, *Lingula sp.* at base	34.00	38.73

TABLE 6.9

The strata from the base of the Dockra Limestone to the Top Hosie Limestone - in boreholes

	Depth (metres) from	to
Dunniflat Borehole /NS 4203 5314/		
Top Hosie Limestone: mudstones, calcareous and argillaceous limestones, dark grey with brachiopods, crinoids and solitary corals	11.87	16.78
Mudstone, silty, dark grey with brachiopods at top, ironstone bands	16.78	17.66
Sandstones, medium grained, medium grey, silty and rooty to base	17.66	18.16
Mudstones, silty, dark grey	18.16	18.61
Mudstones, calcareous with crinoids and brachiopod spines and shells	18.61	19.60
Sandstones, medium grained, medium grey, silty to top and base with poorly preserved brachiopods and crinoids	19.60	22.25
Mudstones, dark grey silty with siltstone bands, brachiopods at top, *Lingula sp.* to base	22.25	28.61
Sandstone, medium grained with calcareous patches	28.61	28.70
Dockra Limestone: limestones and calcareous mudstones, medium grey to dark grey with brachiopods, crinoids, bivalves and bryozoa	28.70	37.80
Mudstones, dark grey, carbonaceous, brachiopods and bivalves with occasional *Lingula sp.*		

also represented in the Dunniflat Borehole by rooty sandstones at 17.66 m.

The borehole data reveal another series of rooty beds at a position immediately above the Dockra Limestone, at 23.15 m in the Kirkwood Borehole, at 67.33 m in the Coalhill No 2 Borehole, at 53.98 m in the Muirlaught Borehole and at 114.04 m in the Montgreenan Borehole. Sandstones and siltstones are only occasionally present at this stratigraphic position in the sequences obtained from the boreholes. In the Kirkwood Borehole a thin siltstone band occurs above the root bed at 18.00 m and sandstones and siltstones occur immediately below the lower rooty bed in the Coalhill No 2 Borehole. In the Ardrossan Borehole sandstones, coarse-grained in places, occur just above the Dockra Limestone in a position characterised elsewhere by rooty beds. In the Dunniflat Borehole sandstone beds occur in the roof of the Dockra Limestone and higher in the sequence about midway between that limestone and the Top Hosie Limestone. Thin beds of sandstone also occur towards the top of the Lower Limestone Group in the Montgreenan Borehole but the lithology differs from the other beds in the sequence by being mainly fine-grained.

These observations indicate that medium to coarse-grained sandstones and/or rooty beds are developed commonly at two horizons within the sequence, one midway between the Top Hosie and Dockra limestones (a position correlated with the Hosie Fireclay in the Glasgow) and the second immediately above the Dockra Limestone.

6.5 Sandstones between the Dockra and Top Hosie Limestones

The occurrence of sandstones at these two stratigraphic

positions has been noted also in old borehole data, though rooty beds are seldom recorded. The lateral extent of these sandstone bodies is shown in fig 6.1 which shows a marked north-easterly linear geometry for the Hosie Fireclay sandstone.

6.6 Marine Lithologies between the Dockra and Top Hosie Limestones

The limestones within the Hosie Limestone Formation are seldom more than a metre thick in any individual bed. They are argillaceous (Plate 6.1 and 6.2), usually bedded though often bioturbated, with generally a brachiopod/crinoid fauna. The proportion of bioclastic material to matrix and the content of material derived from different organisms vary from bed to bed (see Plate 6.3a). Roots may also penetrate the limestone disrupting the structure (Plate 6.3b).

The calcareous mudstones are similar to the limestones but are less bioturbated and have retained both bedding and fissility. The fauna present in both the calcareous mudstones and limestones is also similar though bryozoa (Plate 6.3a) seem to be confined to the former.

The mudstones whether with or without Lingula sp. differ from the calcareous mudstones in fauna and in colour, being dark grey generally in contrast to the medium grey of the calcareous mudstones. They are usually well-bedded, commonly weathering to give the appearance of 'paper shales'. While Lingula sp. is the most common fossil in this lithology, other marine organisms, including brachiopods and goniatites, have been recorded.

6.7 Cyclicity in the Lower Limestone Group from the base of the Dockra Limestone to the Top Hosie Limestone

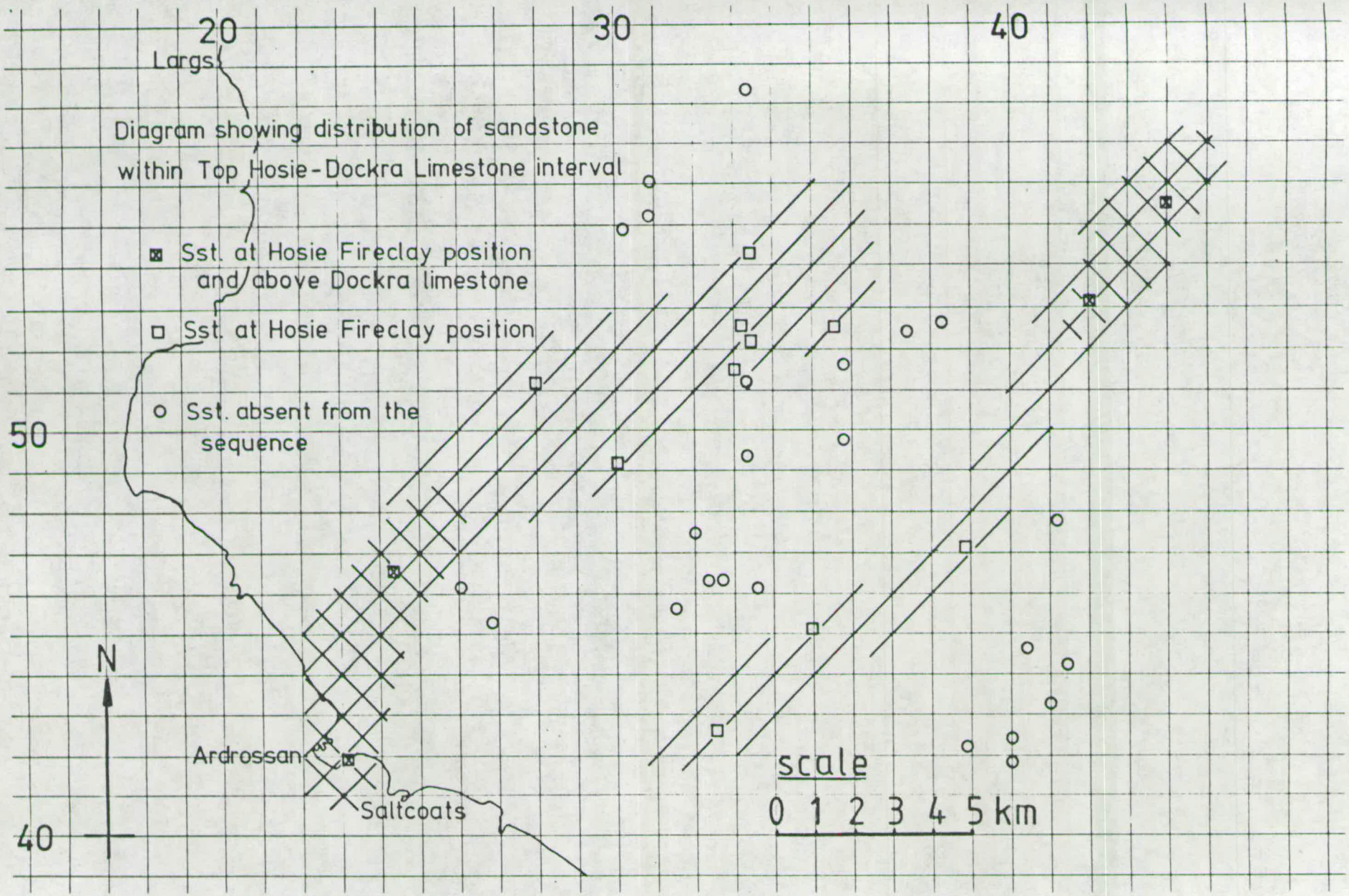

20
30
40
Largs
Diagram showing distribution of sandstone within Top Hosie-Dockra Limestone interval
Sst. at Hosie Fireclay position and above Dockra limestone
Sst. at Hosie Fireclay position
Sst. absent from the sequence
50
N
Ardrossan
Saltcoats
40
scale
0 1 2 3 4 5 km

Fig. 8.1

PLATE 6.1

a. Polished and etched slab of argillaceous limestone, bedded, with brachiopod and crinoid fragments from the Hosie Limestone Formation
Lora Burn Borehole at 15.20 m

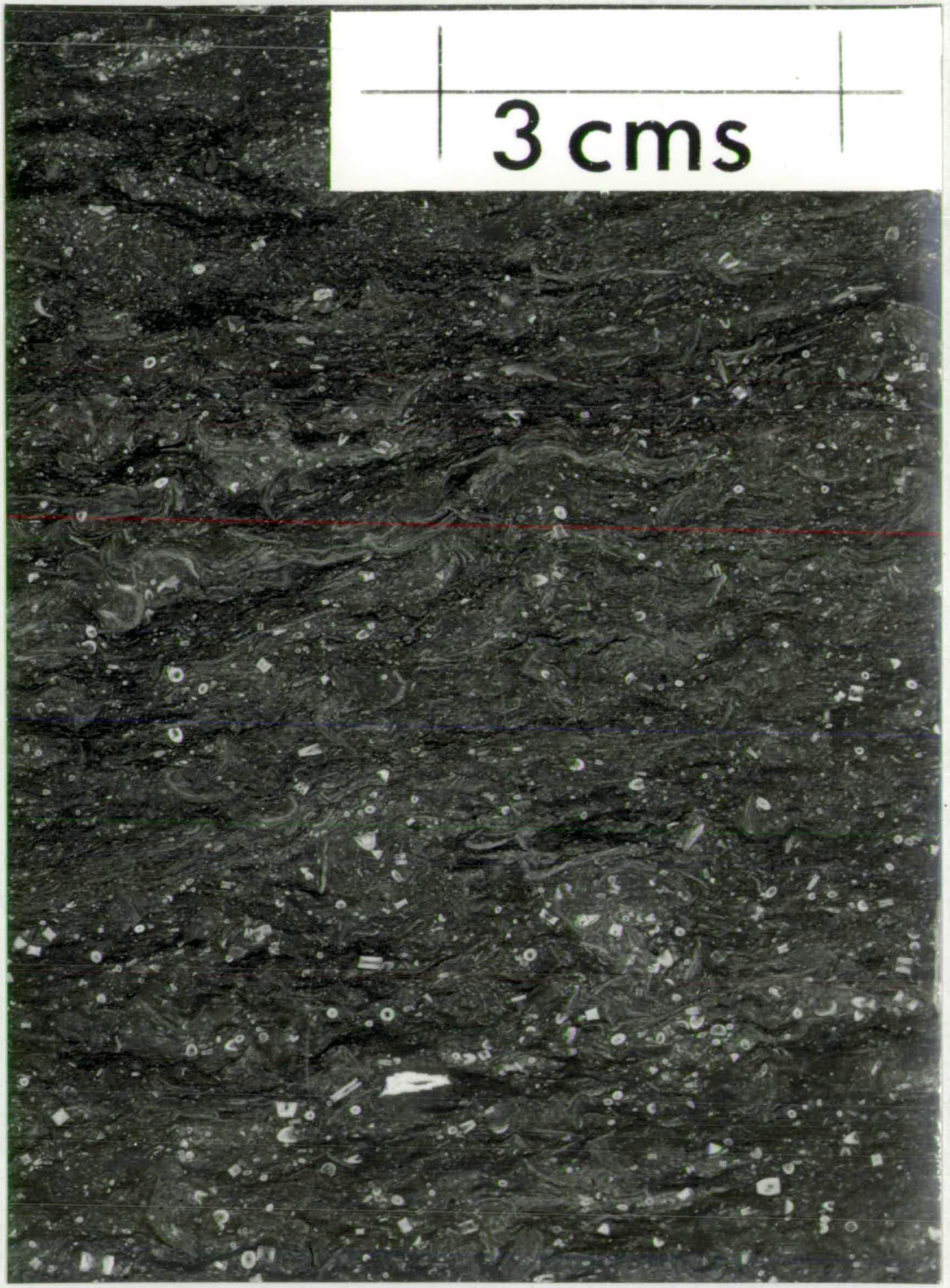
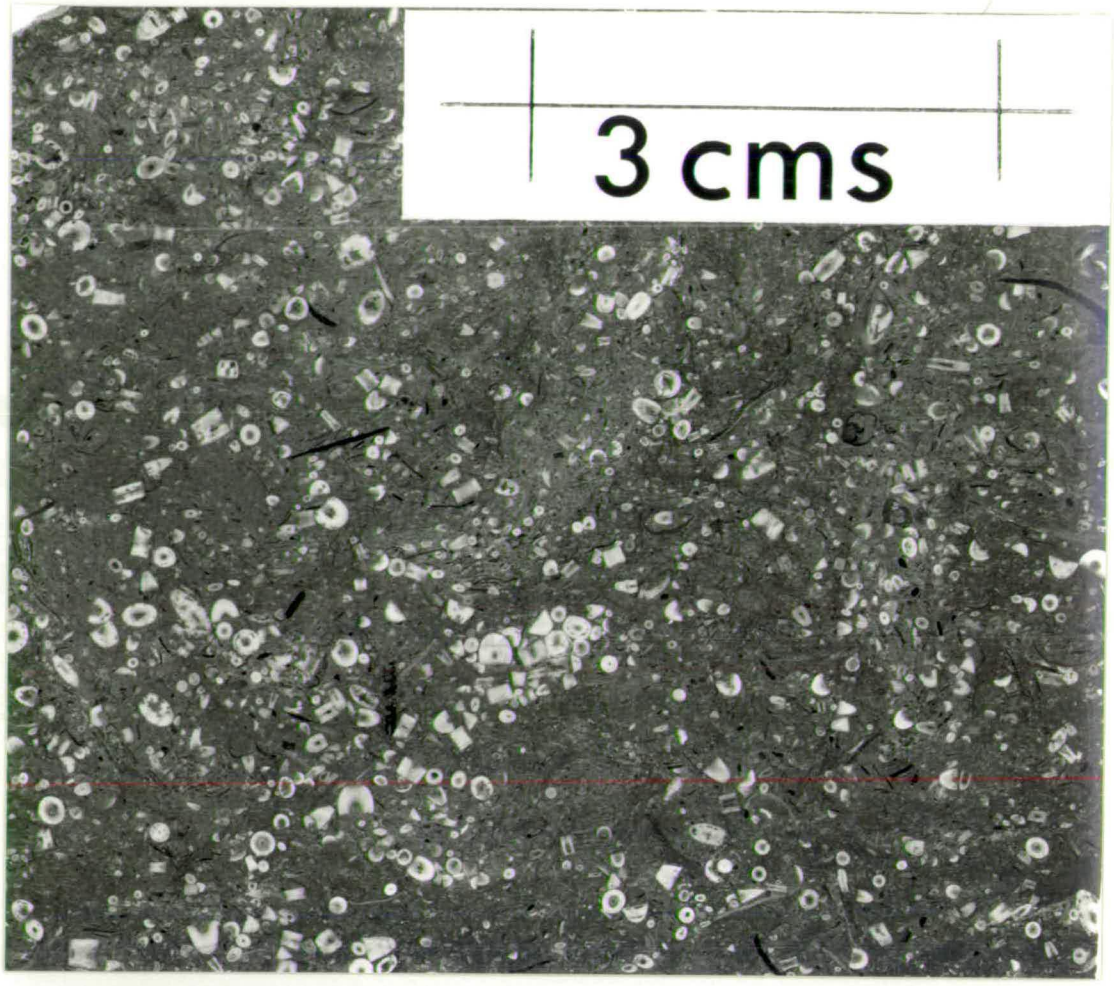

3 cms

PLATE 6.2

PLATE 6.2

a. Polished and etched slabs of a bioturbated crinoidal limestone from the Hosie Limestone Formation
Lora Burn Borehole at 15.60 m

b. Polished and etched slab of argillaceous limestone with brachiopod fragments, poorly bedded from the Top Hosie Limestone
Muirlaught Borehole at 37.07 m


3 cms

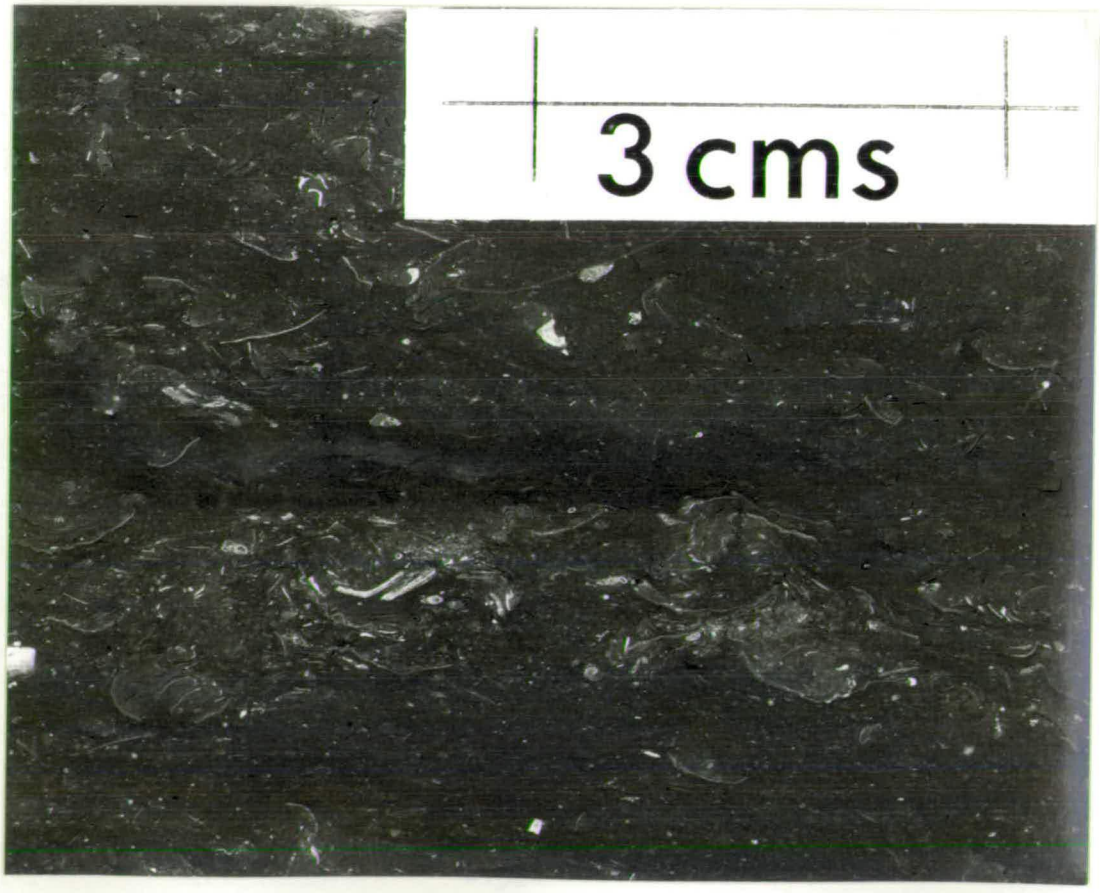
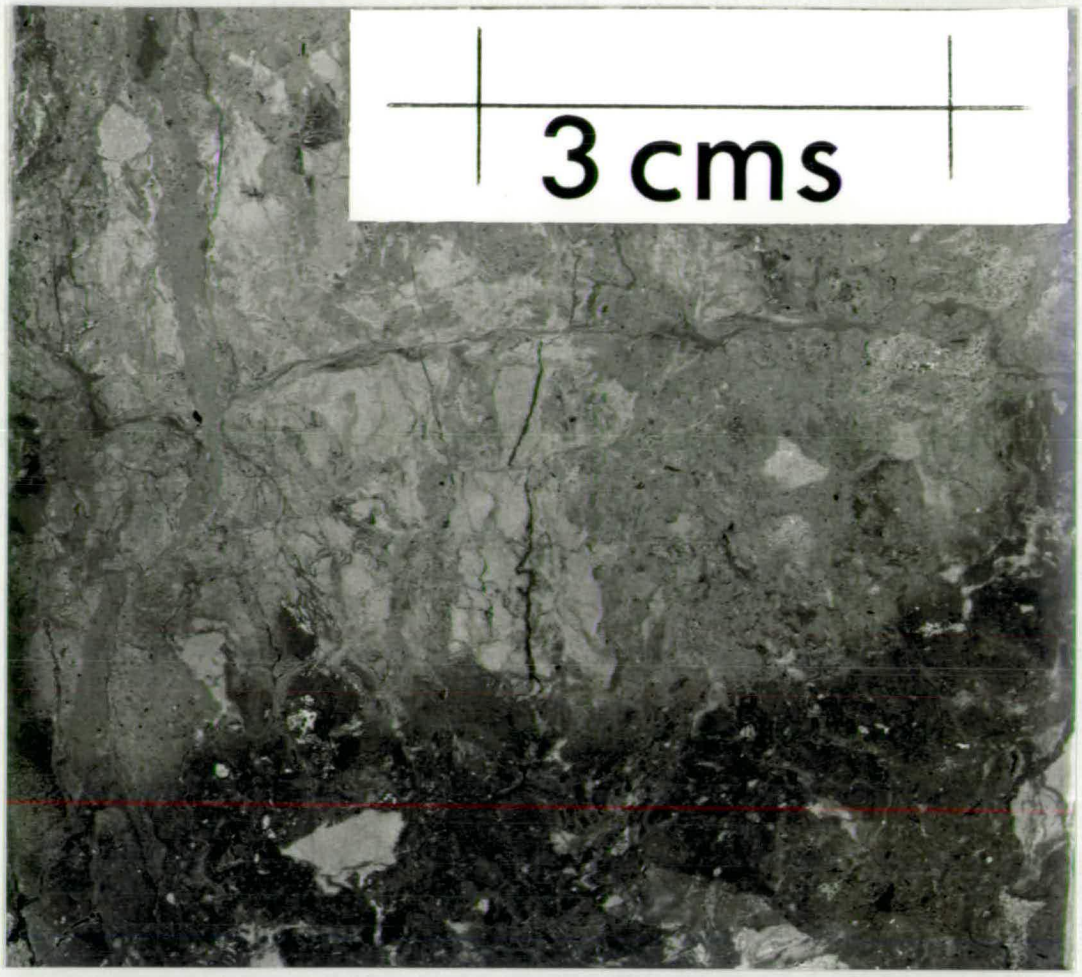

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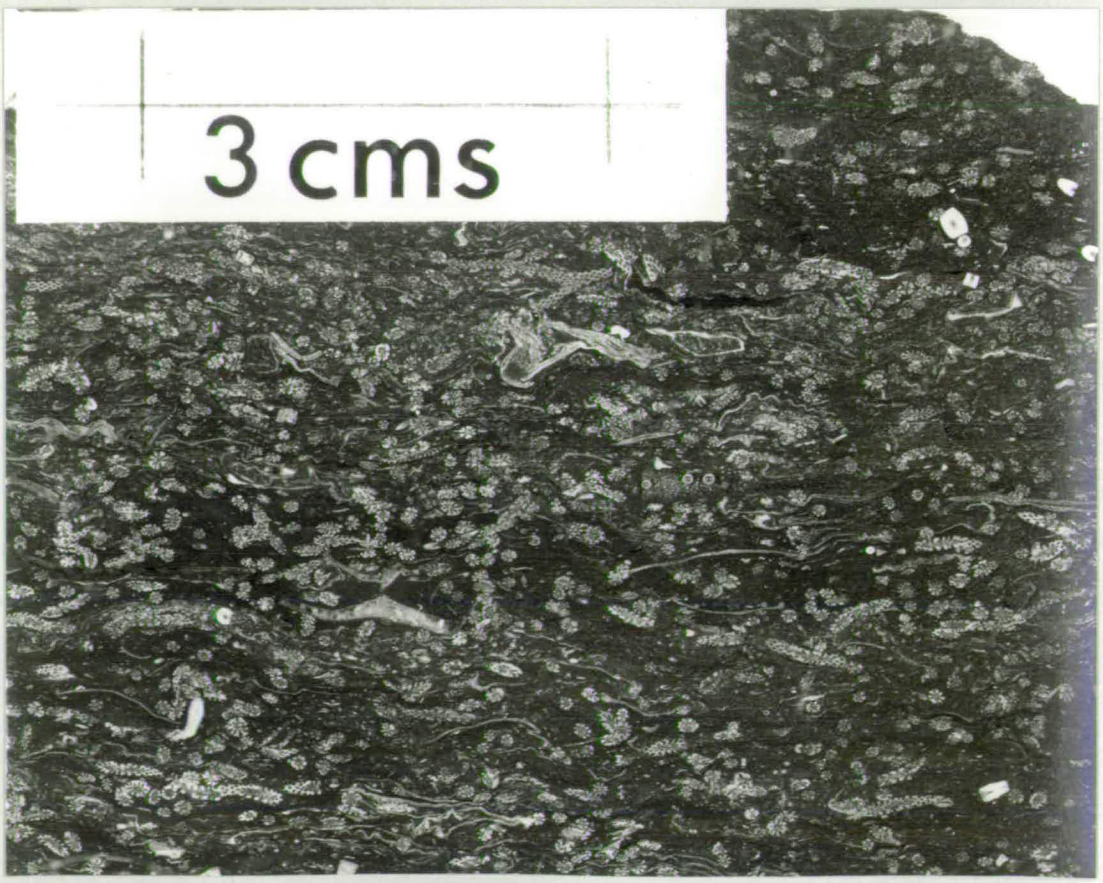
PLATE 6.3

PLATE 6.3

a. Polished and etched slab of limestone altered by roots, Hosie Limestone Formation
Muirlaught Borehole at 41.70 m

b. Polished and etched slab of calcareous mudstone with abundant bryozoa, Hosie Limestone Formation
Lora Burn Borehole at 19.35 m


3 cms


3 cms

Cyclical sequences of sediments are far less readily identified in this sequence than in the Lower Limestone Group strata below the Dockra Limestone (see chapter 4.4). Associations of different sediment types have been recognised and the occurrence of sandstones and siltstones with rooty beds has been noted.

An analysis of the transitions using the method described in chapter 4.4 was applied to the sequence of strata between the Dockra and the Top Hosie Limestones in seven IGS boreholes - the Kirkwood, Coalhill No 2, Muirlaught, Montgreenan, Ardrossan, Lora Burn and Dunniflat boreholes (see table 6.10-6.16).

In some boreholes, the occurrence of a particular lithology or group of lithologies is not dependent on the preceding lithology in the sequence. In the Dunniflat sequence (table 6.16) both the most common upward and downward transition diagram and the diagram derived from the modified matrix show that the occurrence of a limestone or calcareous mudstone lithology is, in this case, not dependent on any other preceding lithology. Likewise in the Ardrossan sequence (table 6.14), the occurrence of a siltstone or sandstone lithology is not dependent on the nature of the preceding lithology. In the Muirlaught sequence (table 6.12) a clear relationship is apparent from the most common upward and downward transition diagram but when these data are modified to take into account the transitions which may be expected in a random sequence, the clear relationship is no longer apparent.

The apparent 'poor memory' of one lithology or group of lithologies for the others in the sequence probably indicates that the mechanism of deposition of these lithologies may be independent of that of the others.

Analysis of sequences - Kirkwood Borehole

Lower Limestone Group from base of Dockra Limestone to Top Hosie Limestone

	Calc mudst	Lst	Mudst	Seat	Coal	Siltst	
Calc mudst	0	8	2	2	0	0	12
Lst	8	2	1	0	1	0	12
Mudst	3	0	5	1	0	0	9
Seat	1	0	1	0	0	1	3
Coal	0	1	0	0	0	0	1
Siltst	0	0	1	0	0	0	1
	12	11	10	3	1	1	38

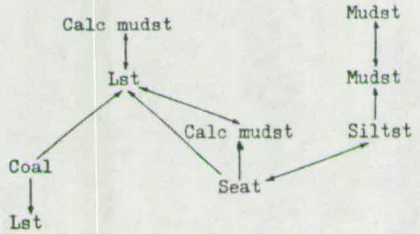
(a) data array of bed transitions

	Calc mudst	Lst	Mudst	Seat	Coal	Siltst
Calc mudst	4	3	3	1	0	0
Lst	4	3	3	1	0	0
Mudst	3	3	2	1	0	0
Seat	1	1	1	0	0	0
Coal	0	0	0	0	0	0
Siltst	0	0	0	0	0	0

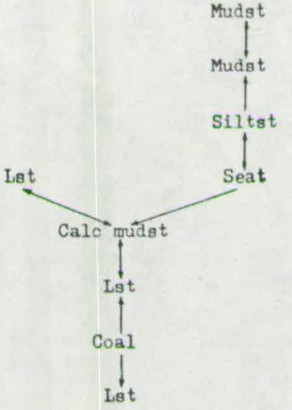
(c) predicted data array assuming a random arrangement of lithologies (calculated to nearest whole number)

	Calc mudst	Lst	Mudst	Seat	Coal	Siltst
Calc mudst	-4	+5	-1	+1	0	0
Lst	+4	-1	-2	-1	+1	0
Mudst	0	-3	+3	0	0	0
Seat	0	-1	0	0	0	+1
Coal	0	+1	0	0	0	0
Siltst	0	0	+1	0	0	0

(d) table showing the difference between the observed number of transitions and the predicted number assuming a random arrangement



(b) facies relationship diagram showing the most common upward and downward transitions for each lithology



(e) facies relationship diagram showing the largest number of upward and downward transitions that occur for each lithology after subtracting those predicted if the beds were arranged randomly

Analysis of sequences - Coalhill No 2 Borehole

Lower Limestone Group from base of Dockra Limestone to Top Hosie Limestone

	Mudst	Lst	Seat	Coal	Siltst	Sst	Calc mudst	
Mudst	4	1	0	0	1	0	0	6
Lst	1	4	0	0	0	0	1	6
Seat	1	0	2	1	0	0	0	4
Coal	0	1	0	0	0	0	0	1
Siltst	0	0	0	0	0	1	0	1
Sst	0	0	1	0	0	0	0	1
Calc Mudst	1	0	0	0	0	0	0	1
	7	6	3	1	1	1	1	20

(a) data array of bed transitions

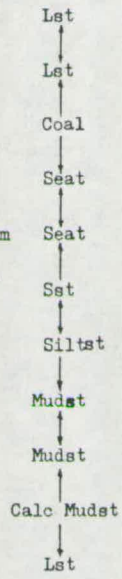
	Mudst	Lst	Seat	Coal	Siltst	Sst	Calc mudst
Mudst	2	2	1	0	0	0	0
Lst	2	2	1	0	0	0	0
Seat	1	1	1	0	0	0	0
Coal	0	0	0	0	0	0	0
Siltst	0	0	0	0	0	0	0
Sst	0	0	0	0	0	0	0
Calc mudst	0	0	0	0	0	0	0

(c) predicted data array assuming a random arrangement of lithologies (calculated to nearest whole number)

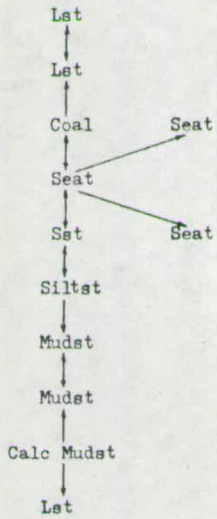
	Mudst	Lst	Seat	Coal	Siltst	Sst	Calc mudst
Mudst	+2	-1	-1	0	+1	0	0
Lst	-1	+2	-1	0	0	0	+1
Seat	0	+1	0	0	0	0	0
Coal	0	+1	0	0	0	0	0
Siltst	0	0	0	0	0	+1	
Sst	0	0	+1	0	0	0	0
Calc mudst	+1	0	0	0	0	0	0

(d) table showing the difference between the observed number of transitions and the predicted number assuming a random arrangement

(b) facies relationship diagram showing the most common upward and downward transitions for each lithology



(e) facies relationship diagram showing the largest number of upward and downward transitions that occur for each lithology after subtracting those predicted if the beds were arranged randomly



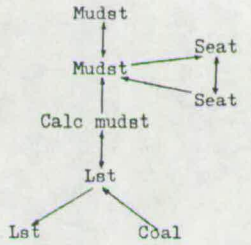
Analysis of sequences - Muirlaught Borehole

Lower Limestone Group from base of Dockra Limestone to Top Hosie Limestone

	Mudst	Lst	Calc mudst	Seat	Coal	
Mudst	11	1	3	2	0	17
Lst	0	5	6	1	0	12
Calc mudst	5	4	3	0	0	12
Seat	2	1	0	2	0	5
Coal	0	1	0	0	0	1
	18	12	12	5	0	47

(a) data array of bed transitions

(b) facies relationship diagram showing the most common upward and downward transitions for each lithology



	Mudst	Lst	Calc mudst	Seat	Coal
Mudst	7	4	4	2	0
Lst	5	3	3	1	0
Calc mudst	5	3	3	1	0
Seat	2	1	1	1	0
Coal	0	0	0	0	0

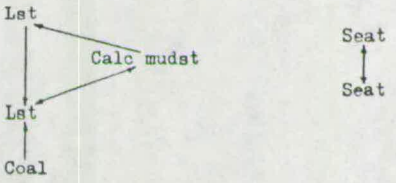
(c) predicted data array assuming a random arrangement of lithologies (calculated to nearest whole number)



Mudst	+4	-3	-1	0	0
Lst	-5	+2	+3	0	0
Calc mudst	0	+1	0	-1	0
Seat	0	0	-1	+1	0
Coal	0	+1	0	0	0

(d) table showing the difference between the observed number of transitions and the predicted number assuming a random arrangement

(e) facies relationship diagram showing the largest number of upward and downward transitions that occur for each lithology after subtracting those predicted if the beds were arranged randomly. Note uncertainty of relationship between Mudst, Seat and other lithologies

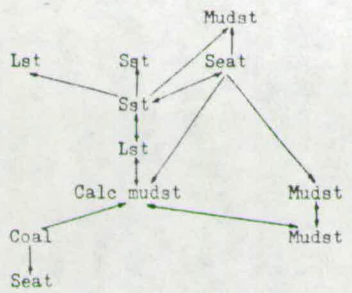


Analysis of sequences - Montgreenan Borehole

Lower Limestone Group from base of Dockra Limestone to Top Hosie Limestone

	Mudst	Lst	Calc mudst	Sst	Seat	Coal	
Mudst	4	2	4	0	1	0	11
Lst	2	1	1	3	0	0	7
Calc mudst	2	3	0	0	1	0	6
Sst	1	1	0	1	1	0	4
Seat	3	0	0	0	0	1	4
Coal	0	0	1	0	0	0	1
	12	7	6	4	3	1	33

(a) data array of bed transitions



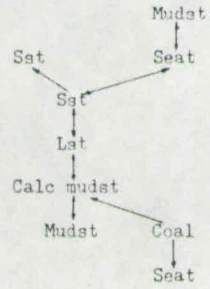
(b) facies relationship diagram showing the most common upward and downward transitions for each lithology

	Mudst	Lst	Calc mudst	Sst	Seat	Coal
Mudst	4	2	2	1	1	0
Lst	3	1	1	1	1	0
Calc mudst	2	1	1	1	1	0
Sst	1	1	1	0	0	0
Seat	1	1	1	0	0	0
Coal	0	0	0	0	0	0

(c) predicted data array assuming a random arrangement of lithologies (calculated to nearest whole number)

	Mudst	Lst	Calc mudst	Sst	Seat	Coal
Mudst	0	0	+2	-1	0	0
Lst	-1	0	0	+2	-1	0
Calc mudst	0	+2	-1	-1	0	0
Sst	0	0	-1	+1	+1	0
Seat	+2	-1	-1	0	0	+1
Coal	0	0	+1	0	0	0

(d) table showing the difference between the observed number of transitions and the predicted number assuming a random arrangement



(e) facies relationship diagram showing the largest number of upward and downward transitions that occur for each lithology after subtracting those predicted if the beds were arranged randomly

Analysis of sequences - Ardrossan Borehole

Lower Limestone Group from base of Dockra Limestone to Top Hosie Limestone

	Mudst	Sst	Lst	Calc mudst	Siltst	Seat	Coal	
Mudst	8	1	3	0	6	3	0	15
Sst	1	8	0	0	4	0	0	13
Lst	2	0	2	4	0	0	0	8
Calc mudst	2	0	2	2	0	0	0	6
Siltst	0	4	0	0	0	0	0	4
Seat	1	0	0	0	0	0	1	2
Coal	0	0	1	0	0	0	0	1
	14	13	8	6	4	3	1	48

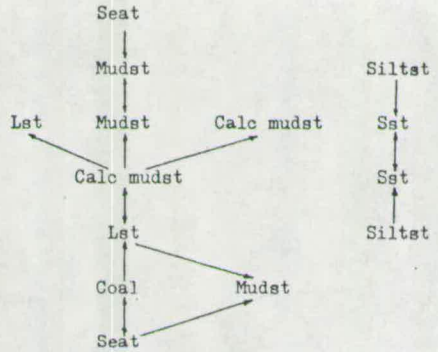
(a) data array of bed transitions

	Mudst	Sst	Lst	Calc mudst	Siltst	Seat	Coal
Mudst	4	4	3	2	1	1	0
Sst	4	4	2	2	1	1	0
Lst	2	2	1	1	1	1	0
Calc mudst	2	2	1	1	1	0	0
Siltst	1	1	1	1	0	0	0
Seat	1	1	0	0	0	0	0
Coal	0	0	0	0	0	0	0

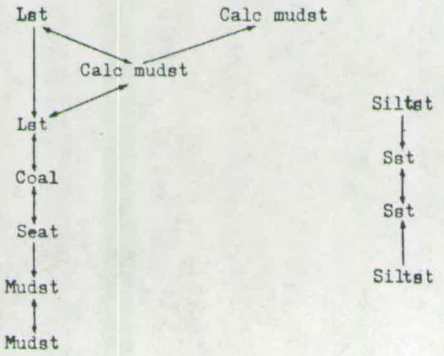
(c) predicted data array assuming a random arrangement of lithologies (calculated to nearest whole number)

	Mudst	Sst	Lst	Calc mudst	Siltst	Seat	Coal
Mudst	+4	-3	0	-2	-1	+2	0
Sst	-3	+4	-2	-2	+3	-1	0
Lst	0	-2	+1	+3	-1	-1	0
Calc mudst	0	-2	+1	+1	-1	0	0
Siltst	-1	+3	-1	-1	0	0	0
Seat	0	-1	0	0	0	0	+1
Coal	0	0	+1	0	0	0	0

(d) table showing the difference between the observed number of transitions and the predicted number assuming a random arrangement



(b) facies relationship diagram showing the most common upward and downward transitions for each lithology. Note uncertainty of relationship with Sst/Siltst lithologies



(e) facies relationship diagram showing the largest number of upward and downward transitions that occur for each lithology after subtracting those predicted if the beds were arranged randomly. Note uncertainty of relationship with Sst/Siltst lithologies

Analysis of sequences - Lora Burn Borehole

Lower Limestone Group from base of Dockra Limestone to Top Hosie Limestone

	Mudst	Calc mudst	Lst	Seat	Coal	
Mudst	6	4	3	1	1	15
Calc mudst	5	2	7	0	0	13
Lst	3	8	0	0	0	11
Seat	0	0	1	0	0	1
Coal	1	0	0	0	0	1
	14	14	11	1	1	41

(a) data array of bed transitions

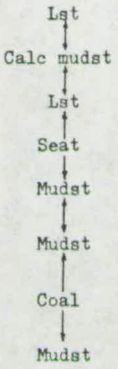
	Mudst	Calc mudst	Lst	Seat	Coal
Mudst	5	5	4	0	0
Calc mudst	4	4	3	0	0
Lst	4	4	3	0	0
Seat	0	0	0	0	0
Coal	0	0	0	0	0

(c) predicted data array assuming a random arrangement of lithologies (calculated to nearest whole number)

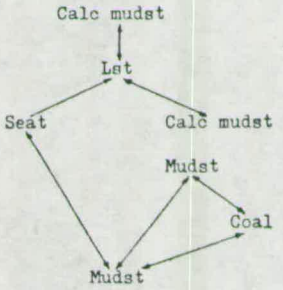
	Mudst	Calc mudst	Lst	Seat	Coal
Mudst	+1	-1	-1	+1	+1
Calc mudst	0	-2	+4	0	0
Lst	-1	+4	-3	0	0
Seat	0	0	+1	0	0
Coal	+1	0	0	0	0

(d) table showing the difference between the observed number of transitions and the predicted number assuming a random arrangement

(b) facies relationship diagram showing the most common upward and downward transitions for each lithology



(e) facies relationship diagram showing the largest number of upward and downward transitions that occur for each lithology after subtracting those predicted if the beds were arranged randomly



Analysis of sequences - Dunniflat Borehole

Lower Limestone Group from base of Dockra Limestone to Top Hosie Limestone

	Mudst	Calc mudst	Lst	Siltst	Sst	Coal	Seat	
Mudst	5	2	0	3	0	1	1	12
Calc mudst	2	0	8	0	0	0	0	10
Lst	0	7	1	0	1	0	0	9
Siltst	1	1	0	0	2	0	0	4
Sst	2	0	0	1	0	0	0	3
Coal	2	0	0	0	0	0	0	2
Seat	0	0	0	0	0	1	0	1
	12	10	9	4	3	2	1	41

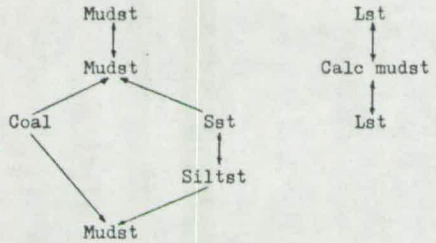
(a) data array of bed transitions

	Mudst	Calc mudst	Lst	Siltst	Sst	Coal	Seat
Mudst	4	3	3	1	1	1	0
Calc mudst	3	2	2	1	1	0	0
Lst	3	2	2	1	1	0	0
Siltst	1	1	1	0	0	0	0
Sst	1	1	1	0	0	0	0
Coal	1	0	0	0	0	0	0
Seat	0	0	0	0	0	0	0

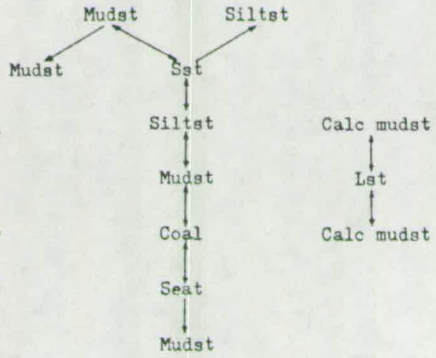
(c) predicted data array assuming a random arrangement of lithologies (calculated to nearest whole number)

	Mudst	Calc mudst	Lst	Siltst	Sst	Coal	Seat
Mudst	+1	-1	-3	+2	-1	0	+1
Calc mudst	-1	-2	+6	-1	-1	0	0
Lst	-3	+5	-1	-1	0	0	0
Siltst	0	0	-1	0	+2	0	0
Sst	+1	-1	-1	+1	0	0	0
Coal	+1	0	0	0	0	0	0
Seat	0	0	0	0	0	+1	0

(d) table showing the difference between the observed number of transitions and the predicted number assuming a random arrangement



(b) facies relationship diagram showing the most common upward and downward transitions for each lithology. Note uncertainty of relationship with Lst/calc mudst lithologies



(e) facies relationship diagram showing the largest number of upward and downward transitions that occur for each lithology after subtracting those predicted if the beds were arranged randomly. Note uncertainty of relationship with Lst/ calc mudst lithologies

Some general conclusions may be drawn:

1. Coal generally passes up into calcareous mudstone or limestone;
2. Seatclay passes up into coal;
3. Sandstones and siltstones generally pass up into seatclay;
4. The clastic sediments, mudstone, siltstone and sandstone seldom show an ordered progression in grain size except in the Coalhill No 2 Borehole where a coarsening upwards sequence is displayed.

There is a marked similarity between these conclusions and those given in chapter 4.4 for the Lower Limestone Group strata below the Dockra Limestone, which suggests similar patterns of sedimentation for the two groups of strata despite apparent differences in lithological sequences.

6.8 Lower Limestone Group between the Dockra and Top Hosie Limestones - environment of deposition

The environment of deposition of the strata between the Dockra and Top Hosie limestones may be interpreted by examining

1. Correlation and thickness variation;
2. Characteristics of marine lithologies;
3. Nature of cyclicity;
4. Local sediment variation.

1. Correlation and thickness variation: The observations made in chapters 6.2, 6.3 and 6.4 suggest that the beds which can best be traced laterally are not the four individual Hosie Limestones (Hosies A, B, C and D) but the rooty beds which occur within them. Two such beds are distinguished, the upper at a position which

elsewhere is called the Hosie Fireclay and the lower within the strata immediately above the Dockra Limestone. In fig 4.2 the sequences for each of the IGS boreholes is shown in their geographical relationships one with another. The Top Hosie Limestone is the top limestone in the sequence in all but the Old Mill Borehole which started below that bed. The Hosie Fireclay bed is seen in each borehole though represented by a rooty sandstone at Dunniflat. This correlation may be taken across the line of the Dusk Water Fault with no significant change in lithological sequence.

The rooty bed immediately above the Dockra Limestone is recognised in the Coalhill No 2, Muirlaught, Montgreenan and Kirkwood boreholes and roots are recorded within the Dockra Limestone at Lora Burn and Old Mill. In the Ardrossan Borehole this part of the sequence consists of medium and coarse-grained sandstones.

The correlation of these strata highlight two periods when the Dalry Basin was silted up to the extent that plants could grow. It further suggests that in some areas there was either no sedimentation immediately after deposition of the Dockra Limestone or else that this sediment was eroded allowing vegetation to colonise the Dockra Limestone substrate (see also chapter 5.4). These periods also appear to correspond with the deposition of coarser clastic sediments.

The variation in thickness of the interval between the Top Hosie and the Dockra Limestones across the Dalry Basin is shown in the isopach map (fig 6.2). The full thickness of the Dockra Limestone has been included because the base of the Dockra Limestone was clearly defined in many of the old boreholes whereas the top was indefinite. The isopach maps of the Top Hosie to Dockra Limestone

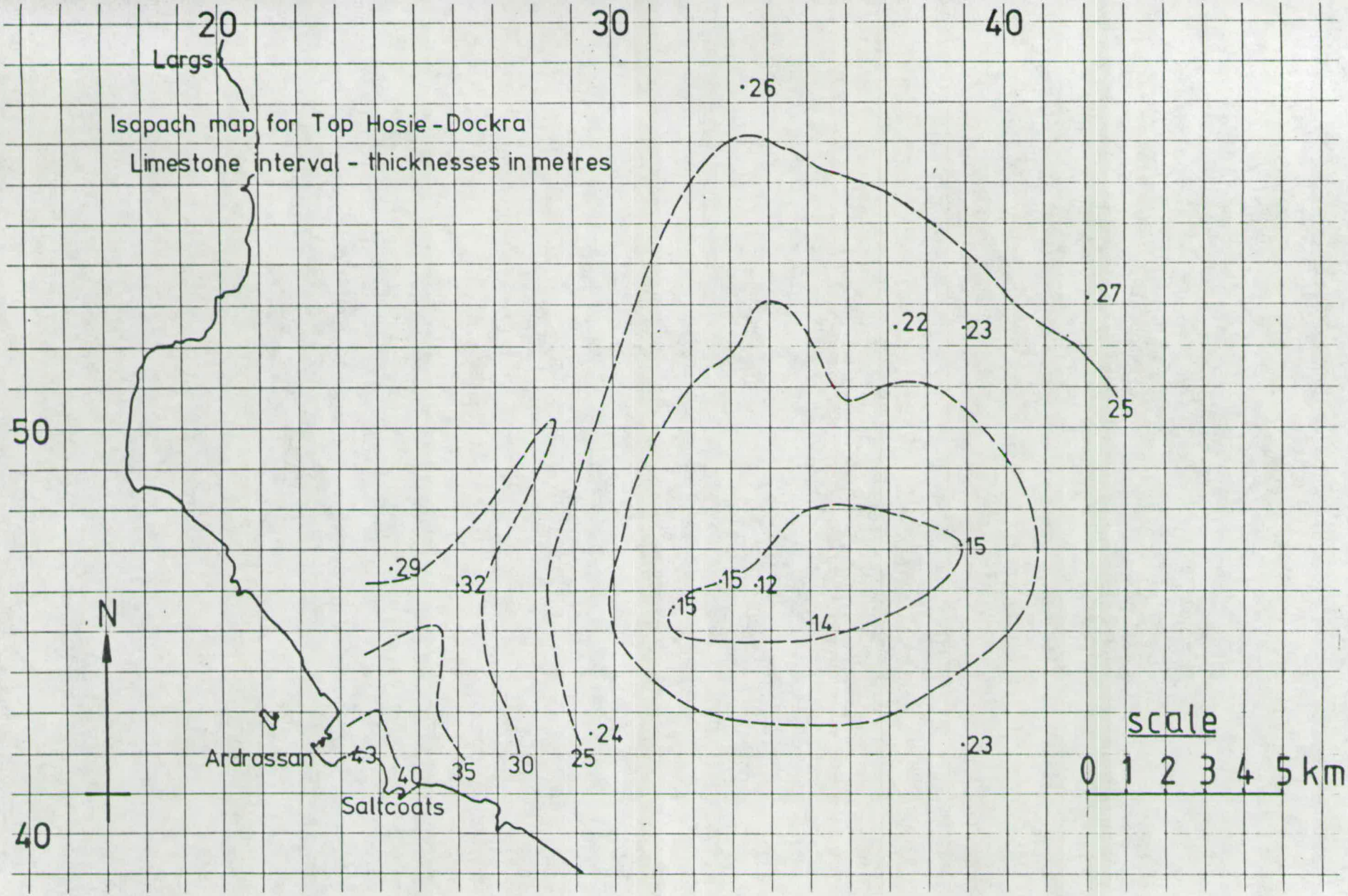

20
30
40
50
40
Largs
Isopach map for Top Hosie - Dockra
Limestone interval - thicknesses in metres
·26
·27
·22
·23
25
·29
·32
15
·15
·12
·15
·14
·24
·23
N
Ardrossan
43
40
35
30
25
Saltcoats
scale
0 1 2 3 4 5 km

Fig. 6.2

interval (fig 6.2) and the Dockra Limestone (fig 5.4) should be considered together. While the isopach map of the Dockra Limestone indicates some control of sedimentation by major north-easterly trending faults, the pattern of thickness variation taken over the full stratigraphic interval between the Top Hosie and Dockra limestones is less clear. The interval seems to thicken away from the centre of the basin and is particularly thick in areas such as Ardrossan where sandstones are developed within the sequence. The thick development of sandstone at Ardrossan does not apparently influence the pattern of subsequent sedimentation in that area and it appears to have been accommodated by differential subsidence.

Unlike the strata below the Dockra Limestone, the distribution of marine sediments between the Dockra and Top Hosie limestones was not influenced significantly by the underlying topography. The marine transgressions during this period extended over the entire area.

2. Characteristics of marine sediments: The marine sediments are of two main types. Limestones and calcareous mudstones with a rich marine fauna were deposited in an open marine environment with a steady supply of fine-grained detritus, and mudstones with a more restricted marine fauna, notably Lingula sp. were deposited in a marginal marine, often brackish-water environment. Mudstone with Lingula sp. frequently lies above and below calcareous mudstone or limestone demonstrating the changing nature of the marine environment at that location with time, from marginal marine to open marine and back to marginal marine.

3. Nature of cyclicity: The cycles developed in the Lower Limestone Group between the Dockra and the Top Hosie limestones are similar to

those below the Dockra Limestone, although not as clearly defined. Analysis of the cyclicity indicates marine transgression on to a surface on which either plant debris was accumulating (eventually to give coal) or plants had established themselves (though only the root traces are preserved now). The silting-up of this marine environment generally involves fine-grained sediment but in areas where coarser-grained sediments are deposited, such as in the Coalhill No 2 Borehole, a coarsening upwards pattern is evident.

4. Local sediment variation: The sediments between the Dockra and the Top Hosie limestones vary laterally from limestone and calcareous mudstone with a rich marine fauna to mudstone with Lingula sp. particularly within the Hosie Limestone Formation, indicating a change from the marginal to the open marine environment. The sandstones and siltstones have the upward-coarsening characteristics of deltaic deposits but the elongate geometry of these deposits (fig 6.1) suggests that they may represent off-shore bars or coastal barrier sands. However, deltaic origin would explain the association of these deposits laterally with rooty beds and the observation that the sandstones are commonly rooty at the top.

Chapter 7 Limestone Coal Group

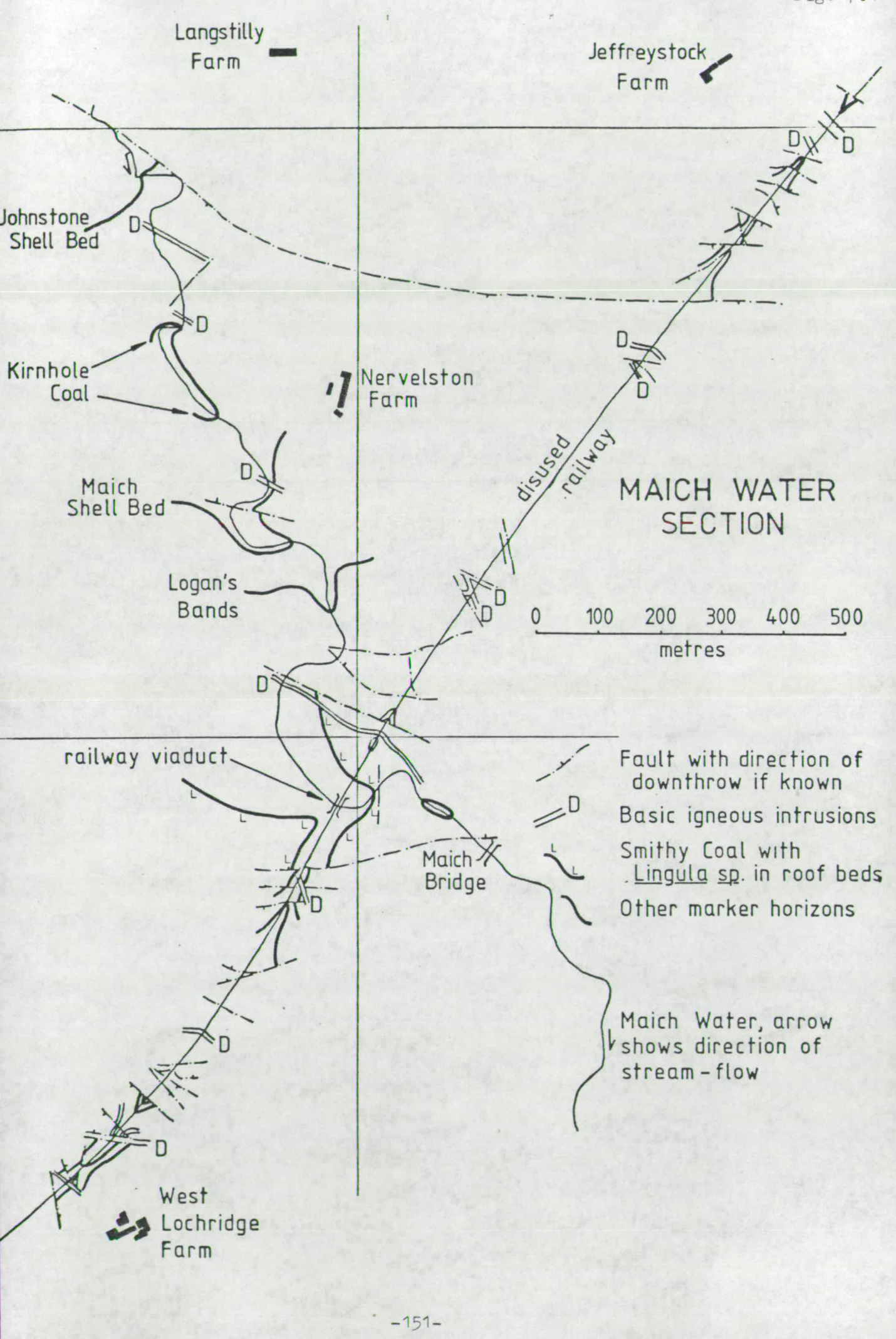
7.1 Introduction

This chapter seeks to describe the strata within the Limestone Coal Group in the Dalry Basin and to assess the means of correlation within the 'group'. Cyclicity and lateral variation, both in thickness and lithology, will be examined in an attempt to establish a) the factors controlling sediment distribution, b) the depositional environment of these sediments and c) the palaeogeography of the area in Limestone Coal Group times. The lower and upper boundaries of the Limestone Coal Group are the Top Hosie Limestone and the Index Limestone respectively (see chapter 2.11). Both these horizons are readily identifiable in both boreholes and natural sections.

7.2 Limestone Coal Group - outcrop data

Complete sections into the Limestone Coal Group are not exposed in the Dalry Basin. Sequences may be interrupted either through lack of exposure or else by faulting. The vertical distribution of lithologies within the Limestone Coal Group and the distinctive (correlative) horizons within this 'group' may be assessed from the following descriptions of the principal sections:

Maich Water The Limestone Coal Group section in the Maich Water is the most complete within the Dalry Basin. The section crops out between a fault, 300 m WSW of Langstilly Farm /NS 3260 5700/ and the Maich Bridge /NS 3321 5581/ and generally the rocks dip at around 8° to the southeast (fig. 7.1). The oldest strata exposed at the northern end of the section are mudstones containing a bed with a marine fauna, principally brachiopods. This bed is correlated


Langstilly Farm
Jeffreystock Farm
Johnstone Shell Bed
Kirnhole Coal
Nervelston Farm
Maich Shell Bed
Logan's Bands
disused railway
MAICH WATER SECTION
0 100 200 300 400 500
metres
railway viaduct
Maich Bridge
West Lochridge Farm
Fault with direction of downthrow if known
Basic igneous intrusions
Smithy Coal with Lingula sp. in roof beds
Other marker horizons
Maich Water, arrow shows direction of stream-flow

on the basis of its fauna and lithostratigraphic position with the Johnstone Shell Bed.

Sandstone beds begin to appear within the strata exposed 250 m downstream from the Johnstone Shell Bed. They occur within repeated upward-coarsening cycles of mudstone, siltstone and sandstone, with the thickness of each lithology being variable. At Kirnhole /NS 3272 5068/ a bright coal, 14 cm thick, is present resting on a light brownish grey sandstone with a rooty top. This coal, locally called the Kirnhole Coal, is the lowest coal developed in the Limestone Coal Group of Dalry Basin. It is succeeded by 2.60 m mudstone coarsening upwards through 0.80 m siltstone and into 3.00 m+ sandstone. Similar cycles, often incomplete and of variable thickness and lithological proportion, are developed downstream to a cliff section 280 m south of Nervelston Farm /NS 3287 5631/. At the base of the cliff are mudstones with two ironstones each 30 cm thick below which are mudstones containing a marine fauna which has been called the Maich Shell Bed.

The sequence between the Maich Shell Bed and a fault trending at 120° and downthrowing to the south-west /NS 3288 5610/ consists of cycles with thin coals passing up into mudstones, siltstones and sandstones. The thickness and proportion of each lithological unit within the cycle is variable and any part, particularly the coals, may be absent. A mudstone unit, at least 4 m thick, cropping

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Footnote: The Maich Shell Bed contains the following fauna identified by Dr R B Wilson: Lingula squamiformis, Aviculopecten inequalis, Paracarbonicola cf. pervetusta, Naiadites cf. crassus and Naiadites cf. tumidus, a fauna very similar to that of the Linwood Shell Bed of the Glasgow district (Forsyth 1978).

out in the stream 350 m south of Nervelston /NS 3296 5620/ contains thin ironstone bands and carries a Lingula sp fauna. This is a typical development of what is locally termed Logan's Bands.

To the south of the fault the strata present represent the topmost part of the Limestone Coal Group. Sandstone, light grey with ripple lamination and larger scale cross bedding, occurs downstream to the railway viaduct. This bed is between 10 and 15 m thick and passes up into seatclay and seatearth with a coal, 20 cm thick. The roof beds of this coal are mudstone with Lingula sp typical of the beds above the Smithy Coal in the Dalry Basin with which this coal is correlated.

Above the Smithy Coal further cycles, starting in coal and passing up into mudstones, siltstones, sandstones and back into coal, are developed. Minor faulting precludes correlation of these coals and exposure ends south of the Maich Bridge.

The strata in the abandoned railway cutting from Jeffreystock Farm /NS 3385 5710/ to West Lochridge Farm /NS 3230 5518/ is in the upper part of the Limestone Coal Group. Small-scale faulting occurs frequently and sedimentary cycles coarsening upwards from mudstone and siltstone to sandstone are typical. Thin coals are often developed above the sandstones.

Paduff Burn The section in the Limestone Coal Group in the Paduff Burn (fig. 7.2) begins 200 m north of Place /NS 3028 5482/, 1 km west of Kilbirnie and continues into Kilbirnie town centre /NS 3248 5450/, the sediments dipping generally to the south at 8°. The strata to the base of the Limestone Coal Group are best exposed in this section. The lowest strata in the Limestone Coal Group are

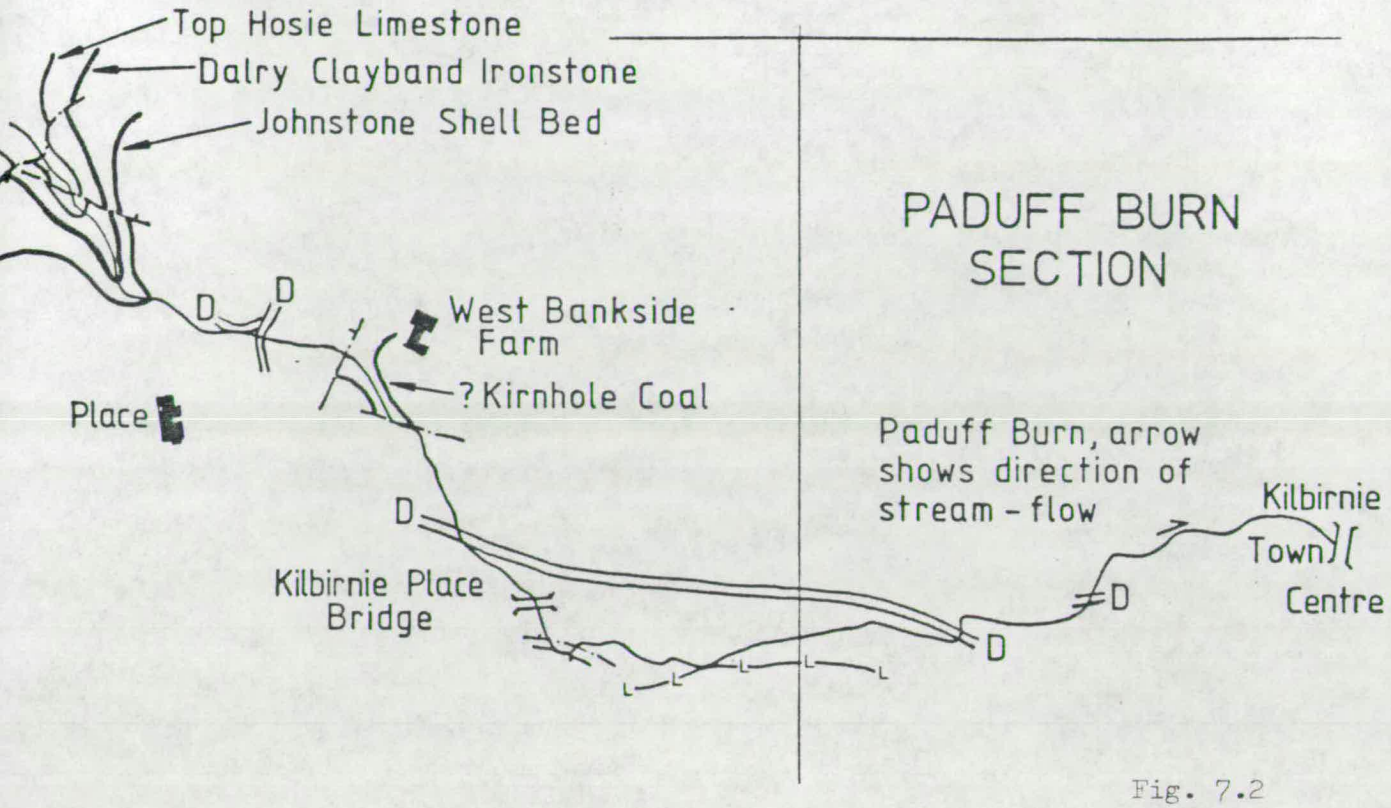

Top Hosie Limestone
Dalry Clayband Ironstone
Johnstone Shell Bed
PADUFF BURN SECTION
D
D
West Bankside Farm
?Kirnhole Coal
Place
Paduff Burn, arrow shows direction of stream-flow
Kilbirnie Town Centre
D
Kilbirnie Place Bridge
D
L
L
L
L
L

Fig. 7.2

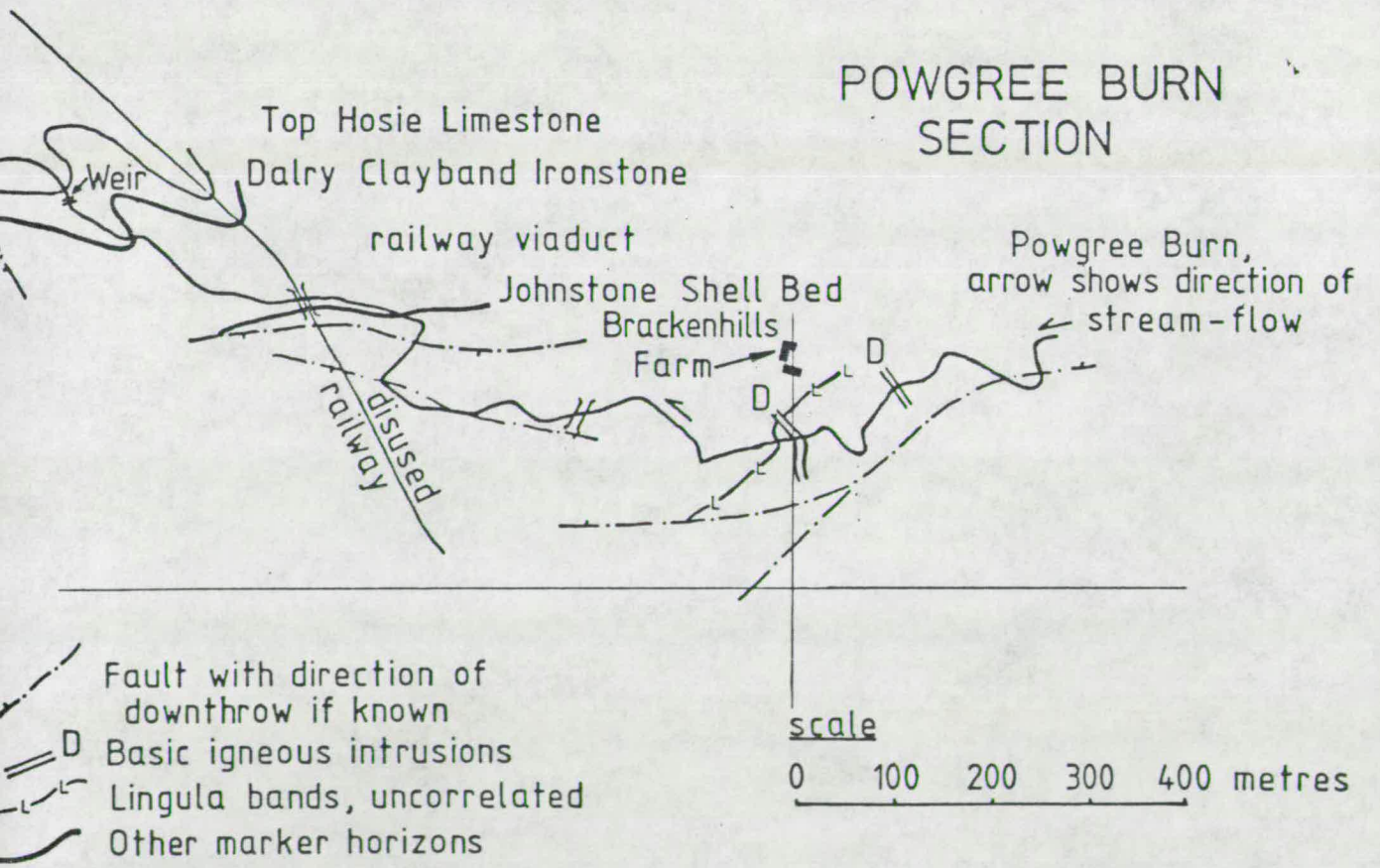

POWGREE BURN SECTION
Top Hosie Limestone
Weir
Dalry Clayband Ironstone
railway viaduct
Johnstone Shell Bed
Brackenhills Farm
Powgree Burn, arrow shows direction of stream-flow
D
D
L
L
railway
disused
Fault with direction of downthrow if known
D
Basic igneous intrusions
Lingula bands, uncorrelated
Other marker horizons
scale
0 100 200 300 400 metres

Fig. 7.3

a sequence of mudstones which crop out between the Top Hosie Limestone and a point in the Paduff Burn 100 m north-east of Place /NS 3040 5470/. Within this sequence two horizons can be identified, the Dalry Clayband Ironstone /NS 3030 5475/ and, slightly higher in the sequence, the Johnstone Shell Bed /NS 3035 5473/. The Dalry Clayband Ironstone is a medium grey, argillaceous ironstone 50 cm thick and identified solely on its stratigraphic position. The Johnstone Shell Bed is at least 2.20 m thick, consisting of mudstones with a marine fauna of brachiopods and bivalves.

The strata above the Johnstone Shell Bed cropping out downstream to the Kilbirnie Place Bridge /NS 3073 5442/ are faulted and intruded by basic igneous dykes. The sediments in this part of the sequence begin to include sandstones with beds commonly in excess of 4 m thick. They occur, as described in the Maich Water section, in upward-coarsening cycles with a thin coal occasionally developed on top. Immediately to the south of West Bankside Farm /NS 3060 5462/ the following section is seen:

	Thickness (m)
Mudstone, dark grey, bedded with ironstone nodules	0.25+
COAL, dull with pyrite	0.14
Sandstone, medium grained, medium grey, dark grey rooty top, cross bedded to base	1.80
Siltstone, dark grey with light grey sandy ribs and laminae	0.45
Mudstone, dark grey, well bedded with small ironstone nodules	1.00+

This sequence of strata, adjacent to a fault, is not sufficiently extensive vertically to allow a lithostratigraphic correlation for this coal seam but its general stratigraphic position would suggest

that it is the Kirnhole Coal.

Between the Kilbirnie Place Bridge and the centre of Kilbirnie the exposure in the Paduff Burn is intermittent. The outcrops are of lithologies and sequences similar to that described above though no coals have been observed. A section from a point 200 m downstream from Kilbirnie Place Bridge /NS 3043 5436/ is:

	Thickness (m)
Sandstone, medium grained, light brownish grey with dark grey, silty bands and laminae	1.10+
Sandstone, medium grained, silty medium grey with silty laminate, well bedded	0.95
Mudstone, silty, dark grey, well bedded	0.85
Mudstone, silty, dark grey, iron-stained joints, Lingula sp	0.15
Seatclay, silty, dark grey, small ironstone nodules	0.15
Mudstone, silty, dark grey, ironstone nodules	0.40
Seatearth, silty, dark grey, irony patches	0.15
Sandstone, medium grained, light grey to light brownish grey, fine silty laminae	1.05+

Again the sequence exposed in this outcrop is too limited to be able to correlate the Lingula band with any of the known occurrences in the Limestone Coal Group. The nature of the sedimentation would suggest that the strata lies around the middle of the Limestone Coal Group.

Powgree Burn The section in the Powgree Burn (Fig. 7.3) extends from the weir /NS 3326 5241/ westwards to a point 250 m east of Brackenhills Farm. The dips are generally to the south but eastward where the section comes closer to a major fault downthrowing to the

north, the direction of the dip is to the north. Between the weir and the railway viaduct /NS 3350 5230/ the lowest Limestone Coal Group strata are exposed resting on the Top Hosie Limestone. These consist of mudstones with occasional ironstone ribs and nodules including the prominent ironstone bed, the Dalry Clayband Ironstone, which has been locally worked. At the former railway viaduct mudstones containing a marine fauna including brachiopods and Lingula sp have been identified as the Johnstone Shell Bed. Eastwards from the railway viaduct exposure is intermittent with sandstone, siltstone and mudstone lithologies present. A Lingula band is present 100 m south of Brackenhills Farm /NS 3398 5214/ but insufficient of the sequence is exposed to make an accurate correlation.

Pitcon Burn The Limestone Coal Group section in the Pitcon Burn begins 350 m south-west of Balgray Farm /NS 2926 5370/ where Limestone Coal Group strata are in fault contact with the Dockra Limestone. The outcrop persists southwards till it disappears beneath the alluvial plain /NS 2983 5244/. The section is highly faulted but displays similar lithologies and sequences to those described previously from adjacent areas. A tuff band, 1.50 m thick, occurs within the strata in Pitcon Burn 400 m west of Swinlees Farm /NS 2979 5280/. Similar bands are also exposed in Swinlees Burn /NS 2966 5251/ and in Hardcroft Burn /NS 2940 5183/ and /NS 2917 5180/. An outcrop in a small stream 200 m west of Hawhill Farm /NS 2890 5127/ shows a highly altered lava resting on tuff.

Away from this immediate area tuff bands also occur in Limestone Coal Group strata at Dykehead Bridge /NS 2568 4755/, in the disused railway cutting 550 m north-east of South Lissens cottage /NS 3310 4740/ where a 1 m band of coarse tuff is exposed and 250 m

south-west of Caddell Farm /NS 2696 4708/ where rotten basaltic lava, 1 m thick, is overlain by sandstone. Borehole evidence for volcanically derived sediments in the Limestone Coal Group will be discussed later (chapter 7.5).

Ardrossan shore A very short section into the Limestone Coal Group is exposed on the shore at Ardrossan /NS 232 419/. The Johnstone Shell Bed is occasionally exposed (depending on shifting sand) at the topmost eastern end of the section. Below the Johnstone Shell Bed the sediments are largely mudstones with ironstone bands and nodules but beds of sandstone 2-3 m thick occur. The southernmost end of the section includes strata which have been folded.
This folding is significant being on the projected line of the Dusk Water Fault.

7.3 Limestone Coal Group - borehole data

The IGS drilling programme (1976-78) proved the full thickness of the Limestone Coal Group in only one borehole, the Montgreenan Borehole (table 7.1 and fig. 4.1). The Maich Water Borehole (table 7.2 and fig. 7.4) penetrated part of the Limestone Coal Group to establish the stratigraphic relationship between the Maich Shell Bed and the Johnstone Shell Bed. The results from this drilling show a similar vertical distribution of lithologies to the outcrop sections. From a point above the Johnstone Shell Bed sandstones begin to account for a greater proportion of the sediment thickness.

7.4 Limestone Coal Group - correlation

In attempting to correlate these sequences with sequences

TABLE 7.1

Limestone Coal Group in the Montgreenan Borehole /NS 3503 4523/

	Depth (metres) from	to
Index Limestone: limestones, dark grey, argillaceous nodular, calcareous mudstone to base	42.58	44.82
Mudstone, silty, dark grey, micaceous, well bedded plant scraps	44.82	45.02
Sandstone, medium grained, medium grey with dark grey silty ribs and laminae	45.02	45.36
Mudstone, silty, dark grey, sandstone and siltstone ribs, well bedded top 0.40 m, occasional plant scraps, irony ribs and nodules from 48.10 m	45.36	50.12
Sandstone, medium grained becoming coarse grained, light grey to light brownish grey, rooty top 0.25 m	50.12	51.60
Seatclay, brownish grey, mottled, micaceous in places, some bedding	51.60	52.50
Sandstone, medium grained, light grey, bedded, dark grey silty wisps and laminae	52.50	53.00
Siltstone, dark grey, well bedded, micaceous, some sphaerosiderite knots, sandy bands and laminae	53.00	53.24
Seatclay, dark brownish-grey, micaceous with dark grey roots	53.24	54.53
COAL, bright with dull patches, vertical joints	54.53	54.77
Seatclay, dark grey, carbonaceous near top, micaceous, some bedding	54.77	55.25
COAL, dull, canneloid	55.25	55.50
Seatclay, dark grey, bedded, finely micaceous	55.50	55.75
Mudstone, silty with fine micas, dark grey, unbedded frequent ironstone nodules	55.75	56.44
Seatearth, medium grey, sandy, micaceous with sharp irregular joints	56.44	57.04
Sandstone, medium grained, light grey, occasional silty wisps	57.04	57.40

TABLE 7.1 (cont'd)

	Depth (metres) from	to
Mudstone, silty, dark grey, finely micaceous, bedded frequent plant scraps	57.40	57.76
COAL, dull with bright patches	57.76	58.24
Mudstone, black, bedded, coaly	58.24	58.36
Seatclay, dark brownish-grey, silty, micaceous, some irony nodules, black and carbonaceous with coaly stringers at top	58.36	59.24
Siltstone, dark grey with silty mudstone bands, bedded, micaceous, rooty, irony nodules, plant scraps	59.24	60.02
Sandstone, medium grained, medium grey with dark grey silty laminae and bands, frequent plant scraps	60.02	60.58
Siltstone, dark grey, micaceous with sandstone and silty mudstone ribs and laminae, bedded, frequent plant scraps	60.58	61.20
Sandstone, medium grained, light grey with dark grey silty ribs and laminae, pebbly erosive base	61.20	61.45
Seatclay, dark grey, carbonaceous, some bedding	61.45	61.60
Mudstone, black, carbonaceous, silty with fine micas, well bedded	61.60	61.78
Seatclay, dark grey, carbonaceous with coaly stringers	61.78	61.86
COAL, dull	61.86	61.91
Seatclay, dark grey, carbonaceous with coaly stringers	61.91	62.10
Sandstone, medium grained, brownish grey, feldspathic unbedded	62.10	62.44
COAL, bright, broken	62.44	62.56
Seatclay, dark grey, structureless	62.56	62.64
Sandstone, medium grained, light brownish grey with dark grey wispy roots	62.64	63.23

TABLE 7.1 (cont'd)

	Depth (metres) from	to
Siltstone, dark grey, well bedded, micaceous with light grey sandy ribs	63.23	63.50
Sandstone, medium grained, light grey with dark grey silty wisps and laminae	63.50	63.85
Siltstone, dark grey, well bedded, micaceous, light grey sandy ribs	63.85	64.50
Mudstone, dark grey, silty with fine micas, bedded, occasional plant scraps and listric surfaces	64.50	65.13
Sandstone, medium grained, light grey to light brownish grey, dark grey, wispy silty laminae, occasional silty mudstone ribs, plant scraps, wispy roots at top	65.13	68.30
Mudstone, dark grey, silty with fine micas, well bedded, ironstone bands and nodules becoming black and carbonaceous to base	68.30	70.12
Seatearth, dark brownish-grey, micaceous, structureless	70.12	70.37
Sandstone, medium grained, light grey with dark grey silty laminae	70.37	70.71
Mudstone, silty, dark grey, finely micaceous, well bedded	70.71	70.79
Sandstone, medium grained, brownish-grey with dark grey silty wisps, some roots, micaceous	70.79	71.62
Siltstone, dark grey, well bedded, micaceous, abundant fine sandy laminae	71.62	72.15
Mudstone, silty, dark grey, bedded, frequent listric surfaces, occasional ironstone ribs, carbonaceous to base, Naiadites sp. from 75.40 to 76.06	72.15	76.42
Basalt, medium to fine grained, greenish-grey	76.42	77.02
Mudstone, black, carbonaceous, well bedded, frequent pyrite stringers and patches, lipy at base	77.02	77.58
Seatearth, dark grey, silty, rather structureless	77.58	78.68
Siltstone, dark grey, bedded, rooty, sandy ribs and laminae	78.68	79.00

TABLE 7.1 (cont'd)

	Depth (metres) from	to
Mudstone, dark grey, well bedded, frequent listric surfaces, frequent plant scraps, occasional black carbonaceous bands, Lingula sp. from 80.90	79.00	81.22
COAL, bright with dull ribs	81.22	81.38
Mudstone, black, carbonaceous, some roots, lipy	81.38	81.74
Siltstone, medium grey, well bedded, micaceous, frequent sandy ribs, some plant scraps	81.74	83.00
Mudstone, silty, dark grey, well bedded, micaceous, plant scraps, frequent ironstone ribs and nodules, occasional carbonaceous bands, coal traces at base	83.00	86.90
Seatearth, dark brownish grey, silty, micaceous, structureless	86.90	87.50
Sandstone, medium grained, light grey with dark grey silty laminae, small scale cross bedding	87.50	90.50
Mudstone, dark grey, well bedded, finely micaceous graphitised plant scraps, shells at 95.85	90.50	98.83
Basalt, brownish grey with greenish-grey mottling	98.83	99.76
Mudstone, dark grey, well bedded, frequent ironstone ribs, steep joints with carbonate veinlets, Lingula sp.	99.76	100.56
Johnstone Shell Bed: Mudstone, medium to dark grey, well bedded, abundant pyrite on joints and bedding plains, Lingula sp., brachiopods and bivalves, occasional ironstone nodules	100.56	104.20
Mudstone, medium grey, bedded, steep near vertical joints	104.20	105.46
Mudstone, medium grey, baked with frequent fine basaltic intrusions	105.46	106.96
Basalt, coarse grained, medium to fine grained at top, medium grey with greenish and pinkish tinges, fine grained, chilled base	106.96	133.80
Mudstone, greenish grey to dark brownish grey, mottled, bedded, abundant pyrite, rounded clasps at top	133.80	134.20

TABLE 7.1 (cont'd)

	Depth (metres) from	to
Seatclay, brownish grey, some sphaerosiderite, abundant pyrite	134.20	135.15
Sandstone, fine grained, light greenish grey to light grey	135.15	135.52
Top Hosie Limestone: Limestone, medium grey, fine grained	135.52	135.60

TABLE 7.2

Limestone Coal Group in the Maich Water Borehole /NS 3290 5637/

	Depth (metres) from	to
Mudstone, silty, dark grey with ironstone bands and nodules	3.00	5.92
Mudstone, silty, dark grey to black with Naiadites sp.	5.92	7.37
Mudstone, dark grey to black, some irony bands with fish scales	7.37	8.00
COAL, bright with dull ribs, some pyrite on bedding and joint plains	8.00	8.25
Seatclay, dark grey with ironstone bands and nodules Lingula sp. from 8.78	8.25	9.45
Mudstone, silty, dark grey with ironstone bands, black and carbonaceous in places, Lingula sp. and Naiadites sp. from 10.05	9.45	10.40
Sandstone, medium grained, dark grey	10.40	10.50
COAL, foul, bright patches	10.50	10.60
Sandstone, medium grained, dark grey with coaly stringers	10.60	10.71
COAL, bright with dull ribs	10.71	10.86
Sandstone, light grey with dark grey silty micaceous laminae, rooty at top, frequent plant scraps	10.86	12.40
Siltstone, dark grey, micaceous, bedded, frequent roots and plant scraps	12.40	12.55
Mudstone, silty, dark grey, well bedded, finely micaceous, plant scraps, occasional ironstone bands, Naiadites sp.	12.55	13.82
Mudstone, dark grey, bedded with frequent ironstone bands, Naiadites sp. from 13.60 to 14.58	13.82	14.58
Maich Shell Bed: Mudstone, dark grey, irony Paracarbonicola sp., Naiadites sp. and Lingula sp.	14.58	14.90
Mudstone, dark grey, bedded, frequent listric surfaces, ironstone nodules, Lingula sp.	14.90	16.13

TABLE 7.2 (cont'd)

	Depth (metres) from	to
Mudstone, silty, dark grey with ironstone bands, *Naiadites sp.*	16.13	18.39
Sandstone, medium grained, light grey with dark grey silty laminae, frequent plant scraps, occasional roots	18.39	18.67
Siltstone, silty mudstone, dark grey, well bedded abundant plant scraps, frequent fine sandy laminae, occasional irony nodules	18.67	19.89
Sandstone, medium grained, light to very light grey, dark grey silty laminae and roots at top, small scale ripple lamination	19.89	24.16
Siltstone, dark grey, well bedded, frequent sandy ribs and laminae, micaceous, abundant plant scraps	24.16	25.00
Mudstone, silty, dark grey, well bedded, finely micaceous	25.00	27.25
Mudstone, black, carbonaceous	27.25	27.97
COAL, dull with bright patches	27.97	28.07
Sandstone, medium grained, light grey, rooty at top, dark grey wispy silty laminae, steep joints, fine ripple lamination	28.07	33.55
Siltstone to silty mudstone, dark grey, bedded with light grey sandy ribs, frequent plant scraps, *Naiadites sp.* at 33.80	33.55	34.13
Mudstone, silty, dark grey, bedded, finely micaceous, occasional listric surfaces, frequent plant scraps, *Naiadites sp.*	34.13	36.70
Mudstone, dark grey to black, frequent listric surfaces	36.70	46.00
Mudstone, dark grey to black, bedded, frequent listric surfaces, occasional ironstone bands, *Lingula sp.*	46.00	47.28
Ironstone, dark grey, hard, carbonate veinlets	47.28	47.52
Mudstone, dark grey	47.52	47.62
Ironstone, dark grey, bedded, carbonate veinlets	47.62	47.85

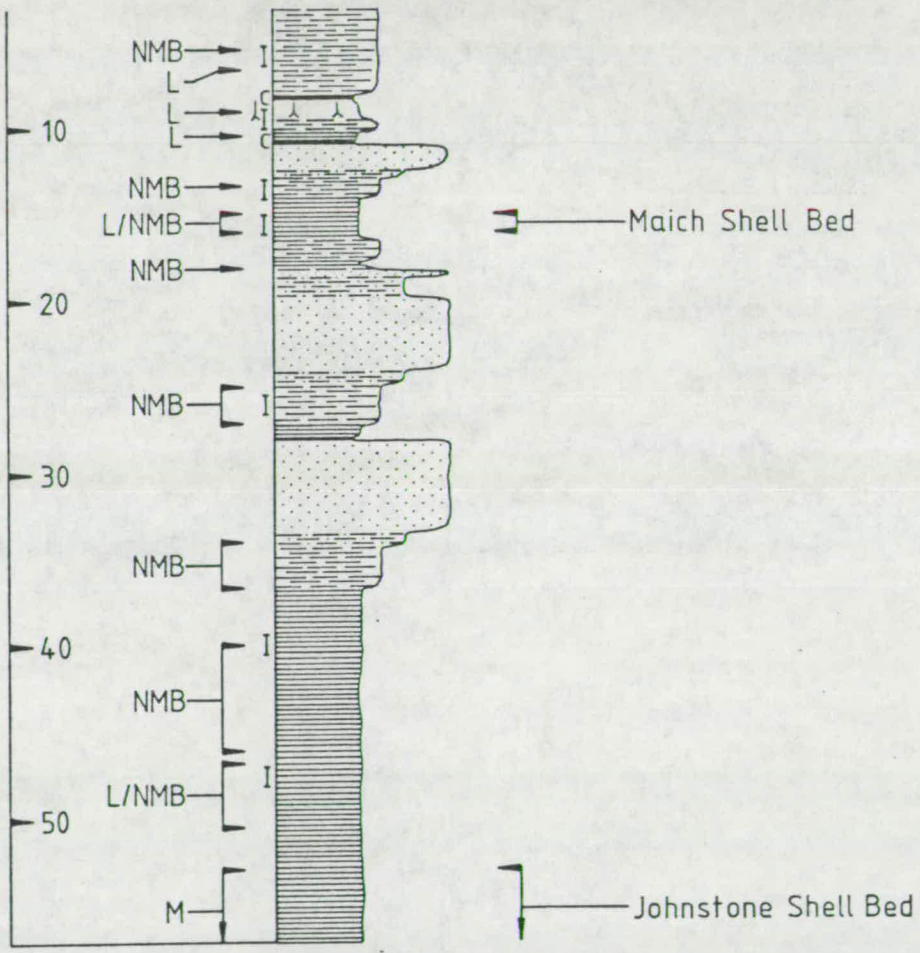
TABLE 7.2 (cont'd)

	Depth (metres) from	to
Mudstone, dark grey, poorly bedded, abundant listric surfaces, Lingula sp. and Carbonicola sp.	47.85	49.25
Mudstone, dark grey to black, poorly bedded, frequent listric surfaces, silty in places with fine micas	49.25	51.05
Mudstone, dark grey, bedded, frequent listric surfaces, pyrite nodules and stringers, Naiadites sp.	51.05	52.80
Johnstone Shell Bed: Mudstone, dark grey, bedded, occasional carbonate veinlets, steep pyritised joints, marine gastropods and bivalves	52.80	57.10

MAICH WATER BOREHOLE

metres from surface

[NS 3290 5637]



from old boreholes in the IGS records, it becomes apparent that the reliable correlatable horizons are not those defined solely on a lithological basis such as the ironstone bands but those which also carry a distinctive fauna. These faunas are generally marine though often with only Lingula sp present. The important horizons in the Dalry Basin are listed below in descending order.

Lingula band in roof of Smithy Coal

Logan's Bands (correlated with Black Metals of Glasgow area)

Maich Shell Bed (correlated with Linwood Shell Bed of Glasgow area)

Johnstone Shell Bed.

The Johnstone Shell Bed is present throughout the Dalry Basin as a sequence of mudstones of variable thickness but usually less than 8 m thick with a marine fauna. It can be correlated with little change northwards into the Glasgow area (Forsyth 1978). The Maich Shell Bed at its type locality in the Maich Water has an identical fauna to the Linwood Shell Bed (Wilson in Forsyth 1978). The Linwood Shell Bed fauna is considered to have lived in brackish-water in which only a few species could exist in abundance. Away from the area of the Maich Water, the Maich Shell Bed is not so easily recognised and may be represented by a band which only bears Lingula sp. or Naiadites sp. This inference is based largely on borehole evidence and, while in the stream section at Maich Water a full Maich Shell Bed fauna was obtained, in the nearby borehole only Lingula squariformis, Paracarbonicole cf. pervetusta and ?Naiadites sp. were found. The difference in the size of the fauna must be directly related to the volume of rock sampled. The comparison between the fauna obtained from the stream section and

that from the borehole highlights the limitations of a fauna obtained from a single borehole. It may only represent a part of the fauna of that horizon and correlation must take into consideration both the lighological sequence around that horizon and the faunas obtained from other boreholes through the same part of the sequence.

Logan's Bands are a series of thin ironstone bands in mudstones or silty mudstones usually with Lingula sp. or non-marine bivalves present. The horizon is of variable thickness and appears to be laterally persistent. It has been correlated with the Black Metals of the Glasgow area (Richey 1930).

The Lingula band in the roof beds of the Smithy Coal has been discussed previously (see chapter 7.2). It is persistent laterally but may be absent, as may be the Smithy Coal, in areas where sandstones are more abundant.

7.5 Volcanism in the Limestone Coal Group

Outcrop evidence suggests that locally, in the area to the west of Dalry, tuffs and volcanic rocks are interbedded with the normal sediments. Richey (1930, figs. 19 and 20) demonstrated the presence of tuffs from sections in the Linn Pit, the Bankhead Pit and the High Monkcastle Bore. Boreholes, sunk to determine foundation conditions for development around Dalry, have shown that the tuffs spread eastwards at least that far. The exact stratigraphical position of these tuff bands is not known but one at least may occur some 10 m below the Borestone Coal. In some of these bores thin ferruginous limestones up to 0.53 m thick are developed within the tuff bands. The Bankend No. 3 Borehole sunk 1940-41 for the Lochwood Coal Company proved an 8 m tuff bed below the Borestone

Coal and a further 1 m tuff band below Logan's Bands.

The distribution of volcanic horizons is shown in fig. 7.5, derived from both outcrop and borehole data. It is not possible to analyse the geometry of these volcanic horizons as individual beds cannot be correlated laterally but a basic magma source is envisaged with a vent centred on the thickest development of the tuffs some way to the west of Dalry.

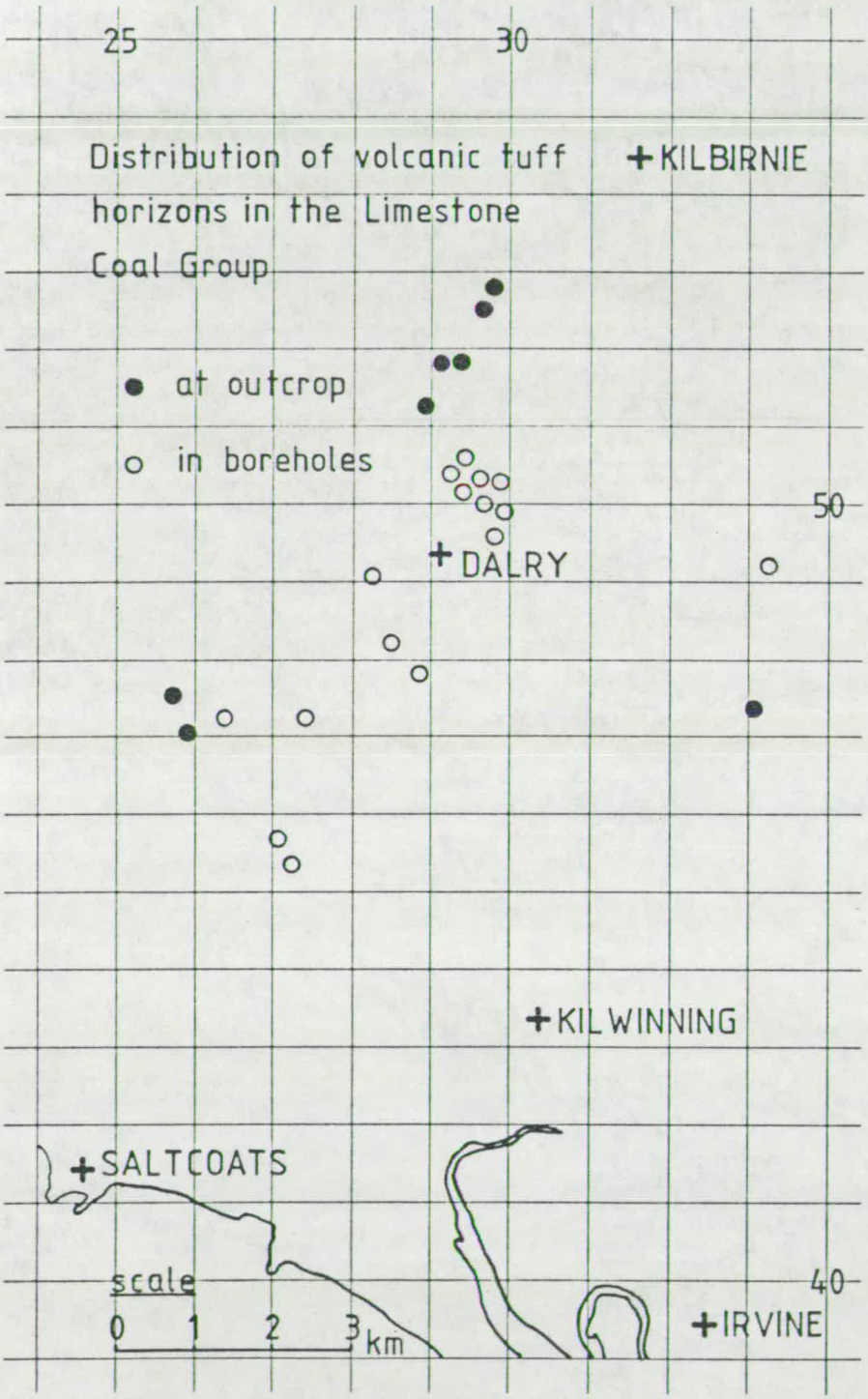
7.6 Thickness variation in the Limestone Coal Group

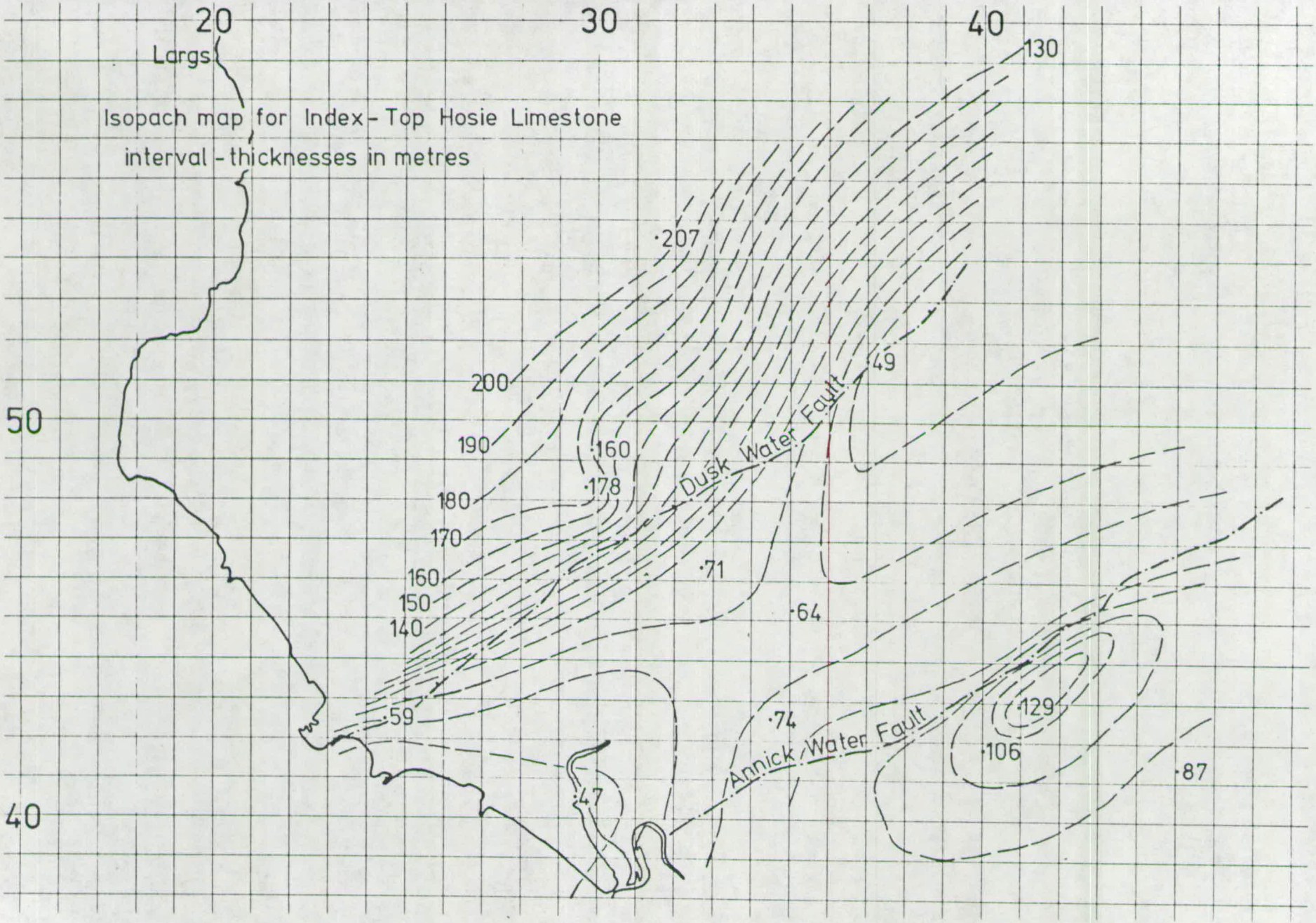
Borehole data, largely drawn from old records, is sufficient to compile an isopach map for the Limestone Coal Group (fig. 7.6). It highlights the rapid change in thickness which takes place across the Dusk Water Fault and suggests that a similar change takes place across the Annick Water Fault, but in the opposite sense. The area between the faults seems to have been stable or subsiding more slowly relative to the adjacent areas during deposition of the Limestone Coal Group sediments.

In correlating the borehole sections used to construct the map no appreciable loss of strata across either of the faults was noted and it is clear that the thickness differences are due to an overall thickening or thinning.

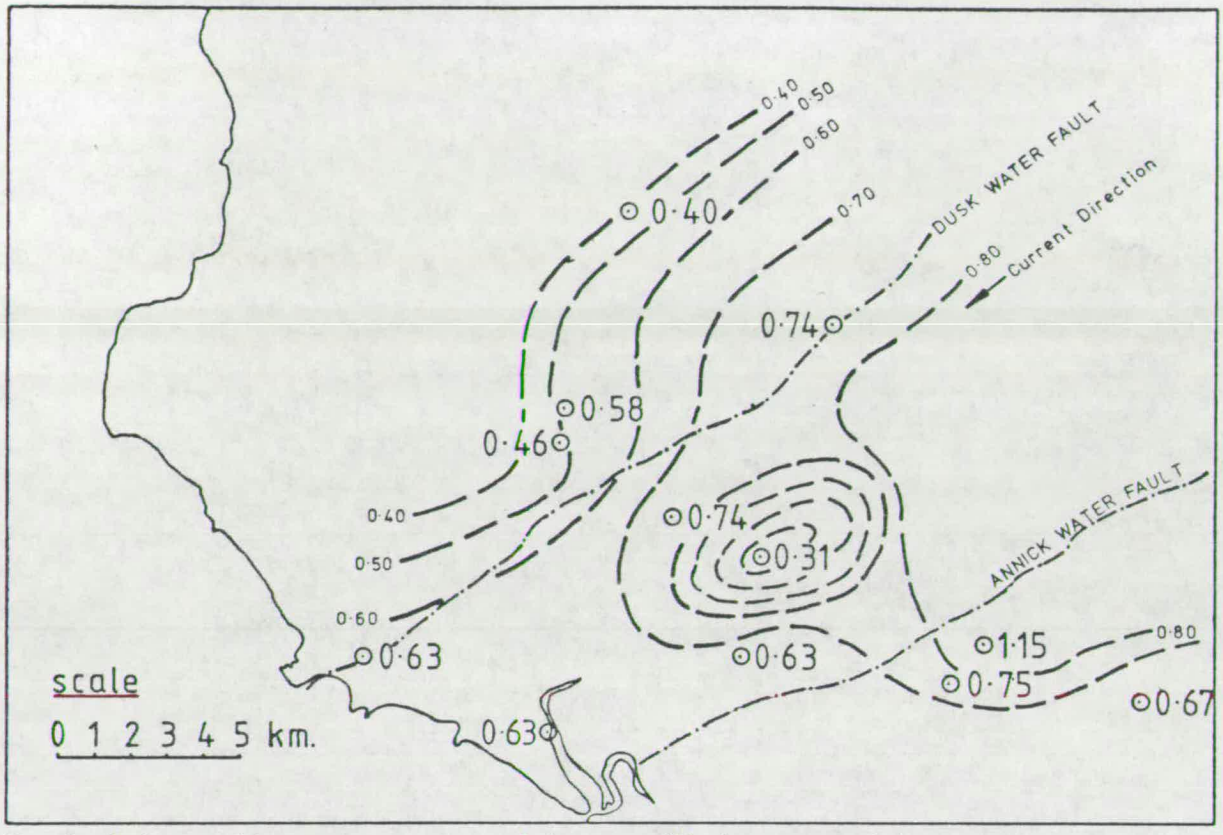
7.7 Facies variation in the Limestone Coal Group

Both borehole and outcrop data show a similar vertical pattern of sediment distribution regardless of geographical position. To assess this lithofacies maps have been constructed from borehole data showing variation in the ratio of sandstone to siltstone and mudstone (fig. 7.7) and the ratio of mudstone to sandstone and siltstone


25
30
Distribution of volcanic tuff horizons in the Limestone Coal Group
+KILBIRNIE
● at outcrop
○ in boreholes
50
+DALRY
+KILWINNING
+SALTCOATS
scale
0 1 2 3 km
40
+IRVINE

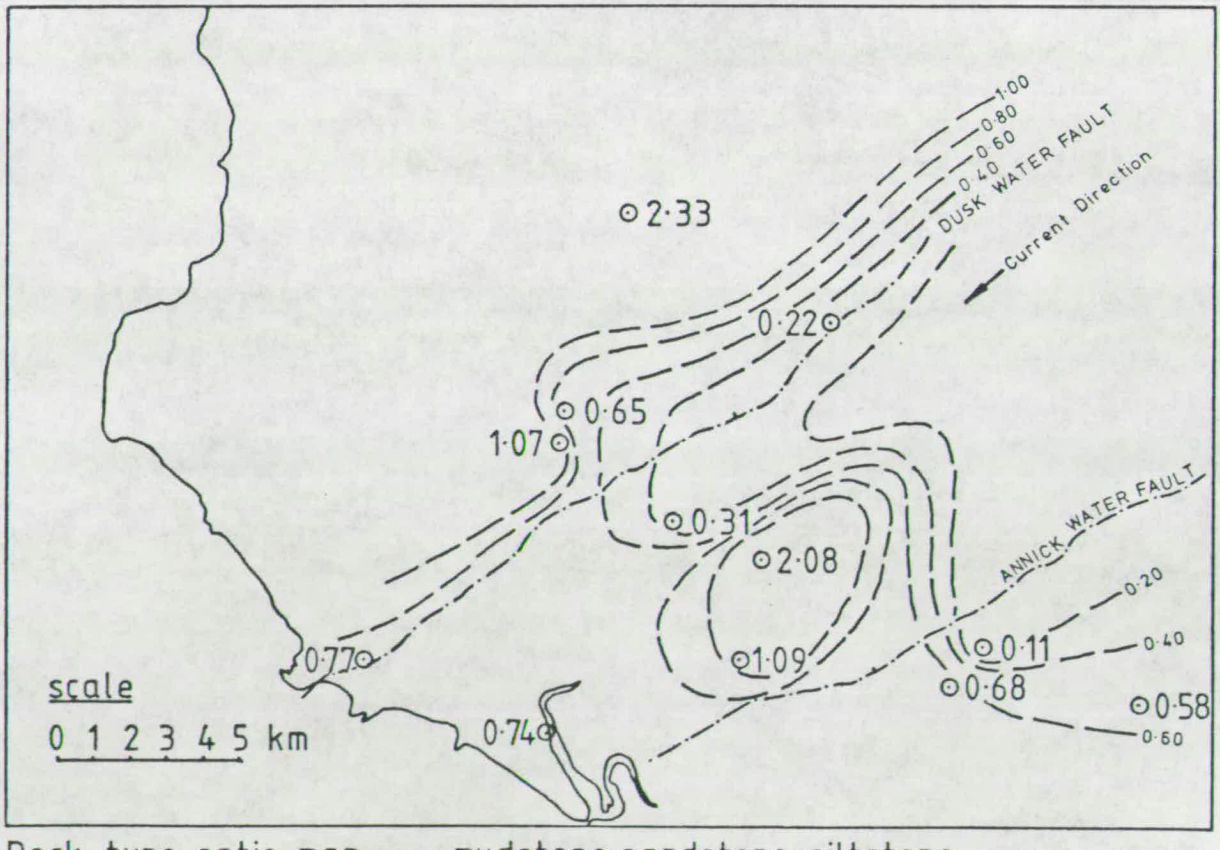

20
30
40
50
40
Largs
Isopach map for Index - Top Hosie Limestone
interval - thicknesses in metres
207
200
190
180
170
160
150
140
160
178
71
64
49
130
59
47
74
129
106
87
Dusk Water Fault
Annick Water Fault

LIMESTONE COAL GROUP - Lithofacies



Rock-type ratio map sandstone: siltstone+mudstone

Fig. 7.7



Rock-type ratio map mudstone:sandstone+siltstone

Fig. 7.8

(fig. 7.8). These ratios may be contoured in two ways, one paralleling the structural features and a second with a lineament at right angles to the structural features. Since structural elements which affect the thickness of sediments also tend to affect their lithofacies the first method of contouring has been used.

The lithofacies maps show a general decrease in sandstone and an increase in mudstone from east to west with the area between the faults having a high mudstone and low sandstone overprint.

7.8 Cyclicity in the Limestone Coal Group

A cyclical pattern of sedimentation has been evident from both borehole and outcrop observations. There is an impression that the cycles are upward-coarsening with coals resting directly on sandstones. The sequences have been analysed more objectively using Selley's simple mathematical device (see chapter 4.4). Suitable data for an analysis of the Limestone Coal Group are limited, the Montgreenan Borehole being the only borehole to penetrate the entire 'group'. Old borehole data are suspect for such an analysis, as the lithological units have not been described in the same detail. Analysis is therefore applied only to the sequence in the Montgreenan Borehole.

The analysis (table 7.3) confirms the observations from outcrop and borehole that the lithologies are arranged in an upward-coarsening sequence with coals and associated seatclays resting directly on sandstones.

7.9 Limestone Coal Group - a depositional model

Both the borehole and outcrop data indicate that two sedimentary facies are represented in the Limestone Coal Group, an

TABLE 7.3

Analysis of sequence - Montgreenan Borehole

Limestone Coal Group

	Sst	Mudst	Seat	Siltst	Coal	
Sst	3	3	7	3	0	16
Mudst	5	4	2	4	1	16
Seat	2	6	1	1	5	15
Siltstone	5	1	2	0	0	8
Coal	1	2	3	0	0	6
	16	16	15	8	6	61

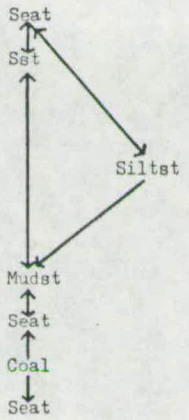
(a) data array of bed transitions

	Sst	Mudst	Seat	Siltst	Coal
Sst	4	4	4	2	2
Mudst	4	4	4	2	2
Seat	4	4	4	2	1
Siltst	2	2	2	1	1
Coal	2	2	1	1	1

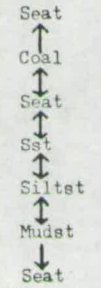
(c) predicted data array assuming a random arrangement of lithologies (calculated to nearest whole number)

	Sst	Mudst	Seat	Siltst	Coal
Sst	-1	-1	+3	+1	-2
Mudst	+1	0	-2	+2	-2
Seat	-2	+2	-3	-1	+4
Siltst	-1	0	+2	-1	-1
Coal	-1	0	+2	-1	-1

(d) table showing the difference between the observed number of transitions and the predictee number assuming a random arrangement



(b) facies relationship diagram showing the most common upward and downward transitions for each lithology



(e) facies relationship diagram showing the largest number of upward and downward transitions that occur for each lithology after subtracting those predicted if the beds were arranged randomly

argillaceous facies and a mixed lithology cyclical facies. In all cases the argillaceous facies passes upwards into the mixed lithology cyclical facies. The argillaceous facies are the basal mudstones, at times marine in origin, in the Johnstone Shell Bed. The transition upwards into cyclical sediments is gradual with sandstone lithologies becoming progressively more common. Marine horizons become, as in the case of the Maich Shell Bed, more restricted in their variety of species with, above the Maich Shell Bed, only Lingula bands present.

The mixed lithology cyclical facies of coarsening upwards cycles terminating in coal can be interpreted as a series of depositional environments typical of a delta. Each lithology represents deposition within a particular area of the delta, the mudstones in the pro-delta area, the sandstones and siltstones on the delta front and the coals and seatclays, sometimes with distributary channels on the delta plain. The vertical sequence of lithologies is generated by the prograding nature of the delta.

The variation in the sandstone: siltstone + mudstone ratio and that of the mudstone: sandstone + siltstone ratio should give an indication of the geometry of the delta. The isopach map should give an indication of contemporaneous fault movements, and, of course, the two may interact with contemporaneous fault movements modifying distribution of sediment within the delta.

The isopach map (fig. 7.6) indicates that the area between the Dusk Water and Annick Water faults was acting as a 'block' area relative to those areas to the north-west and south-east. This block area is reflected in rock type ratio maps (figs. 7.7 and 7.8) where there is a generally fining sequence from the east to the north-west interrupted by anomalously argillaceous sequences between the two faults. The direction of the fining of the rock-type ratios indicate

a source for the deltas to the east. This would also infer that marine conditions should be more prevelant in the north-west. This is borne out by changes in the Maich Shell Bed faunas.

Current directions are seldom indicated in the outcrops of Limestone Coal Group sandstone. Good cross-bedding is preserved in a small quarry south of Lugton /NS 4067 5228/ where eight current directions were measured. The mean directional value was 230°. While these data from outcrop are not significant in themselves, they are compatable with lithofacies interpretation.

Chapter 8 Upper Limestone Group

8.1 Introduction

This chapter seeks to describe the strata within the Upper Limestone Group in the Dalry Basin, to correlate the sequences and to discuss lateral variation in both thickness and lithology across the basin's major structural features. The cyclicity of the sedimentation within these strata is examined and a model postulated for the environment of deposition.

8.2 Stratigraphic boundaries of the Upper Limestone Group.

The difficulties in defining the boundaries of the Upper Limestone Group are discussed briefly in chapter 2.12. The Index Limestone, marks the base of the 'group' and is present over much of the Dalry Basin. In those areas where it is locally absent (see fig. 8.8 and chapter 8.6) an arbitary lithological junction is taken. This junction occurs at a point in the sequence where coal-bearing cycles typical of the Limestone Coal Group give way to cycles containing marine limestones more typical of the Upper Limestone Group. The Castlecary Limestone, defined as the top of the Upper Limestone Group (MacGregor 1960), has not been identified in the Dalry Basin. In consequence the local boundary between the Upper Limestone Group and the Passage Group is taken arbitrarily where limestone-bearing cycles give way to seatearths and sandstones with occasional marine mudstones typical of the Passage Group. Both these arbitrary boundaries are frequently taken locally at the base of coarse-grained sandstone beds which rest disconformably on lower and older strata. These lithological boundaries may only be applied where they are compatible with the age indicated by the fauna.

8.3 Upper Limestone Group - outcrop data

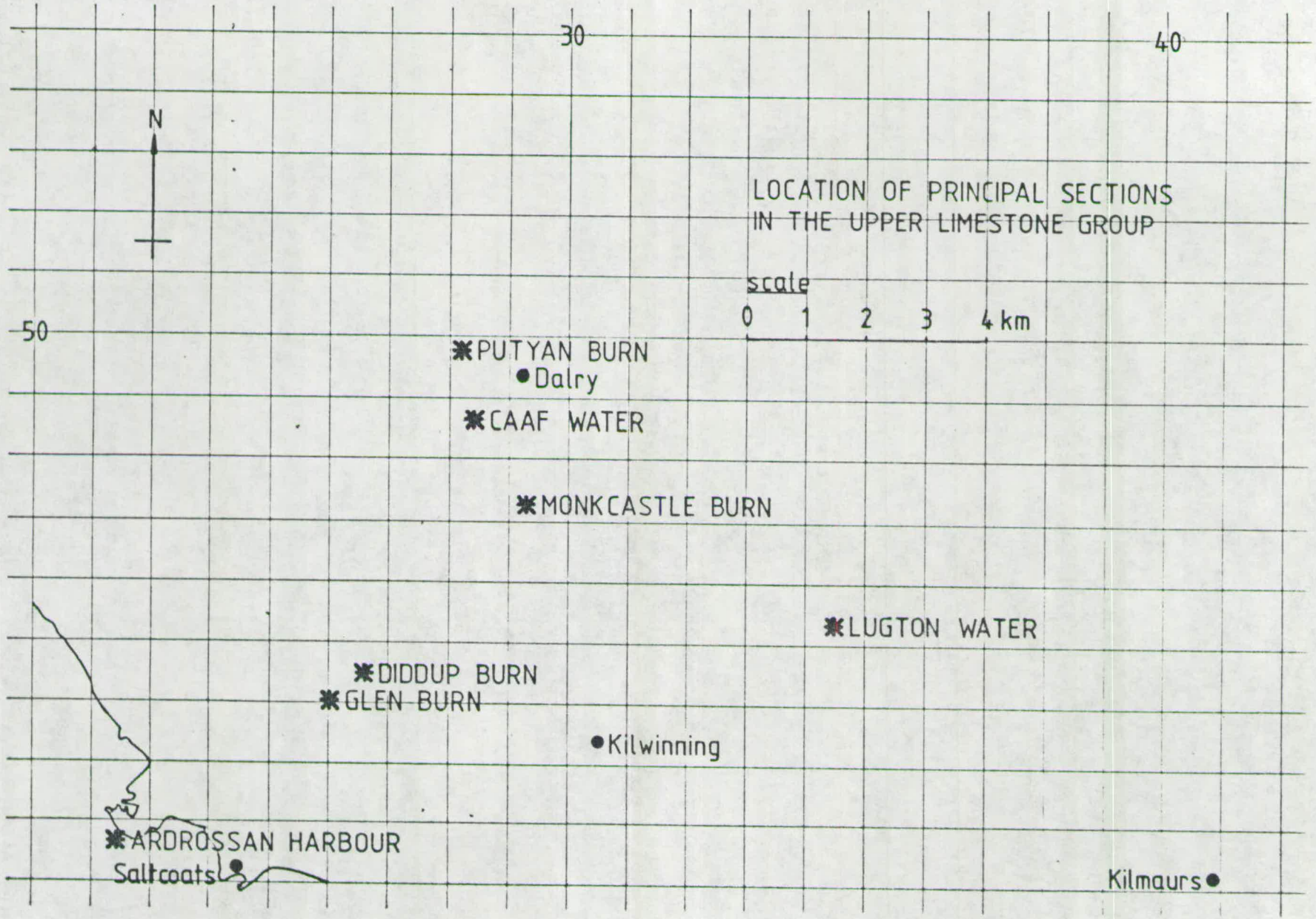
Sections in the Upper Limestone Group (fig. 8.1) are incomplete in the Dalry Basin, invariably interrupted either through lack of exposure or else by faulting. Nevertheless they provide a convenient framework for further sub-surface study.

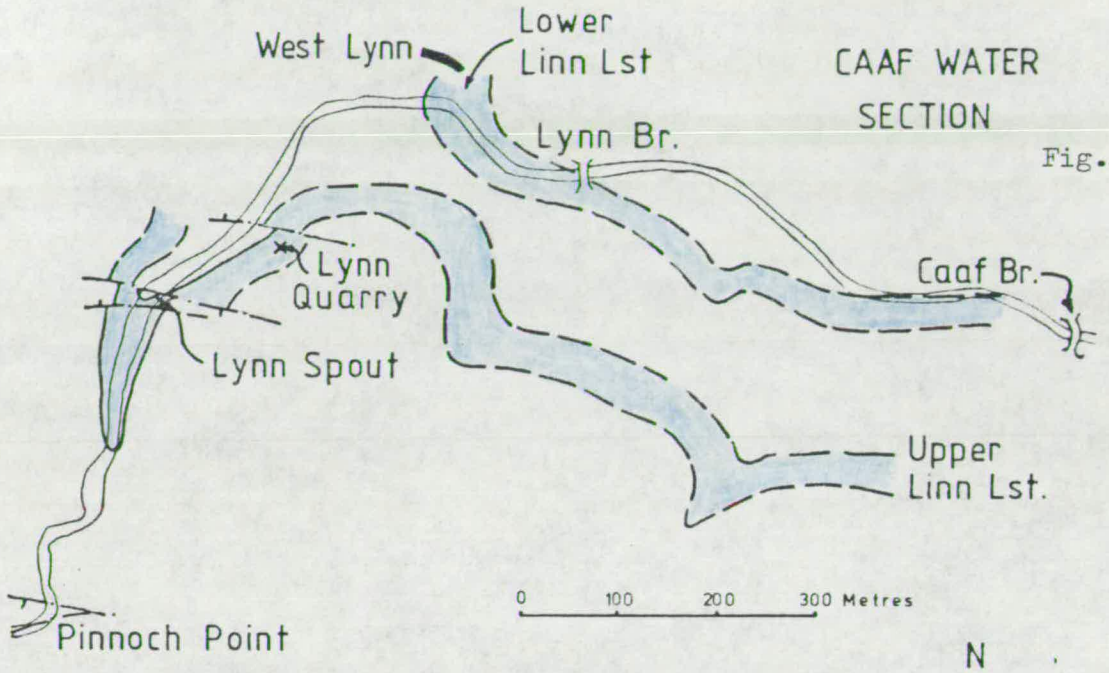
Caaf Water The section in the Caaf Water (fig. 8.2) extends from a point 120 m west of Caaf Bridge /NS 2910 4850/ to Pinnoch Point /NS 2820 4822/ and includes most of the Upper Limestone Group strata above the Lower Linn Limestone. The Lower Linn Limestone crops out 120 m west of Caaf Bridge, at the Lynn Bridge /NS 2870 4863/ and at West Lynn /NS 2860 4872/*. The Lower Linn Limestone is over 5 m thick consisting of dark grey, argillaceous, occasionally concretionary limestone with calcareous mudstone bands. A marine fauna is present throughout.

The strata between the Lower and Upper Linn limestones, although not continuously exposed, are seen to consist largely of sandstones with subordinate mudstones and siltstones. The Upper Linn Limestone crops out in the Lynn quarry /NS 2843 4857/ and at Lynn Spout /NS 2830 4852/. It consists of 14.7 m of limestone, dark grey, argillaceous with calcareous mudstone bands at top and to the base and with fine muddy partings throughout. The member carries a marine fauna and is underlain by mudstones with Edmondia punctatella.

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* Footnote: The discrepancy in spelling between the name of the limestone and of the locality after which it was named is historical. In the original 1871 edition of the Explanation of Sheet 22, A Geikie has spelt both locality and limestone as Linn. A similar spelling occurs on the 1:63 360 topographic base of the 1910 though the 1911 1:10 560 edition has the locality spelt Lynn.


30
40
N
LOCATION OF PRINCIPAL SECTIONS
IN THE UPPER LIMESTONE GROUP
scale
0 1 2 3 4 km
50
PUTYAN BURN
Dalry
CAAF WATER
MONKCASTLE BURN
LUGTON WATER
DIDDUP BURN
GLEN BURN
Kilwinning
ARDROSSAN HARBOUR
Saltcoats
Kilmaurs



CAAF WATER
SECTION

Fig. 8.2

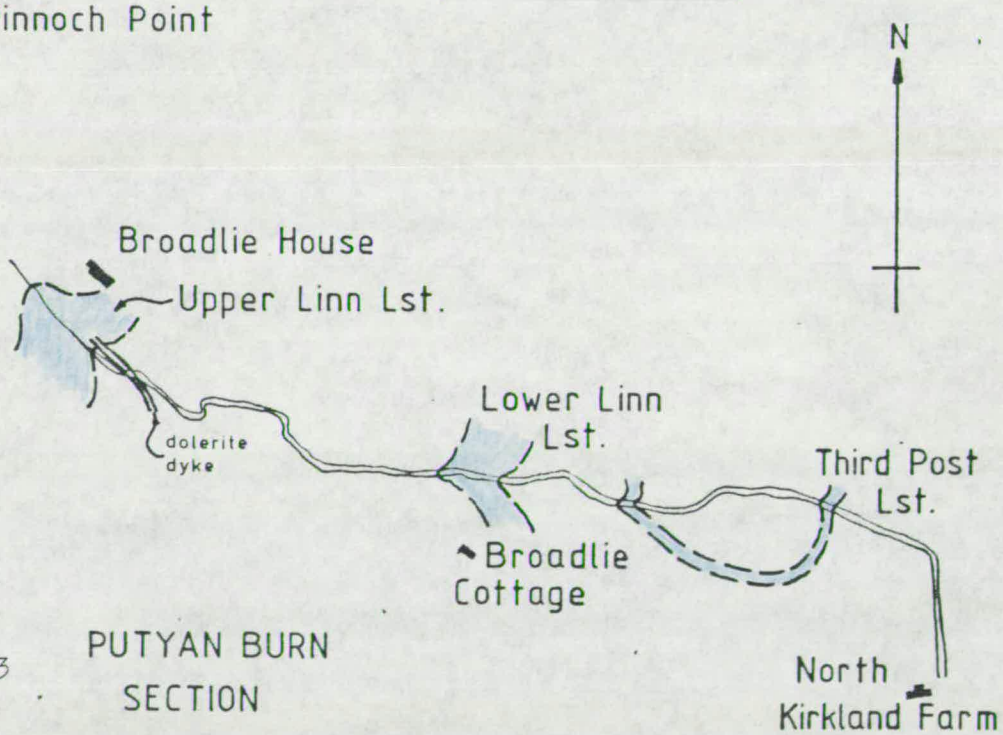


Fig. 8.3

PUTYAN BURN
SECTION

Above the Upper Linn Limestone, the strata consist of thick cross-bedded sandstone units with subordinate siltstones and mudstones. To the west of a fault at Pinnoch Point which downthrows westwards, the strata are sandstones, seatearths and seatclays, lithologies more typical of the lower part of the Passage Group. Faunal evidence from some thin mudstone bands confirms this age.

Putyan Burn: Sandstones, stratigraphically below the Third Post Limestone, are the lowest strata exposed in the Putyan Burn (fig. 8.3). The Third Post Limestone crops out twice, 180 m east of Broadlie Cottage /NS 2841 4975/ and 210 m north-west of North Kirkland farm /NS 2861 4975/ in an anticlinal structure. This limestone consists of limestone and calcareous mudstone, dark grey and argillaceous, 3.50 m thick and with a marine fauna. Above the Third Post Limestone the outcropping lithology is dominantly sandstone.

The strata from the Lower Linn Limestone to the Upper Linn Limestone crops out between a point 80 m north of Broadlie Cottage /NS 2828 4978/ and Broadlie House /NS 2882 4996/ and a sequence similar to that cropping out in the Caaf Water occurs. A coal, the Broadlie Coal, no longer exposed occurs below the Upper Linn Limestone and was formerly worked locally.

Monkcastle Burn: The Lower Linn Limestone crops out in the core of an anticlinal structure in the Monkcastle Burn (fig. 8.4) at Monkcastle Bridge /NS 2933 4729/. The Upper Linn Limestone is exposed to the east by Monkcastle /NS 2911 4745/ and where the Monkcastle Burn enters the Garnock Water /NS 2962 4724/. The

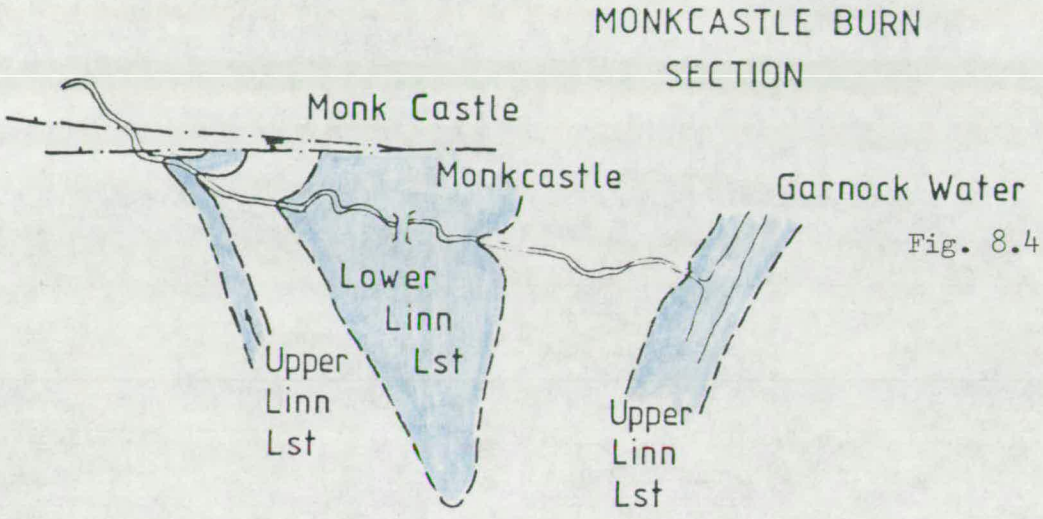

MONKCASTLE BURN
SECTION
Monk Castle
Monkcastle
Garnock Water
Lower
Linn
Lst
Upper
Linn
Lst
Upper
Linn
Lst

Fig. 8.4

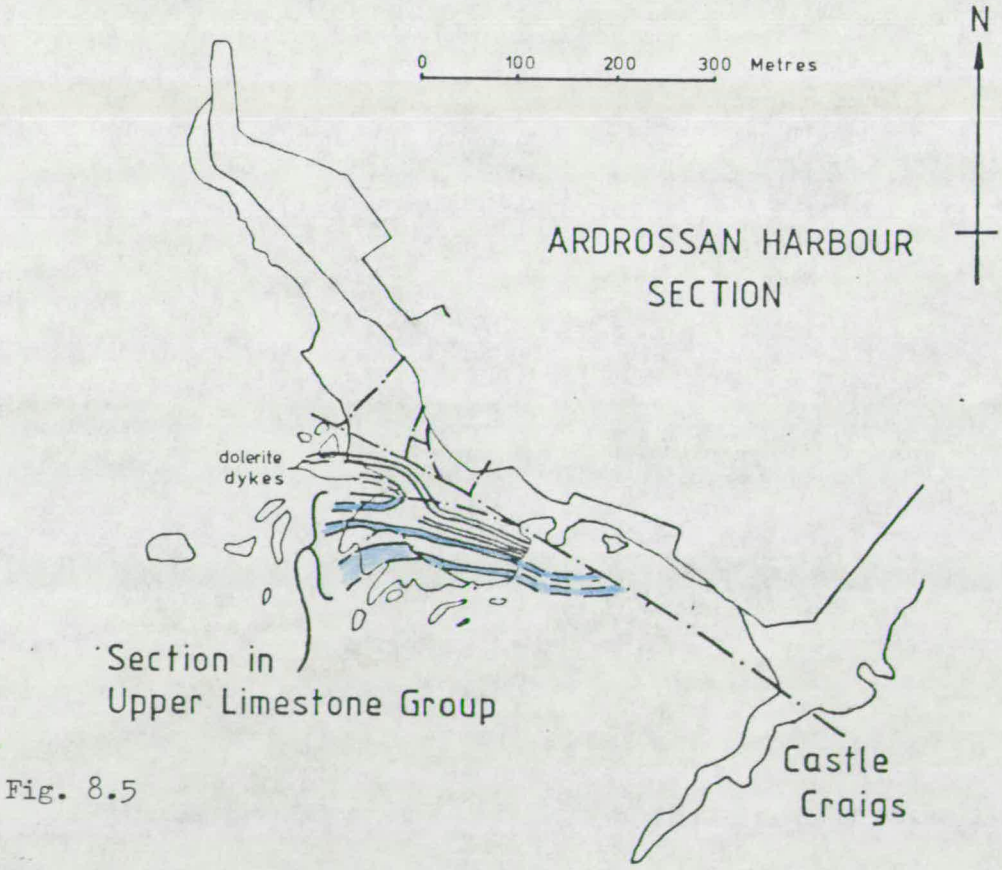

N
0 100 200 300 Metres
ARDROSSAN HARBOUR
SECTION
dolerite
dykes
Section in
Upper Limestone Group
Castle
Craigs

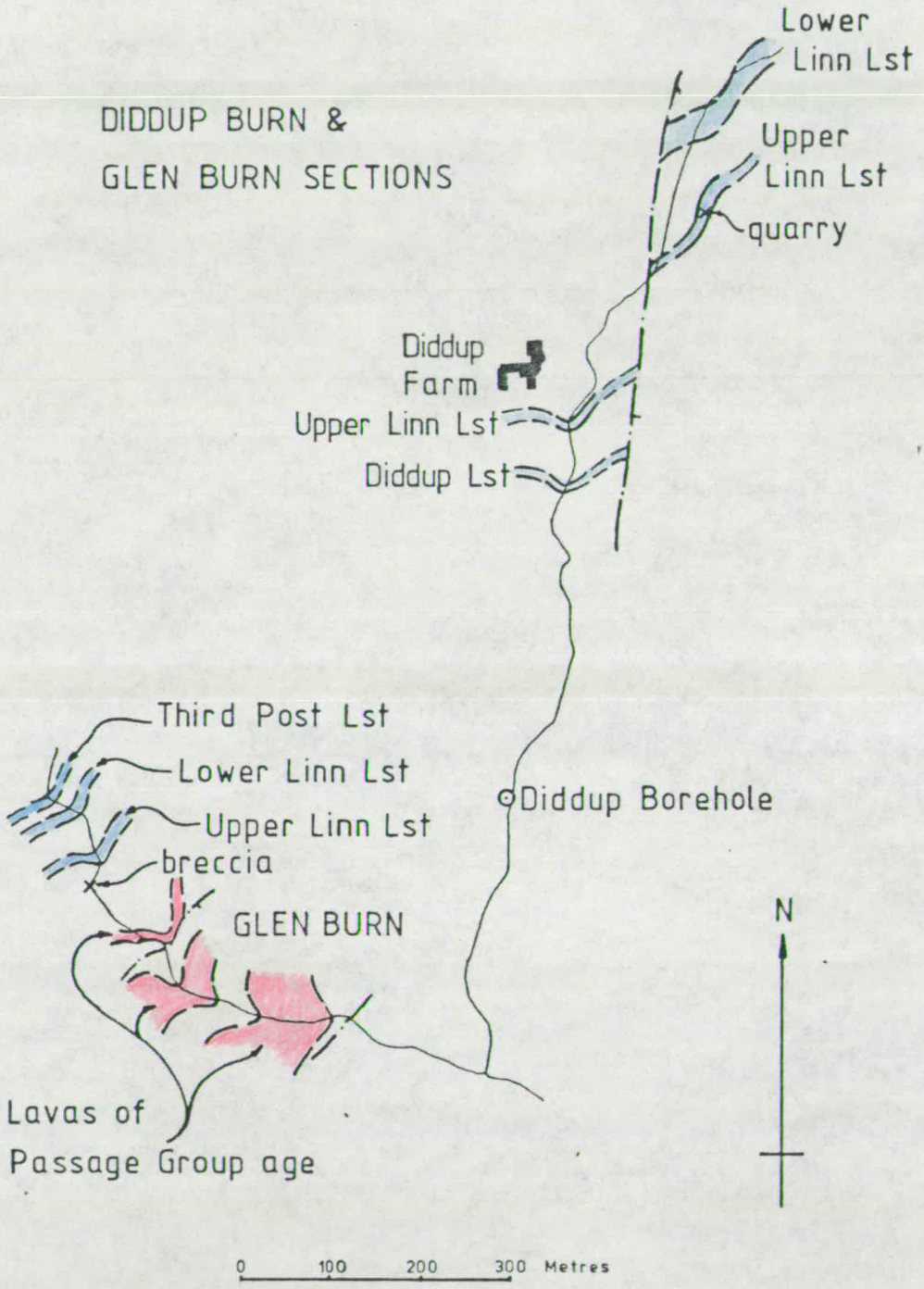
Fig. 8.5

limestone lithologies, thicknesses and the nature of the intervening strata are similar to those in the Caaf Water.

Diddup Burn: The youngest exposed strata of the Upper Limestone Group are seen at outcrop in the Diddup Burn (fig. 8.6). The Lower Linn Limestone crops out in the burn 330 m north-north-east of Diddup Burn /NS 2671 4480/. It is a dark grey, medium to fine-grained limestone, dipping to the south-east at 25°. Above the Lower Linn Limestone are occasional outcrops of sandstone with the Upper Linn Limestone cropping out in a quarry 240 m north-east of Diddup Farm /NS 2670 4469/ and by Diddup Farm itself /NS 2658 4448/. The Upper Linn Limestone is here a brownish grey limestone over 3 m thick with a marine fauna, on 1.00 m dark grey silty mudstone, 0.7 m medium-grained sandstone, 0.15 m dark grey siltstone to silty mudstone and 0.15 m coal.

Above the Upper Linn Limestone the strata are generally sandy with, 140 m south of Diddup Farm /NS 2657 4440/, a thin irony limestone cropping out. This horizon is tentatively correlated with the Diddup Limestone of the Diddup Borehole. Above the Diddup Limestone are intermittent outcrops of sandstone which begin to dip to the north-west as opposed to the south-east dips in the earlier part of the section. It is suspected that a fault crops out immediately to the south of the Diddup Limestone.

Glen Burn: Little rock is seen in the upper part of the Glen Burn (fig. 8.6) and here isolated exposures of the Third Post Limestone /NS 2602 4405/ and the Lower Linn Limestone /NS 2605 4404/ occur with some sandstone between. The strata dip steeply to the


DIDDUP BURN &
GLEN BURN SECTIONS
Lower
Linn Lst
Upper
Linn Lst
quarry
Diddup
Farm
Upper Linn Lst
Diddup Lst
Third Post Lst
Lower Linn Lst
Upper Linn Lst
breccia
GLEN BURN
Diddup Borehole
Lavas of
Passage Group age
N
0
100
200
300 Metres

south-east at around 40° and about 50 m downstream from the Lower Linn Limestone the Upper Linn Limestone crops out /NS 2607 4490/. The Upper Linn Limestone is here a dark grey, argillaceous limestone with a pronounced joint pattern and rests directly on sandstones. About 20 m downstream from the Upper Linn Limestone /NS 2606 4497/ and at a higher stratigraphic level is a band of breccia with angular fragments of limestone, sandstone and siltstone. No limestones are found in the Glen Burn at a stratigraphic level higher than the Upper Linn Limestone and the limestone fragments in the breccia are thought to be the eroded remnants of the Diddup Limestone as exposed in the Diddup Burn. Above the breccia sandstones and siltstones lying beneath basaltic lavas may be of Passage Group age.

Ardrossan Harbour: At Ardrossan Harbour (fig. 8.5) a major north-westerly fault downthrows to the south-west. On the downthrow side, 40 m north-west of Castle Craigs /NS 224 417/, a sequence of strata compares lithologically with those of the Upper Limestone Group. The section is shown in table 8.1 with the limestones correlated on a tentative basis as neither the lithological sequence nor the faunas match those developed elsewhere in the Dalry Basin. It should be noted that at the top of the Upper Linn Limestone lateral variation in lithology can be traced along bedding planes from limestone to sandstone.

Lugton Water: The section in the Lugton Water (fig. 8.7) extends from 300 m east of Bridgend of Montgreenan /NS 3490 4558/ downstream to 460 m west of Montgreenan Cottage /NS 3422 4507/. The Index

TABLE 8.1

Section in the Upper Limestone Group at Ardrossan Harbour /NS 224 417/

	Thickness (metres)
Dolerite sill	
Sandstone, medium to fine grained, light grey with dark grey plant remains, massive, well jointed	0.90
Sandstone, medium to fine grained, massive, siliceous	1.80
Sandstone, medium grained, dark grey, rusty weathery patches	1.20
Siltstone, dark grey, rather sandy, massive	0.80
Sandstone, fine grained, light grey with dark grey silty laminae, some bioturbation	2.10
Sandstone, fine grained, flaggy passes laterally into limestone near base	3.70
Upper Linn Limestone: limestone, brownish grey and massive with differentially weathered surfaces, marine fauna	3.20
mudstone, calcareous dark grey with abundant brachiopods	0.60
Sandstone, medium grained, medium grey, patchy with calcareous nodules, thin-bedded to base	2.50
Sandstone, medium grained, brownish grey	2.50
Lower Linn Limestone: mudstone, calcareous, dark grey, poorly bedded with rich marine fauna	0.90
GAP	
Sandstone, medium grained, brownish grey, well bedded	2.10
Third Post Limestone: mudstone, calcareous, dark grey, poorly bedded, frequent calcareous concretions	1.00+

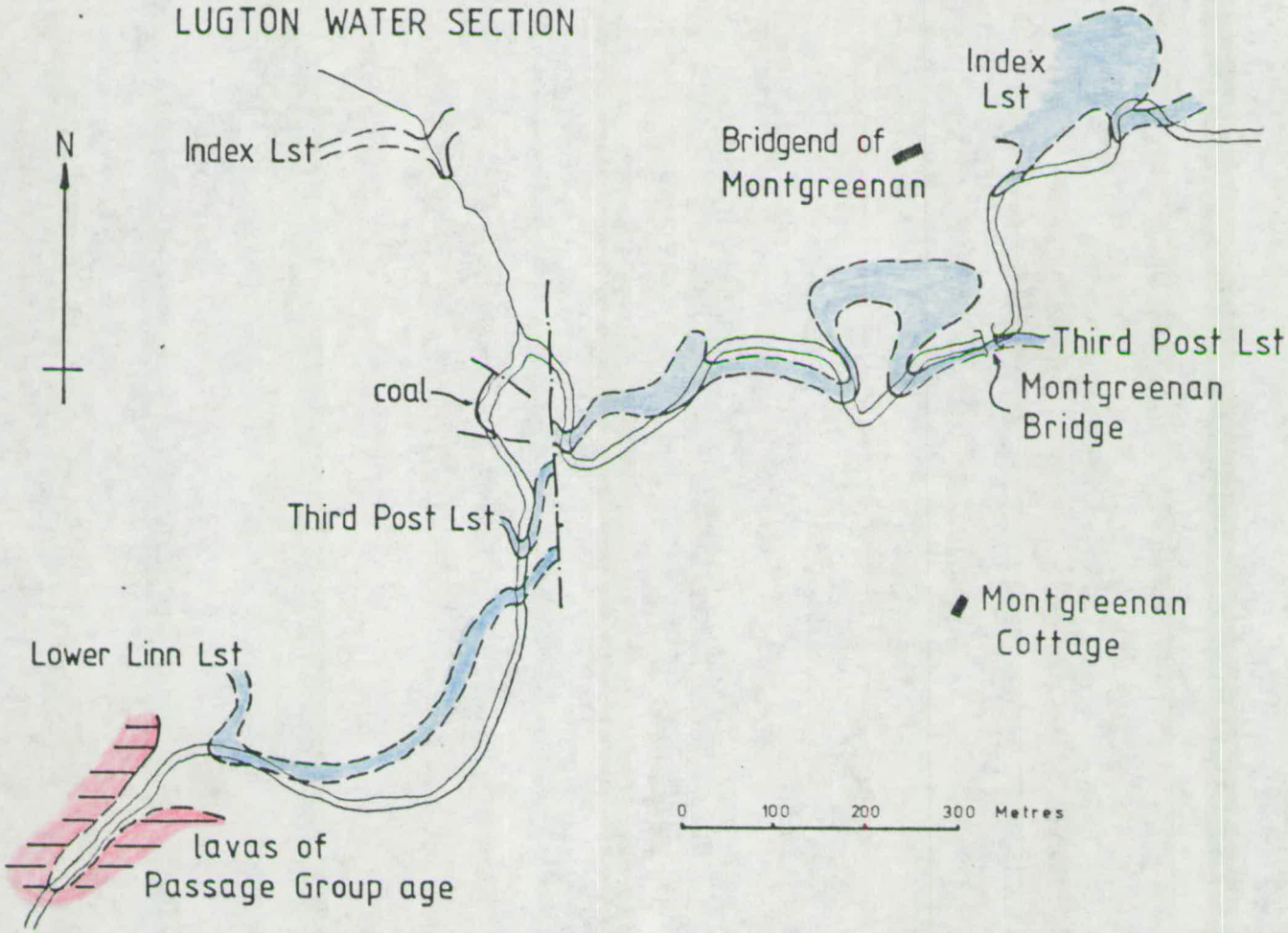

LUGTON WATER SECTION
N
Index Lst
Index
Lst
Bridgend of
Montgreenan
coal
Third Post Lst
Montgreenan
Bridge
Third Post Lst
Montgreenan
Cottage
Lower Linn Lst
lavas of
Passage Group age
0
100
200
300 Metres

Fig. 8.7

Limestone is exposed in the Lugton Water at the base of the section east of Bridgend of Montgreenan. It consists of 2.00 m of dark grey calcareous mudstone and 1.1 m of dark grey argillaceous limestone on dark grey mudstone and carries a marine fauna. Between the Index Limestone outcrop and the Montgreenan Bridge where the Third Post Limestone crops out, the strata are largely sandstones with subordinate siltstones, the sandstones becoming rooty upwards.

The Third Post Limestone is exposed at Montgreenan Bridge /NS 3472 4534/ and at various points in the Lugton Water westwards until a fault is encountered 470 m west of Montgreenan Bridge. The general trend of the valley of the Lugton Water is westwards along the strike of the Third Post Limestone. It is a medium to dark grey limestone, about 1.1 m thick with calcareous mudstone laminae. The strata immediately above and below are largely sandstones with subordinate siltstones.

A N-S trending fault occurs 470 m west of Montgreenan Bridge /NS 3425 4532/ downthrowing the Third Post Limestone to the east. Immediately to the west of the fault the strata above the Third Post Limestone are generally silty sandstones and are poorly exposed with the Lower Linn Limestone cropping out as a hard, dark grey limestone with pronounced rectangular jointing 460 m west of Montgreenan Cottage /NS 3421 4507/.

The outcrop sections described above givea stratigraphic framework for further sub-surface study. It is apparent that the same sequence of marine horizons is not present everywhere in the Dalry Basin but the strata between the marine horizons is not sufficiently well exposed to allow a pattern of sedimentation to be identified.

8.4 Upper Limestone Group - borehole data

IGS drilling (1976-78) proved the thickness and sequence of the Upper Limestone Group strata in four boreholes at Diddup, Hullerhirst, Kilmaurs and Montgreenan. The principal features of the sequences encountered can be seen from the following tables 8.2 to 8.5 in conjunction with the graphic plots of the borehole strata in figures 8.8 to 8.11. Each of these sections can be seen in geographical relationship in fig. 8.12.

Diddup Borehole: This borehole proved the thickest and most complete sequence developed in the Dalry Basin. It is dominantly sandy but marine limestones and calcareous mudstones occur at, at least, six stratigraphic positions. The youngest marine strata encountered in the borehole were silty mudstones with shell traces at 5.40 m. Their age is uncertain but they have been placed tentatively in the Passage Group. The Corsankell Limestone at 56.56 m is considered to be of Upper Limestone Group age and an arbitrary boundary for the top of the Upper Limestone Group is taken at 53.70 m (see chapter 8.2).

The lithologies present in all the marine sequences in the Diddup Borehole are similar. Each limestone is medium to dark grey, usually with calcareous mudstone bands and often, in part, nodular. The strata between these limestones are variable, though the Lower Linn Limestone has a distinctive series of mudstones and silty mudstones with a marine fauna in its roof. Elsewhere the strata are mostly sandstones with subordinate siltstones and mudstones and while coals are not common seatearths are commonly developed at the top of sandstone units. Cyclicity within the sequence will be studied in greater detail later (see chapter 8.7).

TABLE 8.2

Upper Limestone Group in the Diddup Borehole /NS 2651 4406/

	Depth (metres) from	to
Passage Group Volcanic Formation		28.28
COAL, bright with dull patches	28.28	28.78
Mudstone, black, carbonaceous, with coaly stringers	28.78	29.03
Seatearth, dark brownish-grey, soft and friable	29.03	29.43
Sandstone, medium to fine-grained, light brownish grey, friable with silty patches, some bioturbation, occasional roots to base	29.43	34.20
Seatearth, dark grey, carbonaceous in places, tough, compact	34.20	35.10
Seatclay, dark brownish grey, hard, compact with a sub-concoidal fracture, some dark grey roots	35.10	36.20
Sandstone, medium grained, light grey to white, friable, wispy silty laminae to base	36.20	42.55
Siltstone, medium grey, micaceous, well bedded, occasional plant fragments	42.55	43.35
Sandstone, medium grained, medium grey to white, occasional silty laminae	43.35	45.75
Siltstone, medium grey, micaceous, some sandy bands, fine plant debris	45.75	46.30
Sandstone, medium to fine grained, white, hard and compact but friable in places	46.30	49.05
Siltstone, dark grey, unbedded, tough with irony ribs	49.05	49.50
Mudstone, silty, dark grey, bedded, shell traces	49.50	50.40
Sandstone, medium grained, light grey, hard, frequent plant scraps, roots near top	50.40	52.00
Siltstone, medium grey, micaceous, bedded, frequent plant scraps	52.00	52.30
Sandstone, medium grained, medium to light grey, bioturbated at top	52.30	53.70
Siltstone, medium grey, bedded, occasional listric surfaces and plant impressions	53.70	55.85

TABLE 8.2 (cont'd)

	Depth (metres) from	to
Corsankell Limestone: limestone, medium grey, argillaceous, abundant brachiopods	55.85	56.56
Sandstone, medium to fine-grained, medium grey, rounded clasts and roots at top, some red and brown mottling	56.56	59.80
Seatclay, medium grey with olive tinge, listric surfaces	59.80	60.15
Sandstone, medium to fine-grained, light to medium grey, silty, trace tracks near base	60.15	63.20
Siltstone, medium grey, well bedded	63.20	63.51
Mudstone, dark grey, well bedded	63.51	64.70
Diddup Limestone: limestone, dark grey, argillaceous, calcareous, mudstone to base, sandy from 65.50 to 65.95	64.70	67.60
Siltstone, dark grey, well bedded, pyritous burrows	67.60	70.06
Mudstone, silty, dark grey, micaceous	70.06	70.30
Sandstone, medium-grained, medium grey with dark grey silty micaceous laminae	70.30	70.92
Seatearth, light grey with brownish tinge	70.92	71.82
Sandstone, medium grained, light grey, occasional irony concretions	71.82	73.20
Siltstone, light greenish grey, abundant sphaerosiderite, tough, compact	73.20	73.65
Sandstone, white, fine-grained, hard and massive	73.65	73.74
Seatclay, light grey with olive tinge, abundant listric surfaces, soft and broken	73.74	76.94
Upper Linn Limestone: limestone, medium grey, fine grained, hard, compact, concretionary at top, rich marine fauna	76.94	92.40
Sandstone, medium dark grey, medium grained, rooty, silty and bioturbated near base	92.40	93.60
Mudstone, silty, dark grey, poorly bedded, finely micaceous	93.60	94.30

TABLE 8.2 (cont'd)

	Depth (metres) from	to
Sandstone, medium grained, medium grey, bedded with silty laminae	94.30	95.50
Mudstone, dark grey, silty in places, listric surfaces, carbonaceous to base	95.50	95.90
Seatearth, light grey, dark and carbonaceous top 15 cm	95.90	96.35
Seatclay, medium grey, silty	96.35	96.70
Sandstone, medium grained, light grey with dark grey silty laminae, occasional slump structures	96.70	100.84
Mudstone, silty, dark grey, well bedded, some sandy laminae, frequent listric surfaces	100.84	101.25
Sandstone, medium grained, medium grey, abundant dark grey silty laminae and bands, some slump structured and brecciation, roots near base	101.25	107.04
Siltstone, dark grey, well bedded, micaceous, roots at top, plant fragments	107.04	107.64
Mudstone, silty, dark grey, well bedded, micaceous	107.64	108.14
Seatearth, dark grey, silty, micaceous, unbedded	108.14	108.74
Sandstone, medium grained, light grey, micaceous with silty wisps, silty laminae becoming common with small scale ripple lamination	108.74	112.36
Siltstone, medium grained, well bedded, frequent ripple lamination, some slumping and brecciation, micaceous, occasional ironstone nodules	112.36	115.07
Mudstone, dark grey becoming medium grey, silty in places with fine micas, occasional small irony nodules and fine carbonate veinlets, marine fauna from 117.15 metres	115.07	120.33
Lower Linn Limestone: limestone, medium to dark grey, argillaceous, nodular in places, calcareous mudstone bands, rich marine fauna	120.33	129.08
Coal, dull, muddy	129.08	129.16
Seatearth, medium grey with light olive grey seatclay bands, frequent sphaerosiderite, structureless	129.16	132.10

TABLE 8.2 (cont'd)

	Depth (metres) from	to
Sandstone, light to medium grey, medium grained, micaceous, rooty, bedded in places	132.10	133.30
Seatclay, medium grey, silty, frequent micas, abundant listric surfaces	133.30	134.10
Sandstone, medium grained, light grey with dark grey silty laminae, irregular bedding	134.10	134.51
Mudstone, dark grey, silty, micaceous	134.51	134.59
Sandstone, medium grained, medium grey with dark grey silty laminae, bioturbated	134.59	134.76
Mudstone, dark grey, silty, micaceous	134.76	134.86
Sandstone, medium grained, medium grey, silty, extensive bioturbation	134.86	135.39
Mudstone, silty, dark grey, bedded but with some burrows	135.39	135.64
Third Post Limestone: limestone and calcareous mudstone, dark grey, silty with fine micas, nodular to base, rich marine fauna	135.64	140.00
Mudstone, dark grey, silty, bedded	140.00	140.58
Siltstone, dark grey, micaceous, hard, compact	140.58	140.86
Mudstone, dark grey, silty at top, well bedded, occasional pyrite knots, fine coaly streaks to base	140.86	141.93
Siltstone, dark grey, well bedded, occasional sandy bands and laminae, occasional plant scraps	141.93	143.24
Sandstone, medium grained, light grey, bedded, occasional dark grey silty laminae	143.24	147.12
Mudstone, silty, dark grey, bedded	147.12	147.15
Sandstone, medium grained, light grey, micaceous, occasional thin silty bands and laminae, siltstone pellets to base	147.15	149.77
Mudstone, dark grey with a brownish tinge, listric surfaces	149.77	150.17
Seatclay, dark grey, micaceous, structureless, irregular base	150.17	150.33

TABLE 8.2 (cont'd)

	Depth (metres) from	to
Sandstone, medium grained, light grey with dark grey fine sandy laminae	150.33	153.70
Mudstone, dark grey, silty, bedded, finely micaceous, frequent plant scraps, occasional bands with listric surfaces	153.70	154.37
Seatclay, dark grey with brownish tinge, silty, frequent listric surfaces	154.37	154.57
Seatearth, brownish grey, micaceous, hard, compact	154.57	155.66
Mudstone, dark grey becoming medium grey, silty at top, poorly bedded, abundant sphaerosiderite	155.66	158.30
Mudstone, brownish red and olive green mottled, poorly bedded, abundant sphaerosiderite, tuffaceous	158.30	159.87
Index Limestone: limestone, light brownish grey, nodular with olive green argillaceous matrix, marine fauna	159.87	161.70

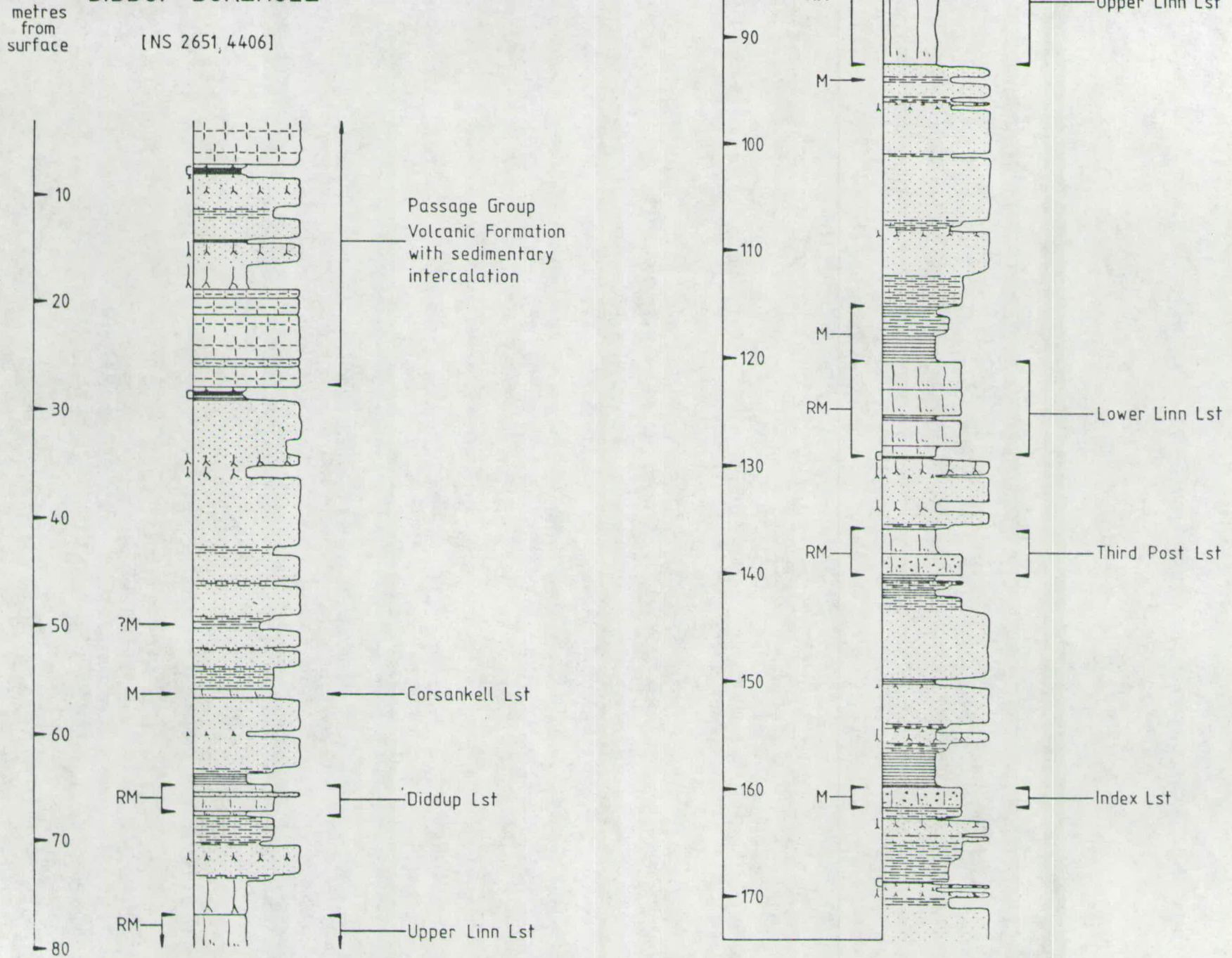

metres from surface
[NS 2651, 4406]
10
20
30
40
50
60
70
80
90
100
110
120
130
140
150
160
170
?M
M
RM
Passage Group
Volcanic Formation
with sedimentary
intercalation
Corsankell Lst
Diddup Lst
Upper Linn Lst
Lower Linn Lst
Third Post Lst
Index Lst

Fig. 8.8

TABLE 8.3

Upper Limestone Group in the Hullerhirst Borehole /NS 2730 4260/

	Depth (metres) from	to
Passage Group Volcanic Formation		11.20
Seatclay, light brownish grey, dark grey roots, some wispy silty laminae and fine coaly partings	11.20	13.60
Sandstone, fine-grained, light brownish grey	13.60	13.70
Seatclay, light grey with brownish tinge	13.70	13.85
Sandstone, light grey, fine-grained, rare fine roots, poorly bedded	13.85	15.25
Mudstone, light greenish grey	15.25	15.40
Sandstone, light grey, fine-grained, irony nodules near top	15.40	15.80
Mudstone, silty, dark grey, finely micaceous, occasional listric surfaces, poorly preserved marine fauna	15.80	16.12
Sandstone, medium to fine-grained, medium dark grey, carbonaceous in places, coalified plant fragments, occasional patches of pyrite	16.12	16.50
Mudstone, dark grey, carbonaceous	16.50	16.52
Seatclay, light olive grey, some bedding	16.52	17.08
Seatearth, light grey	17.08	17.45
Sandstone, fine-grained, poorly bedded, irony with a brownish tinge, wispy silty laminae	17.45	19.35
Siltstone, dark grey, bedded with lighter sandy patches	19.35	19.45
Sandstone, dark grey, medium grained, becoming light grey with dark grey wispy,silty laminae, intensely burrowed in places	19.45	22.23
Siltstone, dark grey, bedded	22.23	22.58
Sandstone, medium grained, light grey, occasional silty laminae and bands, some small scale ripple lamination, sharp erosive base	22.58	23.77

TABLE 8.3 (cont'd)

	Depth (metres) from	to
Siltstone, dark grey, poorly bedded, becoming well bedded, micaceous	23.77	23.97
Mudstone, silty, dark grey	23.97	24.00
Sandstone, medium-grained, light grey, dark grey silty laminae, some ripple lamination	24.00	24.35
Mudstone, silty, dark grey, poorly bedded	24.35	24.42
Sandstone, medium-grained, light grey with dark grey silty laminae and bands	24.42	24.70
Mudstone, silty, dark grey, well bedded, occasional plant fragments	24.70	24.77
Siltstone, dark grey, well-bedded with sandy ribs and laminae, occasional plant fragments, some ripple lamination, micaceous	24.77	25.50
Mudstone, silty, dark grey, well bedded, micaceous, small irony nodules, rich marine fauna	25.50	28.55
Lower Linn Limestone: limestone and calcareous mudstone, dark grey, argillaceous with a rich marine fauna	28.55	33.00
Seatearth, light brownish grey with dark grey roots, frequent pyrite	33.00	33.55
Sandstone, light brownish grey, fine-grained with occasional irregular joints, sharp erosive base	33.55	34.90
Seatclay, light grey-brown becoming light grey, sandy patches	34.90	35.25
Sandstone, light grey, fine-grained with muddy patches, occasional patches of sphaerosiderite, becoming medium-grained with thin sulphide stringers near base, quartz pebbles at base	35.25	38.00
Siltstone, light brownish grey becoming olive grey, bedded with fine sandy laminae	38.00	38.30
Mudstone, silty, dark grey, micaceous, marine fauna	38.30	38.50

TABLE 8.3 (cont'd)

	Depth (metres) from	to
Third Post Limestone: calcareous mudstone and argillaceous limestone, dark grey, nodular in places, marine fauna	38.50	40.65
Sandstone, dark grey, hard and compact	40.65	40.85
Siltstone, dark grey, well bedded, micaceous with Lingula sp.	40.85	41.05
Sandstone, medium-grained, medium grey with dark grey silty laminae, bioturbated, rare Lingula sp.	41.05	42.35
Mudstone, dark grey becoming very dark grey with poorly preserved Estheria to base	42.35	43.40
Siltstone, dark grey, bedded, micaceous, frequent burrows	43.40	43.50
Basalt, dark greenish grey, fine-grained top 30 cm	43.50	45.20
Sandstone, medium-grained, medium grey becoming light grey with dark grey silty laminae, hard and compact to base	45.20	47.30
Siltstone, dark grey, well bedded, micaceous with thin fine light grey sandy laminae, occasional burrows	47.30	47.95
Sandstone, medium-grained, light grey with brownish tinge, bedded, some fine silty carbonaceous laminae	47.95	48.25
Mudstone, silty, dark grey, well bedded with frequent plant fragments	48.25	49.38
Index Limestone: limestone, dark grey with a brownish tinge, hard, compact, marine fauna	49.38	49.96

HULLERHIRST BOREHOLE

[NS 2730 4260]

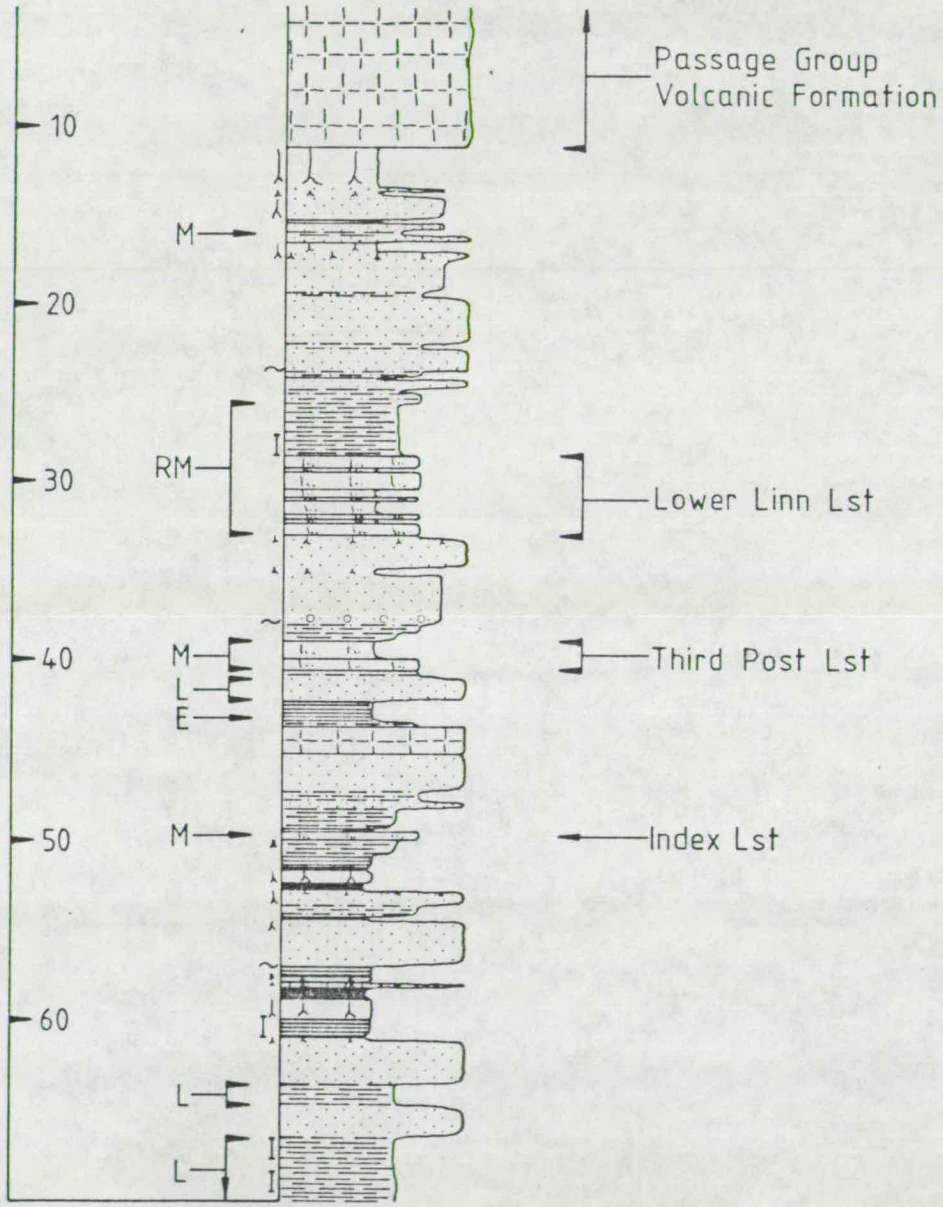


TABLE 8.4

Upper Limestone Group in the Kilmaurs Borehole /NS 3955 4124/

	Depth (metres) from	to
Mudstone, light olive grey, poorly bedded, occasional roots, some mottling	13.67	13.72
Sandstone, medium to fine-grained, yellowish-grey, unbedded becoming bedded with irregular dark grey silty laminae, small coalified plant scraps	13.72	14.40
Seatearth, light olive grey with medium dark grey mottling, structureless	14.40	14.60
Sandstone, fine-grained becoming medium-grained, greenish-grey, rare fine roots	14.60	15.40
Mudstone, greenish-grey, poorly bedded, occasional listric surfaces, some sphaerosiderite	15.40	17.36
Sandstone, fine-grained, light yellowish-brown with dark grey irregular carbonaceous laminae, hard, irony	17.36	17.56
Siltstone, dark grey, micaceous with light grey fine sandy ribs and laminae near top	17.56	19.05
Mudstone, dark grey, silty at top, frequent listric surfaces and ironstone nodules, rich marine fauna	19.05	22.70
Lower Linn Limestone: limestone and calcareous mudstone, medium dark grey, argillaceous, steep carbonate stringers, rich marine fauna	22.70	24.40
Sandstone, medium grained, medium dark grey becoming yellowish grey with medium grey mottling, occasional silty laminae	24.40	28.25
Mudstone, dark grey, silty and light olive grey at top, occasional listric surfaces, occasional roots or burrows, marine fauna	28.25	30.40
Third Post Limestone: limestone, medium dark grey, argillaceous at top, hard, compact with marine fauna	30.40	31.52
Sandstone, medium grained, dark grey, compact	31.52	31.77

TABLE 8.4 (cont'd)

	Depth (metres) from	to
Seatearth, medium to dark grey, frequent silty laminae, plant fragments	31.77	32.20
Sandstone, medium grained, light grey, silty laminae and bands	32.20	33.00
Siltstone, dark grey with fine sandy laminae, frequent plant scraps	33.00	33.60
Mudstone, silty, medium dark grey, bedded, frequent plant scraps, some pyritised burrows, micaceous	33.60	34.30
Sandstone, medium-grained, light grey, occasional yellowish grey micaceous laminae, frequent plant scraps	34.30	37.50
Mudstone, dark grey, black and carbonaceous to base with fine coal partings	37.50	38.25
Sandstone, medium-grained, light grey, dark grey silty laminae, rooty, frequent plant scraps	38.25	39.10
Siltstone, dark grey, micaceous, bedded, frequent plant scraps	39.10	39.30
Coal, dull with muddy partings, pyritous	39.30	39.65
Seatclay, dark grey to olive grey, lipy	39.65	39.95
Seatearth, medium grey with dark grey roots	39.95	40.45
Sandstone, medium grained, medium grey with dark grey silty micaceous laminae, plant scraps	40.45	40.55
Siltstone, medium dark grey, micaceous, bedded, ironstone bands and nodules	40.55	40.95
Mudstone, dark grey, black and silty in places, frequent plant scraps, fine sandy laminae to base	40.95	41.45
Sandstone, medium-grained, light grey, bedded, occasional silty wisps and laminae	41.45	45.70
Sandstone, light grey, coarse-grained, feldspathic with quartz pebbles, becoming very coarse grained to base	45.70	56.20

KILMAURS BOREHOLE

[NS 3955 4124]

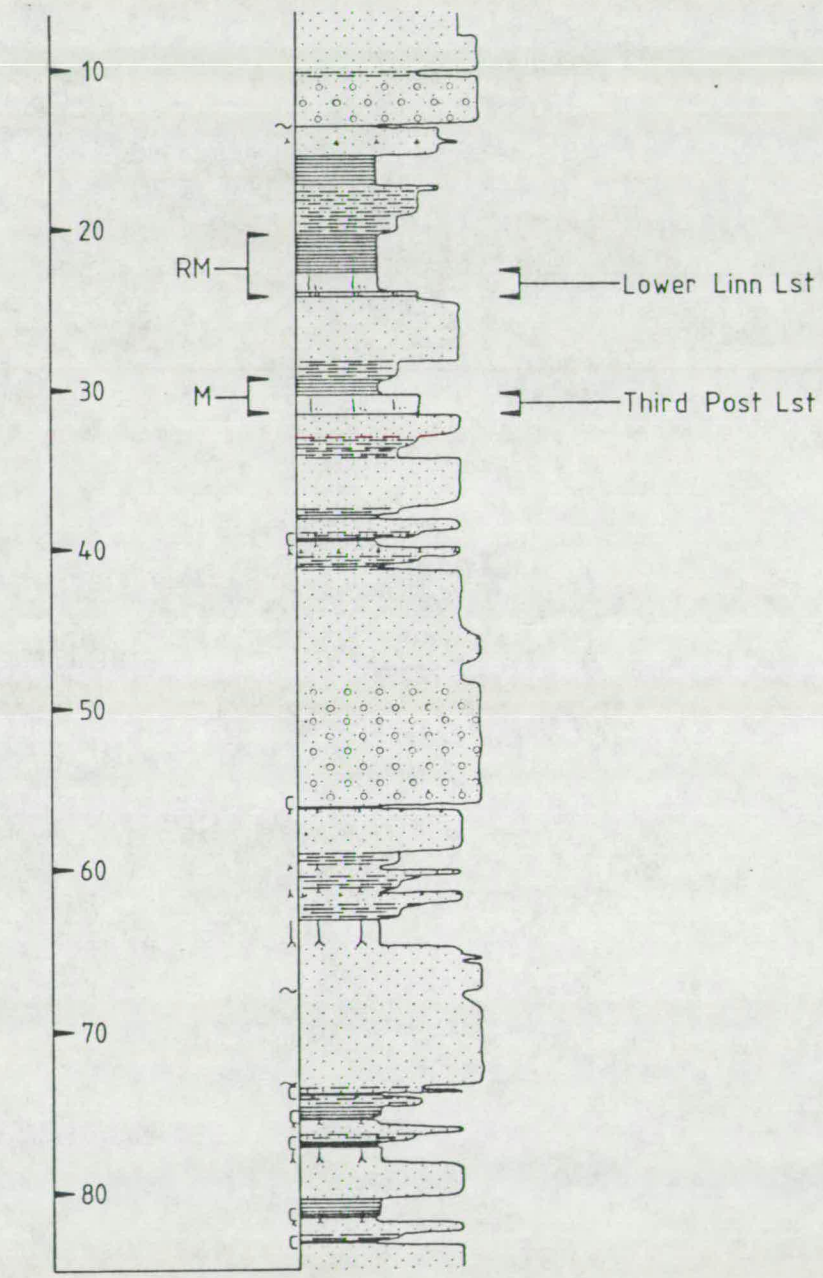


TABLE 8.5

Upper Limestone Group in the Montgreenan Borehole /NS 3503 4523/

	Depth (metres) from	to
Passage Group Volcanic Formation		4.55
Mudstone, light grey becoming red and green mottled, structureless, sphaerosiderite	4.55	6.35
Sandstone, greenish grey, fine-grained, weathered	6.35	8.60
Mudstone, olive grey with red and yellow mottling	8.60	8.75
Sandstone, fine-grained, light grey becoming greenish grey	8.75	9.70
Mudstone, greenish grey with yellowish mottling, becoming grey, abundant sphaerosiderite	9.70	11.90
Siltstone, dark grey, well bedded, micaceous, sandy ribs and laminae, plant scraps	11.90	12.45
Mudstone, silty, dark grey, well bedded, micaceous, frequent plant scraps, rich marine fauna	12.45	17.25
Lower Linn Limestone: Limestone and calcareous mudstone, dark grey, argillaceous with a marine fauna	17.25	18.95
Sandstone, medium grey, compact, hard, siliceous with some roots	18.95	19.18
Seatearth, light grey with olive tinge, structureless	19.18	20.50
Sandstone, medium-grained, light grey becoming medium grey with silty laminae, micaceous, abundant sphaerosiderite	20.50	21.90
Siltstone, medium grey, bedded, micaceous with sphaerosiderite, some fine sandy laminae	21.90	22.50
Mudstone, silty, medium grey, becoming dark grey, bedded, rich marine fauna	22.50	24.30
Third Post Limestone: limestone and calcareous mudstone, medium to dark grey, argillaceous, hard, marine fauna	24.30	25.68
Sandstone, medium-grained, medium grey, becoming light grey with occasional dark grey silty laminae	25.68	28.90

TABLE 8.5 (cont'd)

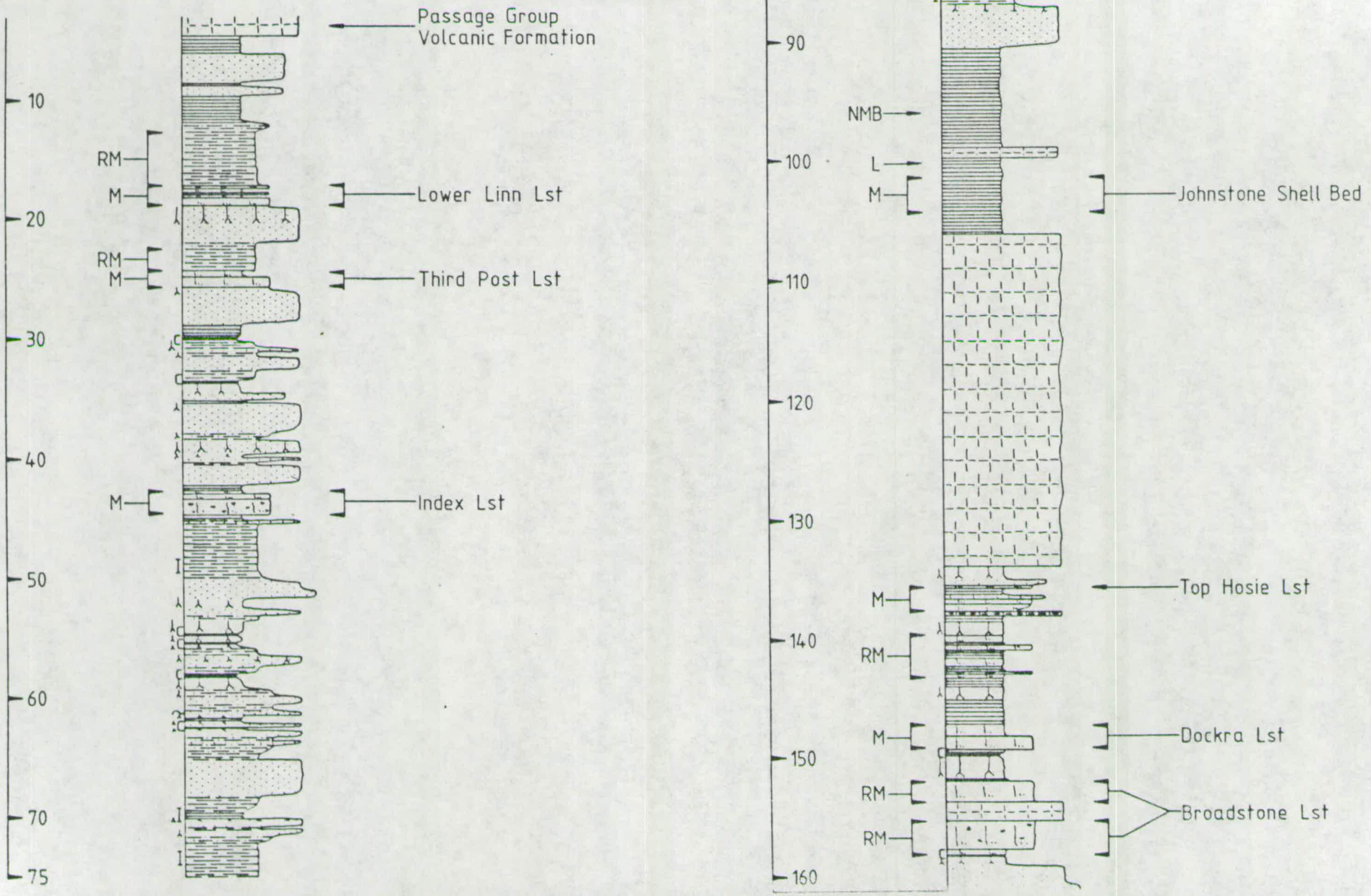
	Depth (metres) from	to
Mudstone, dark grey, silty in places, well bedded, finely micaceous, pyrite burrows and knots	28.90	29.88
COAL, dull	29.88	30.06
Mudstone, silty, dark grey, bedded, frequent roots and plant scraps, micaceous	30.06	30.73
Sandstone, medium-grained, medium grey with dark grey silty patches and laminae, abundant plant scraps, irony	30.73	30.93
Mudstone, silty, dark grey, bedded, frequent roots, micaceous	30.93	31.07
Sandstone, medium-grained, brownish grey with dark grey silty patches and laminae, micaceous	31.07	31.17
Mudstone, silty, dark grey, bedded, occasional roots, occasional plant scraps	31.17	31.46
Sandstone, medium grained, light grey, bedded, abundant dark grey silty laminae	31.46	31.52
Mudstone, silty, dark grey, well bedded, frequent sandy ribs, micaceous	31.52	33.50
COAL, dull with bright patches	33.50	33.70
Seatclay, dark brownish grey, soft and structureless	33.70	34.60
Sandstone, fine-grained, silty, brownish grey, poorly bedded, micaceous	34.60	34.94
Mudstone, dark grey, rooty, finely micaceous, some bedding	34.94	35.29
Sandstone, medium grained, light grey, abundant dark grey silty wisps and laminae at top	35.29	37.82
Siltstone, dark grey, micaceous, light grey sandy ribs and laminae, rooty	37.82	38.07
Mudstone, silty, dark grey, finely micaceous, well bedded	38.07	38.18
Seatearth, medium to fine-grained, brownish grey with light grey bands at top, rooty, structureless, abundant sphaerosiderite	38.18	39.57

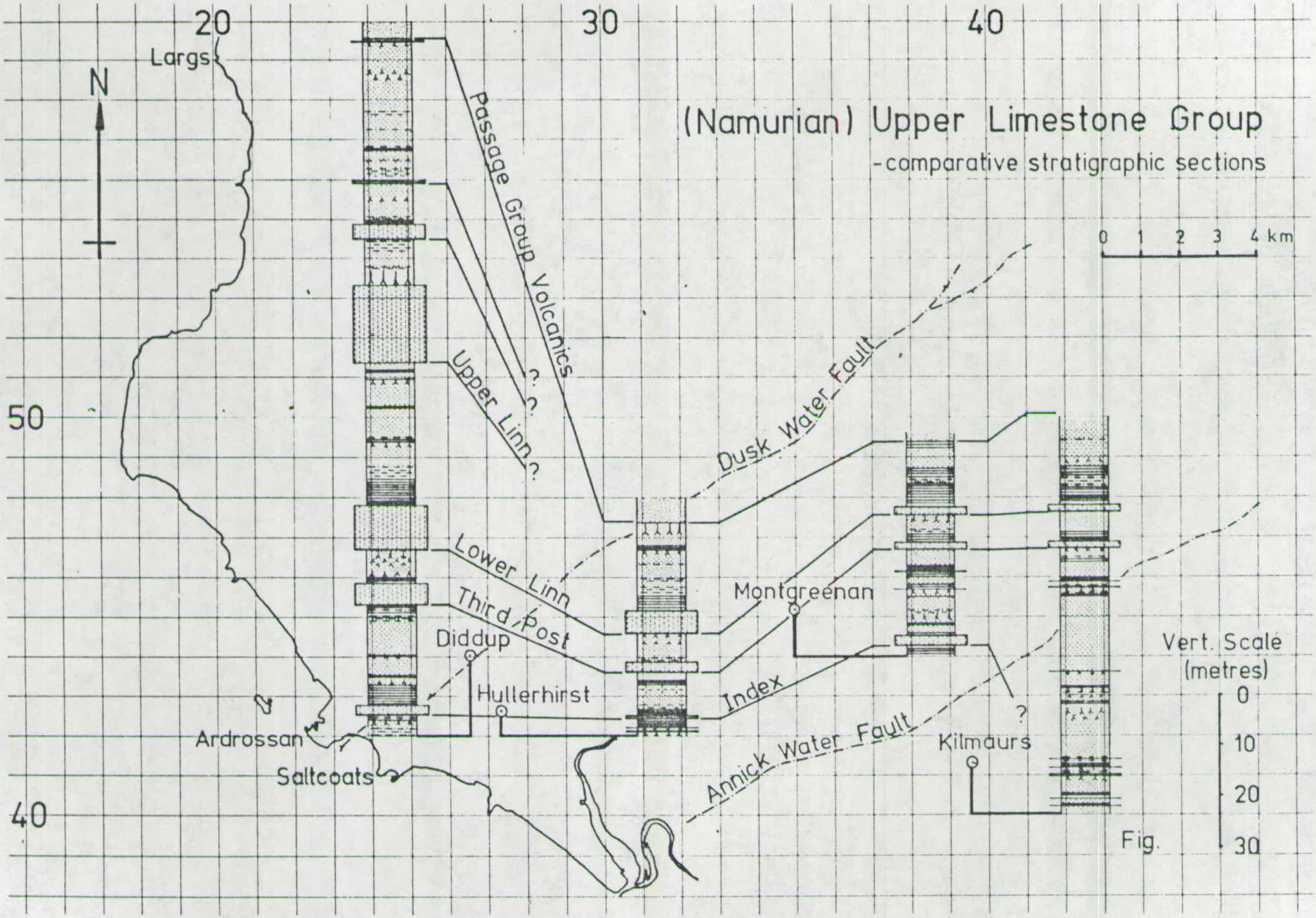
TABLE 8.5 (cont'd)

	Depth (metres) from	to
Seatclay, light olive grey with thin sandy bands, sphaerosiderite	39.57	39.85
Sandstone, medium-grained, light grey, bedded, some siltstone ribs	39.85	40.18
Mudstone, silty, dark grey, well bedded, finely micaceous, irony nodules	40.18	40.54
Sandstone, medium-grained, light grey with occasional dark grey silty ribs and laminae, coalified plant scraps and coaly stringers near base	40.54	42.17
Mudstone, dark grey, well bedded, occasional listric surfaces, marine fauna	42.17	42.58
Index Limestone: calcareous mudstone and limestone dark grey, argillaceous, nodular with marine fauna	42.58	44.82

MONTGREENAN BOREHOLE

[NS 3503 4523]




20
30
40
50
40
N
Largs
(Namurian) Upper Limestone Group
-comparative stratigraphic sections
0 1 2 3 4 km
Passage Group Volcanics
Upper Linn ?
Dusk Water Fault
Lower Linn
Third/Post
Index
Diddup
Hullerhirst
Montgreenan
Ardrossan
Saltcoats
Annick Water Fault
Kilmaurs
?
Vert. Scale
(metres)
0
10
20
30
Fig.

Hullerhirst Borehole: The site of the Hullerhirst Borehole is about 2 km SSE of the Diddup Borehole. It also starts in the Passage Group Volcanic Formation and finishes below the Index Limestone yet, the sequence represented is markedly different.

The top part of the sedimentary succession from the base of the Passage Group Volcanic Formation to around 23.77 m is very similar to the sequence of sediments in the Diddup Borehole which were attributed to the Passage Group. The lithologies are largely sandstones and seatearths with a silty mudstone band with marine fossils, thought to be of Passage Group age at 16.12 m. Using the arbitrary criteria described previously, the top of the Upper Limestone Group is taken at 23.77 m.

The topmost limestone in the Upper Limestone Group at 33.0 m is a dark grey argillaceous limestone with calcareous mudstone bands and a roof consisting of silty mudstones with a rich marine fauna. This limestone is correlated on a lithostratigraphic basis with the Lower Linn Limestone, a correlation confirmed by palaeontology (Wilson pers comm).

The other two marine limestones present at 40.65 m and 49.96 m are correlated with the Third Post and Index Limestones respectively. The intervening strata are comparable in lithology to equivalent strata in the Diddup Borehole though having some coarser sandstone bands.

Kilmaurs Borehole: The Kilmaurs Borehole, about 13 km east of Hullerhirst, starts in sediments immediately below the Passage Group Volcanic Formation. A former quarry into basaltic lavas occurs about 10 m to the south of the site, down dip. The marked erosive base of coarse-grained sandstones occurs at 13.67 m and, although

there are no marine horizons these are thought to be of Passage Group age, and the beds below to be of Upper Limestone Group age.

The topmost marine horizon in the Upper Limestone Group is the Lower Linn Limestone at 24.40 m, medium to dark grey calcareous mudstones and limestones with a rich marine fauna extending up into the overlying mudstones. The strata below the Lower Linn Limestone are sandstones fining downwards into silty mudstones, mudstones and, at 31.52 m, the Third Post Limestone, a medium dark grey argillaceous limestone with a marine fauna.

Below the Third Post Limestone are a series of sandstones, coarse in places with subsidiary siltstones and silty mudstones. Lithologies typical of the Limestone Coal Group occur from 73.60 m downwards. The base of the Upper Limestone Group is, in the absence of the Index Limestone, taken arbitrarily at the base of the coarse sandstone unit at 56.20 m. In this borehole the Index Limestone appears to have been replaced by coarse sandstones.

Montgreenan Borehole: The Montgreenan Borehole was drilled at a site midway between the Hullerhirst and Kilmaurs boreholes. The sediments immediately below the Passage Group Volcanic Formation from 4.55 m to 11.90 m are fine-grained sandstones and mudstones, greenish grey in colour with some red and grey mottling. The age of these strata is unknown as no fossiliferous horizons are present but the lithologies and colours are more typical of Passage Group than of Upper Limestone Group rocks. The Lower Linn Limestone occurs at 18.95 m as a dark grey, argillaceous limestone and calcareous mudstone with a marine fauna and a rich marine fauna in the silty mudstones of the roof. The top of the Upper Limestone Group is therefore taken arbitrarily at 9.70 m at the base of a sandstone unit.

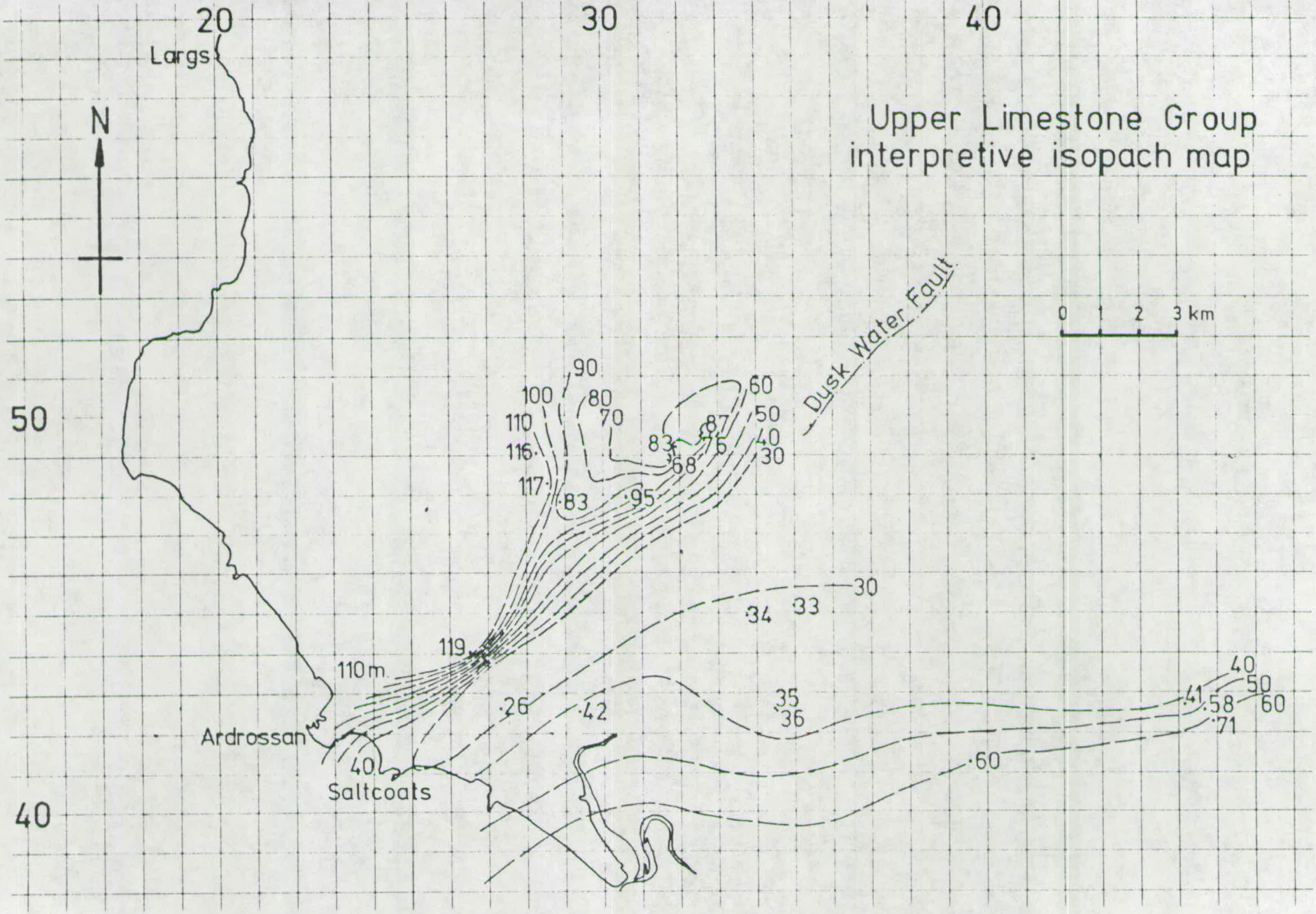
The Third Post Limestone consisting of medium to dark grey argillaceous limestone and calcareous mudstone with a marine fauna occurs at 25.68 m with silty mudstone in the roof with a rich marine fauna. These lithologies coarsen upwards into sandstones. The Index Limestone occurs at 44.82 m as marine calcareous mudstone and nodular argillaceous limestone. The strata between the Index and Third Post limestones is generally sandy with occasional coals developed.

The main features of the sequence which are highlighted by the IGS drilling can be summarised as follows:-

1. There is a variation in the thickness of the Upper Limestone Group across the Dalry Basin.
2. The number of marine horizons present in the Upper Limestone Group varies across the Dalry Basin.
3. There is some evidence of cyclicity in the vertical pattern of sediment distribution.
4. There is little variation in the limestone lithologies.

8.5 Thickness variation in the Upper Limestone Group

An isopach map (fig. 8.13)has been constructed using the new borehole data together with data from old boreholes held in the records of IGS in Scotland. This diagram has not been contoured on a strictly mathematical basis but with a geological bias. Where there is a variation in thickness between two boreholes and where a major structure passes between these two boreholes, the contours have been plotted as running close to the major structure.


20
30
40
Largs
N
Upper Limestone Group
interpretive isopach map
0 1 2 3 km
Dusk Water Fault
50
40
90
100
80
70
60
50
40
30
110
116
117
83
95
87
83
75
68
119
110m
30
34
33
26
42
35
36
40
50
60
41
58
71
60
Ardrossan
40
Saltcoats

8.6 Distribution of limestone members in the Upper Limestone Group

The Diddup Borehole encountered six limestone members within the Upper Limestone Group, the Index, Third Post, Lower Linn, Upper Linn, Diddup and Corsankell limestones. In the other IGS boreholes either (a) the Upper Linn, Diddup and Corsankell limestones were not present or (b) the Index Limestone was not present. A third alternative was that neither the Upper Linn, Diddup and Corsankell limestones nor the Index Limestone were present. The lateral distribution of these missing strata were studied by using the old borehole data in the files of IGS in Scotland, re-correlating it on the basis of recent drilling and plotting where each of the groups of strata are present and absent. These are shown in figures 8.14 and 8.15.

The marine strata below the Third Post Limestone, principally the Index Limestone, are present over much of the Dalry Basin and, with the exception of one occurrence, can be traced throughout the area north of the Annick Water Fault. South of this fault the Index Limestone may be missing locally, usually replaced by coarse sandstone units with marked erosive bases. There are insufficient data to evaluate the shape of the areas where the Index Limestone is missing.

The marine strata above the Lower Linn Limestone are missing over a much wider area of the Dalry Basin. In the area north of the Dusk Water Fault the strata are shown to be present. There are, though, some strata missing in this area when compared with the full succession in the Diddup Borehole. In outcrop the Corsankell Limestone has not been observed and the Diddup Limestone is seen only locally. The eroded remnants of limestones are found in a breccia stratigraphically above the Upper Linn Limestone in the Glen Burn.

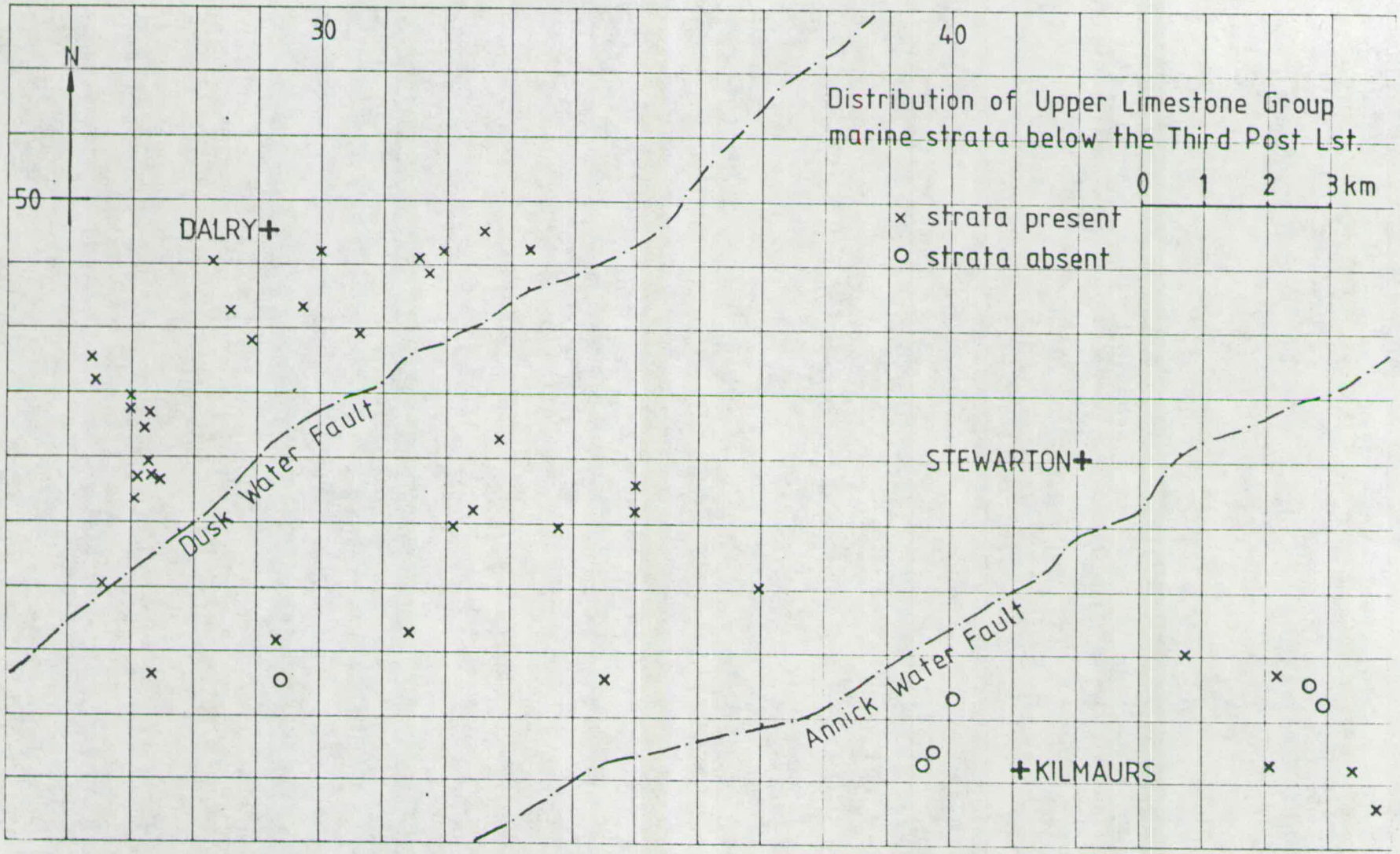
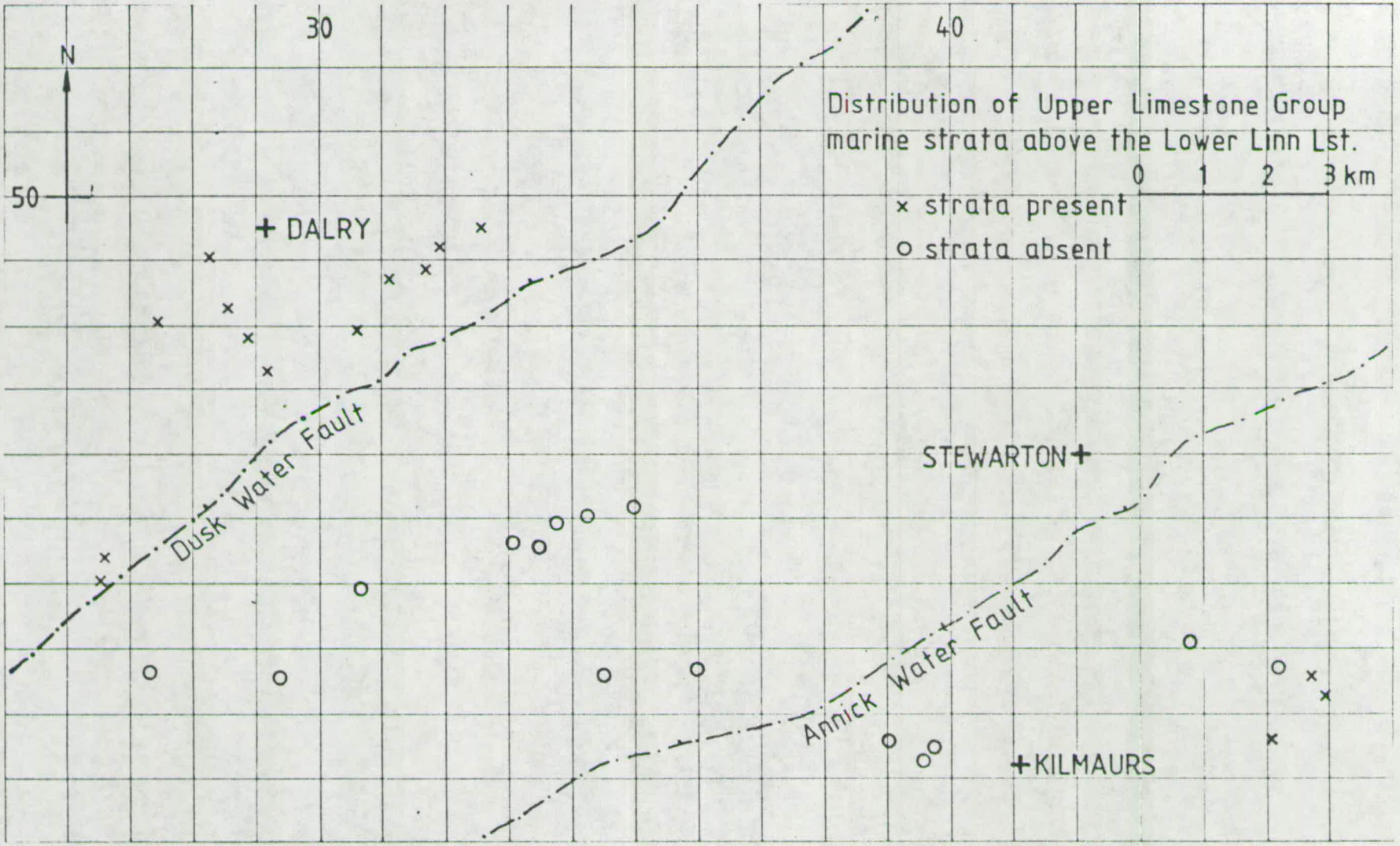

30
40
N
50
Distribution of Upper Limestone Group
marine strata below the Third Post Lst.
0 1 2 3km
× strata present
o strata absent
DALRY
Dusk Water Fault
STEWARTON
Annick Water Fault
KILMAURS

Fig. 8.14


30
40
N
50
Distribution of Upper Limestone Group
marine strata above the Lower Linn Lst.
0 1 2 3 km
× strata present
o strata absent
+ DALRY
Dusk Water Fault
STEWARTON +
Annick Water Fault
+ KILMAURS

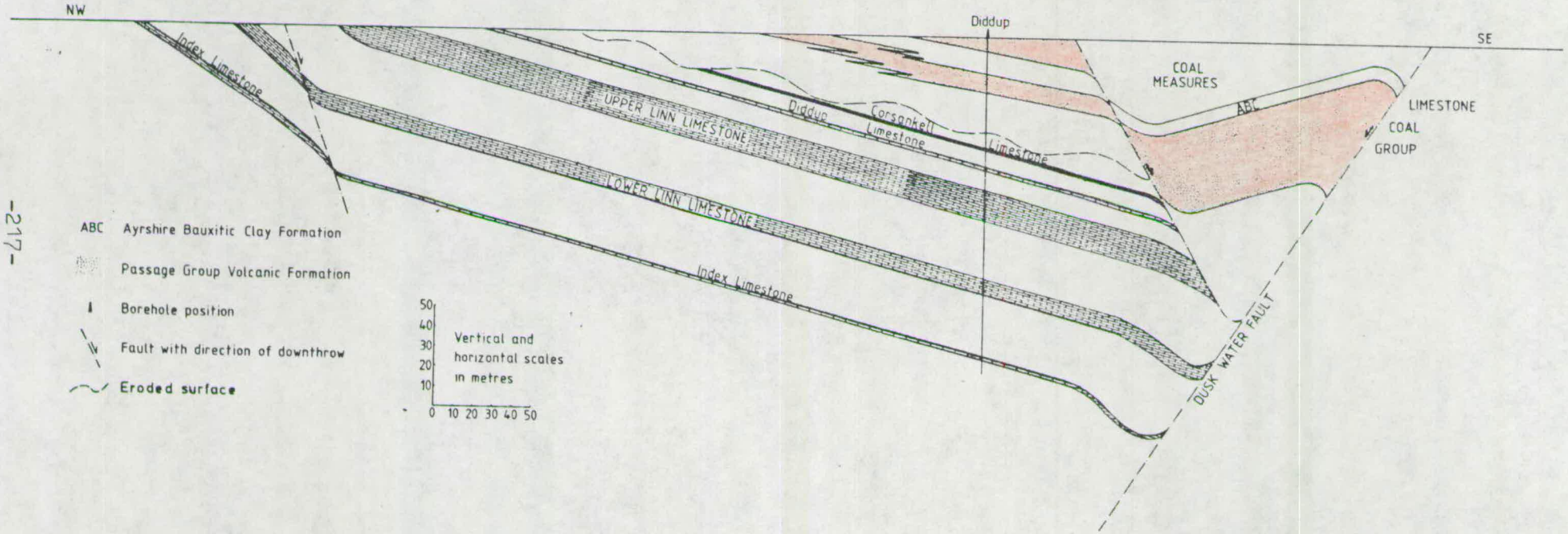
It is concluded that these limestones at least were deposited over a wider area and subsequently eroded. A cross-section north-west to south-east through the Diddup Borehole (fig. 8.16) illustrates what might be the disposition of the strata at depth.

Between the Dusk Water Fault and the Annick Water Fault the marine strata above the Lower Linn Limestone are missing. Immediately to the south of the Annick Water Fault these strata are again missing but the Upper Linn Limestone again appears in the south-west around Fenwick.

8.7 Cyclicity in the Upper Limestone Group

Cyclical sequences of sediments are apparent from the borehole data but the nature of these cycles is not readily discernible. The sedimentary sequences in each of the figured boreholes have been analysed as described in chapter 4.4. The analysis of these data and the diagrams generated are given in tables 8.6 to 8.9. Table 8.10 presents data from all the transitions in each of the boreholes together.

The analysis of the sequences in the Diddup Borehole shows a clear progression from marine limestones and calcareous mudstones upwards through mudstone, siltstone and sandstone to seatclay and coal. The sequence in the Hullerhirst Borehole shows a less clearly defined upward-coarsening succession in the clastics but with sandstones frequently being followed upwards by seatclays and then marine strata. A clearly defined upward-coarsening progression is apparent from the analysis of the sequence in the Kilmaurs Borehole. The Montgreenan Borehole provided a sequence the analysis of which resulted in a rather confused picture. There is a poorly defined


NW
SE
Diddup
Index Limestone
UPPER LINN LIMESTONE
LOWER LINN LIMESTONE
Diddup Limestone
Corsenkell Limestone
COAL MEASURES
ABC
LIMESTONE COAL GROUP
DUSK WATER FAULT
ABC Ayrshire Bauxitic Clay Formation
Passage Group Volcanic Formation
Borehole position
Fault with direction of downthrow
Eroded surface
Vertical and horizontal scales in metres
50
40
30
20
10
0 10 20 30 40 50

Analysis of sequences - Diddup Borehole

Upper Limestone Group

	Mudst	Sst	Seat	Siltst	Lst	Calc mudst	Coal	
Mudst	10	8	1	7	2	0	0	28
Sst	7	2	7	3	3	0	0	22
Seat	4	4	5	0	0	0	1	14
Siltst	2	7	0	1	1	1	0	12
Lst	4	1	1	1	2	1	0	10
Calc mudst	1	0	0	0	2	0	0	3
Coal	0	0	0	0	0	1	0	1
	28	22	14	12	10	3	1	90

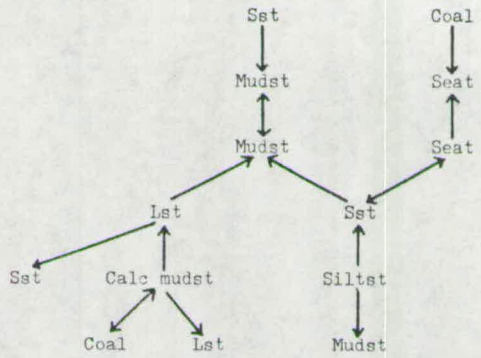
(a) data array of bed transitions

	Mudst	Sst	Seat	Siltst	Lst	Calc mudst	Coal
Mudst	9	7	4	4	3	1	0
Sst	7	5	3	3	2	1	0
Seat	4	3	2	2	2	0	0
Siltst	4	3	2	2	1	0	0
Lst	3	2	2	1	1	0	0
Calc mudst	1	1	0	0	0	0	0
Coal	0	0	0	0	0	0	0

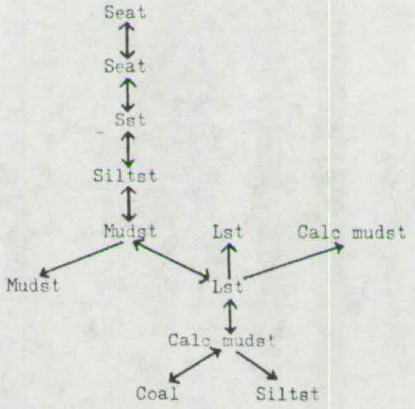
(b) predicted data array assuming a random arrangement of lithologies (calculated to nearest whole number)

	Mudst	Sst	Seat	Siltst	Lst	Calc mudst	Coal
Mudst	+1	+1	-3	+3	-1	-1	0
Sst	0	-3	+4	0	+1	-1	0
Seat	0	+1	+3	-2	-2	0	+1
Siltst	-2	+4	-2	-1	0	+1	0
Lst	+1	-1	-1	0	+1	+1	0
Calc mudst	0	-1	0	0	+2	0	0
Coal	0	0	0	0	0	+1	0

(d) table showing the differences between the observed number of transitions, and the predicted number assuming a random arrangement



(b) facies relationship diagram showing the most common upward and downward transition for each lithology



(e) facies relationship diagram showing the largest number of upward and downward transitions that occur for each lithology after subtracting those predicted if the beds were arranged randomly

TABLE 8.6

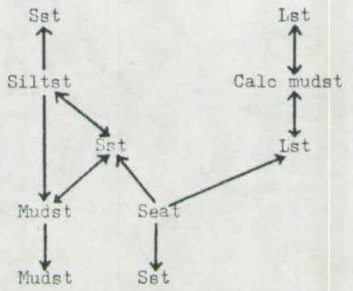
TABLE 8.7

Analysis of sequences - Hullerhirst Borehole

Upper Limestone Group

	Mudst	Lst	Sst	Siltst	Calc mudst	Seat	
Mudst	3	1	4	3	0	0	11
Lst	2	1	0	0	5	0	8
Sst	2	1	0	3	0	2	8
Siltst	2	0	3	0	0	0	5
Calc mudst	1	4	0	0	0	0	5
Seat	0	1	1	0	0	0	2
	10	8	8	6	5	2	39

(a) data array of bed transitions



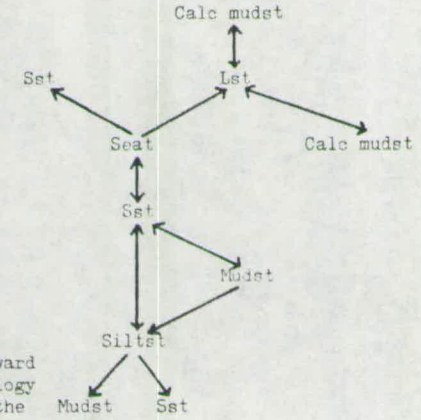
(b) facies relationship diagram showing the most common upward and downward transition for each lithology

	Mudst	Lst	Sst	Siltst	Calc mudst	Seat
Mudst	3	2	2	2	1	1
Lst	2	2	2	1	1	0
Sst	2	2	2	1	1	0
Siltst	1	1	1	1	1	0
Calc mudst	1	1	1	1	1	0
Seat	1	0	0	0	0	0

(c) predicted data array assuming a random arrangement of lithologies (calculated to nearest whole number)

	Mudst	Lst	Sst	Siltst	Calc mudst	Seat
Mudst	0	-1	+2	+1	+4	-1
Lst	0	-1	-2	-1	+4	0
Sst	0	-1	-2	+1	-1	+2
Siltst	+1	-1	+2	-1	-1	0
Calc mudst	0	+3	-1	-1	-1	0
Seat	-1	+1	+1	0	0	0

(d) table showing the differences between the observed number of transitions and the predicted number assuming a random arrangement



(e) facies relationship diagram showing the largest number of upward and downward transitions that occur for each lithology after subtracting those predicted if the beds were arranged randomly

Analysis of sequences - Kilmaurs Borehole

Upper Limestone Group

	Sst	Mudst	Seat	Siltst	Coal	Lst	Calc mudst	
Sst	14	6	11	2	1	2	0	36
Mudst	7	9	0	6	0	0	0	22
Seat	3	3	7	1	6	0	0	20
Siltst	9	0	1	0	0	0	0	10
Coal	3	2	1	1	0	0	0	7
Lst	0	1	0	0	0	0	1	2
Calc mudst	0	1	0	0	0	0	0	1
	36	22	20	10	7	2	7	98

(a) data array of bed transitions

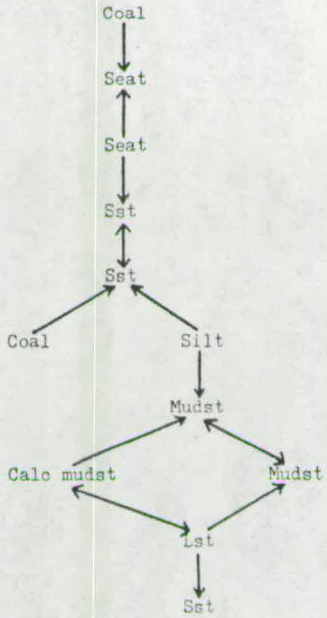
	Sst	Mudst	Seat	Siltst	Coal	Lst	Calc mudst
Sst	13	8	7	4	3	1	0
Mudst	8	5	4	2	2	0	0
Seat	7	4	4	2	1	0	0
Siltst	4	2	2	1	1	0	0
Coal	3	2	1	1	1	0	0
Lst	1	0	0	0	0	0	0
Calc mudst	0	0	0	0	0	0	0

(c) predicted data array assuming a random arrangement of lithologies (calculated to nearest whole number)

	Sst	Mudst	Seat	Siltst	Coal	Lst	Calc mudst
Sst	+1	-2	+4	-2	-2	+1	0
Mudst	-1	+4	-4	+4	-2	0	0
Seat	-4	-1	+3	-1	+5	0	0
Siltst	+5	-2	-1	-1	-1	0	0
Coal	0	0	0	0	-1	0	0
Lst	-1	+1	0	0	0	0	+1
Calc mudst	0	+1	0	0	0	0	0

(d) table showing the differences between the observed number of transitions, and the predicted number assuming a random arrangement

(b) facies relationship diagram showing the most common upward and downward transition for each lithology



(e) facies relationship diagram showing the largest number of upward and downward transitions that occur for each lithology after subtracting those predicted if the beds were arranged randomly

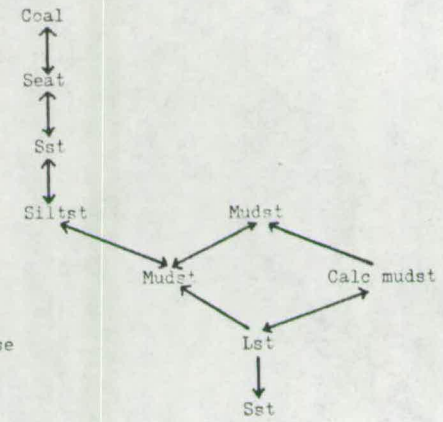


TABLE 8.8

Analysis of sequences - Montgreenan Borehole

Upper Limestone Group

	Mudst	Sst	Lst	Calc mudst	Seat	Coal	Siltst	
Mudst	1	7	0	1	0	1	2	12
Sst	6	2	2	0	3	0	0	13
Lst	1	0	0	4	0	0	0	5
Calc mudst	2	0	3	0	0	0	0	5
Seat	1	1	0	0	1	1	0	4
Coal	2	0	0	0	0	0	0	2
Siltst	0	2	0	0	0	0	0	2
	13	12	5	5	4	2	2	43

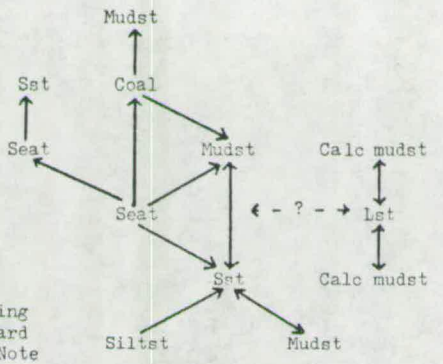
(a) data array of bed transitions

	Mudst	Sst	Lst	Calc mudst	Seat	Coal	Siltst
Mudst	4	3	1	1	1	1	1
Sst	4	4	2	2	1	1	1
Lst	2	1	1	1	0	0	0
Calc mudst	2	1	1	1	0	0	0
Seat	1	1	0	0	0	0	0
Coal	1	1	0	0	0	0	0
Siltst	1	1	0	0	0	0	0

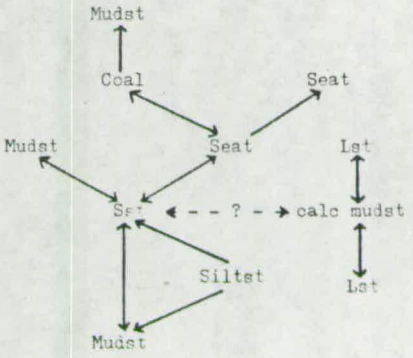
(c) predicted data array assuming a random arrangement of lithologies (calculated to nearest whole number)

	Mudst	Sst	Lst	Calc mudst	Seat	Coal	Siltst
Mudst	-3	+4	-1	0	-1	0	+1
Sst	+2	-2	0	-2	+2	-1	-1
Lst	-1	-1	-1	+3	0	0	0
Calc mudst	0	-1	+2	-1	0	0	0
Seat	0	0	0	0	+1	+1	0
Coal	+1	-1	0	0	0	0	0
Siltst	-1	+1	0	0	0	0	0

(d) table showing the difference between the observed number of transitions, and the predicted number assuming a random arrangement



(b) facies relationship diagram showing the most common upward and downward transitions for each lithology. Note uncertainty of relationship with Lst/calc mudst lithologies



(e) facies relationship diagram showing the largest number of upward and downward transitions that occur for each lithology after subtracting those predicted if the beds were arranged randomly. Note uncertainty of relationships with Lst/calc mudst lithologies

TABLE 8.9

Analysis of sequences - data from all Upper Limestone Group Boreholes

	Sst	Mudst	Seat	Siltst	Lst	Cacl mudst	Coal	
Sst	22	21	3	8	8	0	1	73
Mudst	26	23	1	18	3	1	1	73
Seat	9	8	13	1	1	0	8	40
Siltst	21	4	1	1	1	1	0	29
Lst	1	8	1	1	3	11	0	25
Calc mudst	0	5	0	0	9	0	0	14
Coal	3	4	1	1	0	1	0	10
	82	73	40	30	25	14	10	274

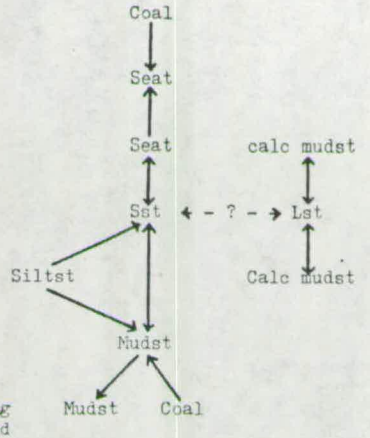
(a) data array of bed transitions

	Sst	Mudst	Seat	Siltst	Lst	Calc mudst	Coal
Sst	25	22	12	9	8	4	3
Mudst	22	19	11	8	7	4	3
Seat	12	11	6	4	4	2	1
Siltst	9	8	4	3	3	1	1
Lst	7	7	4	3	2	1	1
Calc mudst	4	4	2	2	1	1	1
Coal	3	3	1	1	1	1	0

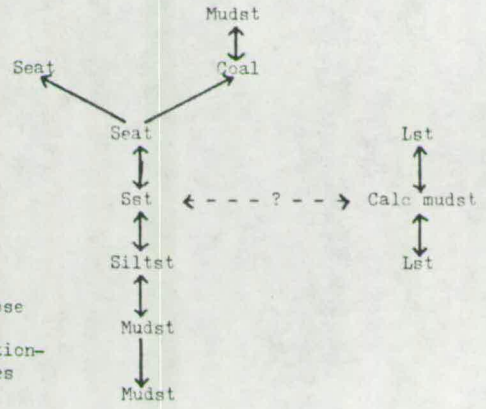
(c) predicted data array assuming a random arrangement of lithologies (calculated to nearest whole number)

	Sst	Mudst	Seat	Siltst	Lst	Calc mudst	Coal
Sst	-3	-1	+11	-1	0	-4	-2
Mudst	+4	+4	-10	+10	-4	-3	-2
Seat	-3	-3	+7	-3	-3	-2	+7
Siltst	+12	-4	-3	-2	-2	0	-1
Lst	-6	+1	-3	-2	-1	+10	-1
Calc mudst	-4	+1	-2	-2	+8	-1	-1
Coal	0	+1	0	0	-1	0	0

(d) table showing the difference between the observed number of transitions and the predicted number assuming a random arrangement



(b) facies relationship diagram showing the most common upward and downward transitions for each lithology. Note the uncertainty of relationship with Lst/calc mudst lithologies



(e) facies relationship diagram showing the largest number of upward and downward transitions that occur for each lithology after subtracting those prediced if the beds were arranged randomly. Note uncertainty of relationship with Lst/calc mudst lithologies

TABLE 8.10

upward-coarsening sequence within the clastic sediments finishing with seatclays and coals. The marine strata, the limestones and calcareous mudstones do not appear to have numbers of transitions into other sediments which differ from those which would be expected given a random distribution. The diagrams based on transitions from all the boreholes likewise do not show a relationship between the marine and the other lithologies but they do highlight the upward-coarsening sequence in the clastic sediments.

8.8 Upper Limestone Group - south of the Inchgotrick Fault

Two boreholes were drilled to investigate the Namurian and Dinantian sequences outside the Dalry Basin, south of the Inchgotrick Fault. The first, the Harelaw Borehole was drilled in 1976 with the aim of proving the Upper Limestone Group, Limestone Coal Group and Lower Limestone Group strata. The results suggested that a further, deeper borehole might be useful and in 1980-81 the Deaconhill Borehole was drilled and penetrated from immediately below the Passage Group Volcanic Formation to the unconformity between the Upper Old Red Sandstone and the Lower Old Red Sandstone lavas.

The Harelaw Borehole /NS 4166 3300/ started in the Passage Group Volcanic Formation and finished at a total depth of 69.76 m in mudstones and cementstones of the Calciferous Sandstone Measures (see table 8.11 and fig. 8.17). The sequence is dramatically different from that in the Dalry Basin with the Upper Limestone Group reduced to just one marine limestone and the Limestone Coal Group - if strata of this age are present - consisting almost entirely of coarse-grained sandstones. Faunal evidence is insufficient to identify the range of strata represented. The base of the coarse

TABLE 8.11

The strata in the Harelaw Borehole /NS 4166 3300/

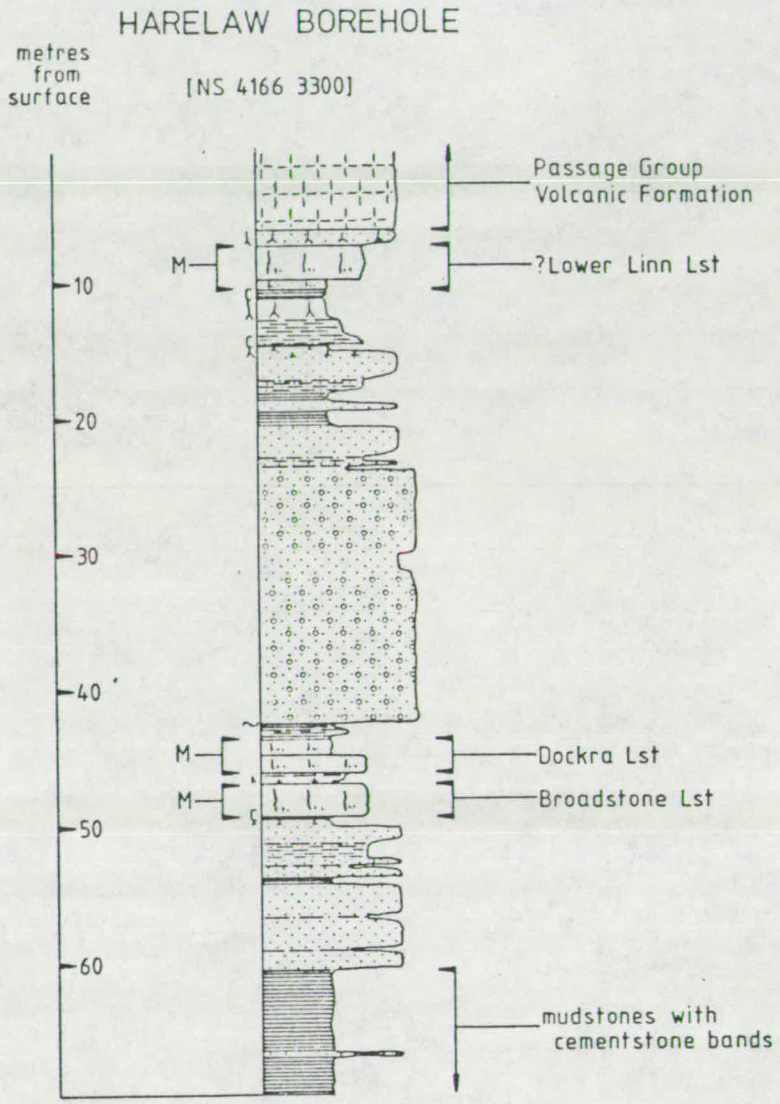
PASSAGE GROUP	Depth (metres) from	to
Passage Group Volcanic Formation		
Seatearth and seatclay, light grey to light brownish grey with abundant sphaerosiderite	6.35	7.35
UPPER LIMESTONE GROUP to ? LIMESTONE COAL GROUP		
Limestone, light to dark grey, fine-grained, hard, rooty, calcareous mudstone bands to base	7.35	10.56
Mudstone, silty, dark grey with *Lingula sp.*	10.56	10.95
Coal, bright with dull bands	10.95	11,32
Seatclay, light olive-grey becoming medium dark grey	11.32	12.75
Mudstone, silty, dark grey, rooty	12.75	14.05
Siltstone, dark grey, bedded with fine sandy laminae, rooty at base	14.05	14.64
Coal, dull with bright bands	14.64	14.70
Seatclay and seatearth, dark to medium grey	14.70	15.67
Sandstone, medium grained, light brownish grey becoming light grey, rooty	15.67	17.15
Siltstone, dark grey, ironstone nodules, abundant sphaerosiderite	17.15	18.05
Mudstone, dark brownish grey, poorly bedded, lipy rooty to base	18.05	18.70
Sandstone, medium grained, light brown, occasional roots.	18.70	19.39
Mudstone, dark grey, becoming olive grey, silty at top, roots and listric surfaces	19.39	20.63
Sandstone, medium grained, light grey with dark grey silty wisps and laminae, occasional mudstone pellets	20.63	22.93
Siltstone, dark grey, well bedded, sandy bands	22.93	23.32
Sandstone, medium grained, light grey, dark grey silty laminae	23.32	23.60

TABLE 8.11 (cont'd)

	Depth (metres) from	to
Mudstone, silty, dark grey, coaly stringers, some sandy laminae to base	23.60	23.71
Sandstone, coarse grained with some medium grained bands, light grey, frequent quartz pebbles, some cross bedding to base, sharp erosive base	23.71	42.52
disconformity		
LOWER LIMESTONE GROUP		
Mudstone, dark-very dark grey, silty and carbonaceous in places, marine fauna at top	42.52	43.65
?Dockra Limestone: Limestone, dark grey, argillaceous and calcareous mudstone with marine fauna	43.65	46.30
Mudstone, dark grey, silty at top, lipy	46.30	46.67
Seatclay, light olive grey, some bedding	46.67	46.85
?Broadstone Limestone: Limestone, light olive grey to light brownish grey, nodular and rooty in places, argillaceous to base	46.85	49.32
Coal, dull, bright patches	49.32	49.36
CALCIFEROUS SANDSTONE MEASURES		
Seatclay, light olive-grey, dark grey and carbonaceous at top	49.36	50.03
Sandstone, medium grained, light grey, poorly bedded, roots at top	50.03	51.24
Siltstone, pale yellowish brown, occasional roots	51.24	52.56
Sandstone, fine grained, light grey, rare roots	52.56	52.74
Mudstone, silty, light olive-grey, occasional roots	52.74	52.94
Sandstone, fine-grained, light grey, hard	52.94	53.02
Mudstone, light olive-grey, some bedding, listric surfaces	53.02	53.14
Sandstone, fine-grained, light grey with olive tinge, abundant sulphides	53.14	53.26

TABLE 8.11 (cont'd)

	Depth (metres) from	to
Mudstone, light olive grey, some mottling, abundant sulphides, often in nodules	53.26	53.70
Sandstone, coarse to medium grained, light to medium grey, occasional thin siltstone and mudstone bands, mudstone pellets and sharply erosive at base	53.70	60.71
Mudstone, dark grey, silty in places, occasional thin sandy bands, frequent cementstone ribs	60.71	69.76


HARELAW BOREHOLE
metres from surface
[NS 4166 3300]
10
20
30
40
50
60
M
M
M
Passage Group
Volcanic Formation
?Lower Linn Lst
Dockra Lst
Broadstone Lst
mudstones with
cementstone bands

sandstones is a marked erosive surface and such surfaces are also present within the sandstone body. The strata below the sandstones are, in age, some way into the Lower Limestone Group and the junction may represent a time break, with erosion of at least some Lower Limestone Group strata.

The Deaconhill Borehole /NS 4893 3153/ started in strata which, from mapping, is immediately below the Passage Group Volcanic Formation in limestones of the Upper Limestone Group. The borehole penetrated the cementstones and mudstones of the Calciferous Sandstone Measures, the red sandstones and cornstones of the Upper Old Red Sandstone and finished at 323.46 m in lavas of Lower Old Red Sandstone age. For comparison with the Dalry Basin sequences the sequence is given down to the mudstones with cementstones of the Calciferous Sandstone Measures (Table 8.12 and fig. 8.18). The borehole did, however, prove 145.97 m of mudstones with cementstones resting on 125.52 m of reddish brown sandstone with cornstones throughout, though more abundant towards the top.

The sequence at the top of the Deaconhill Borehole is similar to that of the Harelaw Borehole and different from those in the Dalry Basin. The Upper Limestone Group sequence is thin, confined to two marine horizons. Faunal evidence is not conclusive but the upper is possibly the Upper Linn (Wilson, pers.comm) while the lower may be the Lower Linn (Wilson, pers. comm.).

The sequence below the upper limestones is finer grained than that in the Harelaw Borehole containing mudstones and rooty beds. The junction with the overlying strata at 40.60 m however is sharp. The faunal evidence from the limestone at 44.40 m suggests a correlation with the Broadstone Limestone (Wilson, pers. comm.). The upper part

TABLE 8.12

The strata in the Deaconhill Borehole /NS 4893 3153/

	Depth (metres) from	to
UPPER LIMESTONE GROUP		
Mudstone, brownish grey with olive grey mottling becoming medium grey to base, poorly preserved marine fauna	7.84	9.65
?Upper Linn Limestone: Limestone, dark grey, argillaceous, marine fauna	9.65	10.60
Mudstone, silty, medium grey, poorly bedded, occasional sandy ribs, carbonaceous to base	10.60	11.76
Seatearth, brownish grey with dark grey roots, abundant sphaerosiderite	11.76	12.94
Mudstone, dark grey, well bedded, marine fauna to base	12.94	14.70
?Lower Linn Limestone: Limestone, dark grey, argillaceous, marine fauna	14.70	15.80
Mudstone, dark grey, well bedded, marine fauna including Lingula sp from 17.75	15.80	20.15
Seatclay, brownish-grey, becoming sandy to base	20.15	22.54
Sandstone, light brownish grey, fine-grained, silty to base	22.54	23.65
Mudstone, silty, dark grey	23.65	24.65
Sandstone, medium grained, light grey	24.65	27.25
Mudstone, dark grey, silty in places, ironstone bands and nodules	27.25	31.05
Seatclay, dark grey, sandy bands, irony nodules	31.05	33.50
Siltstone, dark grey with light grey sandy laminae	33.50	34.30
Sandstone, light grey, fine-grained becoming medium-grained, sharp base	34.30	40.60
disconformity		
LOWER LIMESTONE GROUP		
Mudstone, dark grey, poorly bedded, seatclay band, marine fauna to base	40.60	42.24

TABLE 8.12 (cont'd)

	Depth (metres) from	to
?Broadstone Limestone: Limestone, dark brownish grey, marine fauna	42.24	43.70
Mudstone, calcareous, dark grey, marine fauna	43.70	44.40
CALCIFEROUS SANDSTONE MEASURES		
Mudstone, dark grey, pyritous burrows	44.40	44.65
Sandstone, fine-grained becoming medium-grained, light grey, mudstone bands	44.65	48.97
Coal, bright with muddy laminae	48.97	49.04
Seatclay, medium grey mottled, abundant pyrite, carbonaceous at top, sandy in places	49.04	51.37
Mudstone, medium to dark grey with thin siltstone and sandstone bands, frequent cementstone bands and ribs, gypsum ribs and patches from 128 m, fish scales, ostracods and Modiolus	51.37	194.97
Mudstone, medium grey, cementstone clasts, sharp erosive base	194.97	197.34
disconformity		
UPPER OLD RED SANDSTONE		
Sandstone, medium-grained, light grey, mudstone clasts	197.34	198.15
Mudstone, medium grey with reddish brown mottling, occasional 'cementstone' nodules	198.15	201.40
Sandstone, medium-grained, light grey to reddish brown, small-scale cross-bedding	201.40	209.58
Mudstone, reddish-brown, silty to base, blocky	209.58	213.80
Sandstone, medium-grained, dusky red with frequent light greenish grey cornstone bands and nodules, thin siltstone and mudstone bands	213.80	260.12
Sandstone, medium to coarse-grained, light grey with reddish tinge, bands with quartzite pebbles, calcareous cement in places, thin siltstone and silty mudstone bands	260.12	281.80

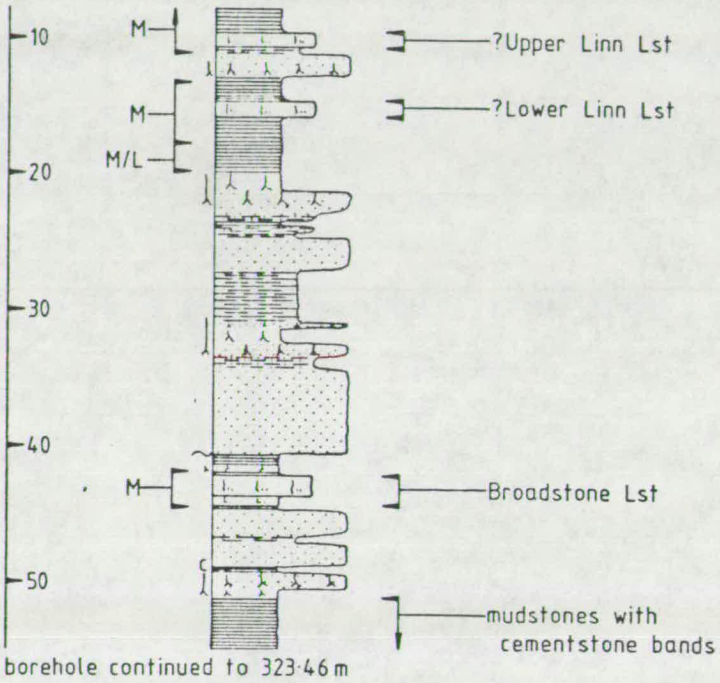
TABLE 8.12 (cont'd)

	Depth (metres) from	to
Sandstone, medium-grained, reddish brown with light greenish grey cornstone bands and nodules, thin silty mudstone bands	281.80	288.80
Sandstone, fine to medium-grained, light grey, reddish brown and purplish grey, rare cornstone bands, occasional thin siltstone and silty mudstone bands	288.80	321.50
Conglomerate, reddish brown and greenish grey clasts up to 5 cm in sandy matrix	321.50	322.86
unconformity		
LOWER DEVONIAN		
Basalt, dark grey with greenish patches, some carbonate veining	322.86	323.46

DEACONHILL BOREHOLE

metres from surface

[NS 4893 3153]



borehole continued to 323·46 m

of the Lower Limestone Group is therefore missing and the sharp junction at 40.60 m may represent a time break with erosion of at least some Lower Limestone Group strata as is also indicated by the Harelaw Borehole.

The age of the strata between the Upper and Lower Limestone Group limestones may, if the suggested correlation is correct, be of Upper Limestone Group age. In the Deaconhill Borehole, therefore, the basal strata of the Upper Limestone Group, all the Limestone Coal Group and much of the Lower Limestone Group were either not deposited or eroded. A similar conclusion, dependent on the correlation of the Upper Limestone Group limestone, may also come from the Harelaw Borehole.

8.9 Upper Limestone Group - definition of lithofacies

Three lithofacies can be identified within the Upper Limestone Group, a marine lithofacies, an upward-coarsening lithofacies and an upward-fining lithofacies. The 'marine' lithofacies includes limestones, calcareous mudstones and mudstones which bear a marine fauna. The upward-coarsening facies consists largely of clastic sediments, sandstones, siltstones and mudstones arranged in an upward-coarsening succession. The upward-fining facies likewise consists of clastic sediments arranged in an upward-fining sequence but in places is characterised by a sharp erosive base and coarse-grained basal sediments. Both clastic lithofacies contain seat beds and coals here and there.

8.10 Marine lithofacies

The limestones, calcareous mudstones and mudstones of the marine

lithofacies all contain marine faunas. They include the principal named horizons in the sequence, the Index, Third Post, Lower Linn, Upper Linn, Diddup and Corsankell limestones. While each of these stratigraphic horizons has a different geographical distribution, the lithological characteristics are similar throughout. The limestones are dark grey and argillaceous but while those stratigraphically above the Lower Linn have no roof mudstones developed, the Lower Linn Limestone and those below generally have some thickness of marine mudstones above the limestone.

In environmental terms the marine lithofacies of the Lower Linn Limestone and below indicate a progression from a shallow open marine sea to a more proximal environment still supporting a marine fauna but subject to heavy muddy sedimentation.

The marine lithofacies in the strata above the Lower Linn Limestone are more abrupt in their transition into clastic-dominated sediments. This may result from tectonic instability, rapid sediment deposition or both.

8.11 Upward—coarsening lithofacies

The upward-coarsening lithofacies dominate the sedimentation pattern in the Upper Limestone Group (see chapter 8.7). The cycles which occur are similar to those in the Limestone Coal Group which are thought to have been deposited in a deltaic environment. The mudstones represent deposition in the pro-delta area while the siltstones and sandstones represent deposition at the delta front. Deposition on the delta plain is represented by the frequent presence of seatclays and coals. The sequences may be repeated with shift of the delta lobe and as successive deltasbuild out.

8.12 Upward -fining lithofacies

The upward -fining lithofacies are less common than those described above but are locally important in the area south of the Inchgotrick Fault (see chapter 8.8). North of the Inchgotrick Fault they are less frequently developed but are present at 38.00 m in the Hullerhirst Borehole and at 56.20 m in the Kilmaurs Borehole where the Index Limestone, if it were deposited and hasn't been subsequently eroded, appears to be represented by this lithofacies. In environmental terms this lithofacies generally represents the infilling of distributary channels within the delta lobe though south of the Inchgotrick Fault the channel itself seems to be cut into older marine sediments.

8.13 Upper Limestone Group - environment of deposition

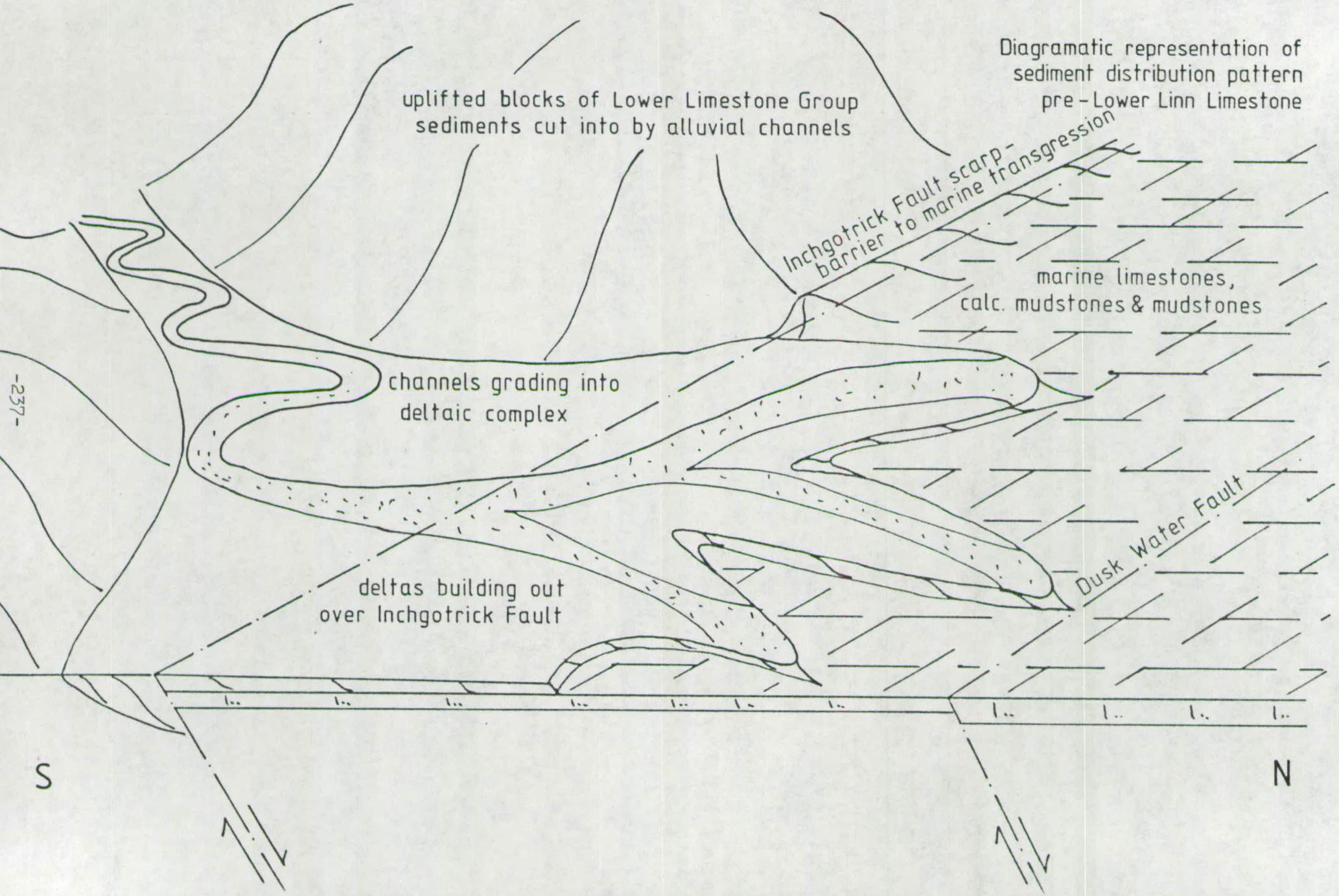
The environment of deposition as it affects the pattern of sediment distribution can be considered during two periods, before deposition of the Lower Linn Limestone and after deposition of the Lower Linn Limestone. The Lower Linn Limestone is apparently the only marine horizon consistently present in the area north of the Dusk Water Fault, between the Dusk Water Fault and the Inchgotrick Fault and south of the Inchgotrick Fault.

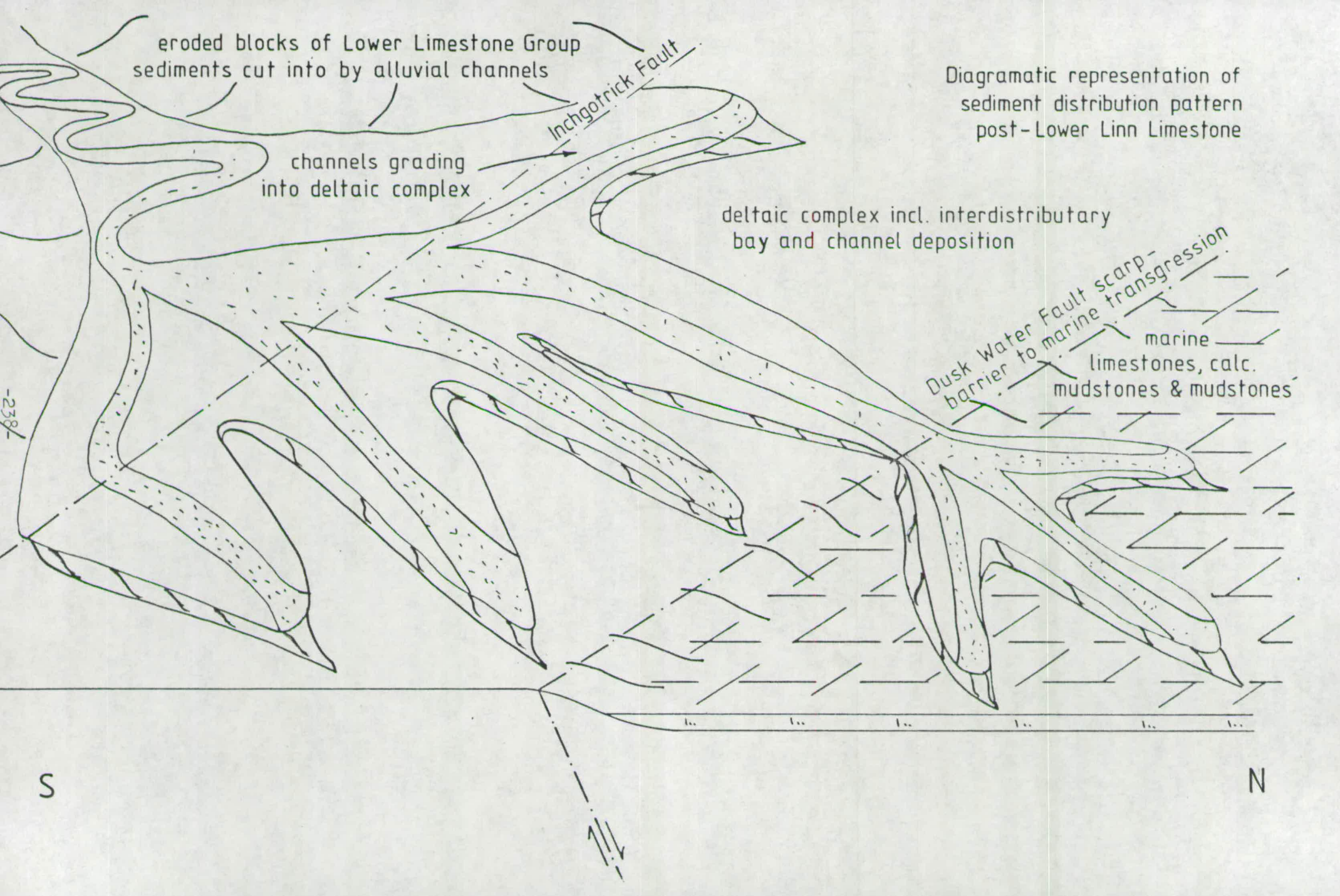
Pre-Lower Linn Limestone: Prior to deposition of the Lower Linn Limestone the pattern of sedimentation may be described as follows:- North of the Dusk Water Fault marine transgressions onto a low-lying topography frequently with coal swamps produced first open marine conditions but becoming more proximal to land and dominated by argillaceous sediments. On to this delta lobes built out culminating in the development of coal swamp conditions on the delta plain. Two

transgressions occurred prior to deposition of the Lower Linn Limestone, the basal Index Limestone and the Third Post Limestone. Between the Dusk Water Fault and the Inchgotrick Fault a similar pattern is developed, though slightly thinner, indicating some differential movement along the Dusk Water Fault downthrowing to the north. In this area distributing channels begin to appear, locally removing or replacing marine marker horizons. South of the Inchgotrick Fault only channel-fill deposits are present.

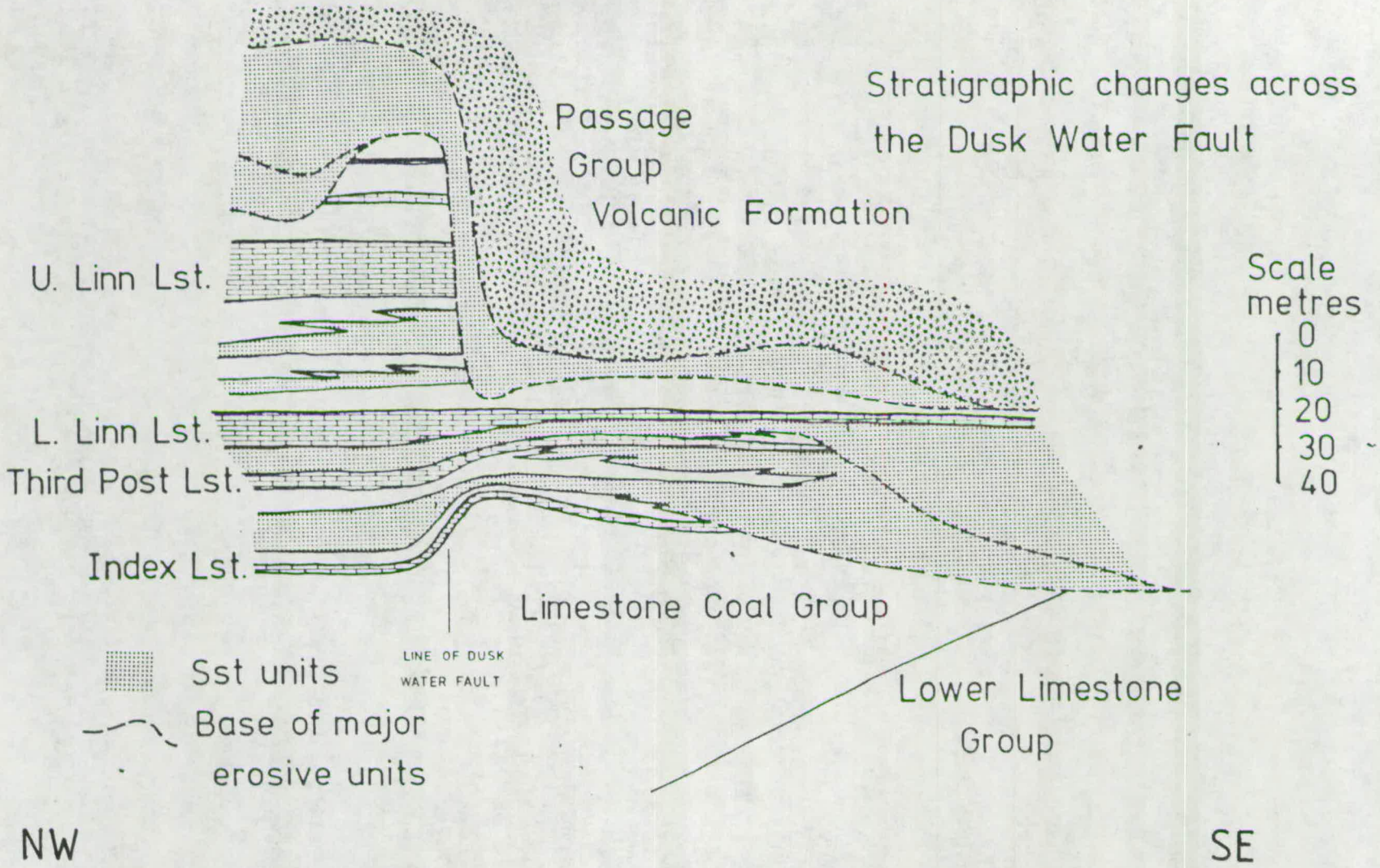
During the pre-Lower Linn Limestone period it seems that contemporaneous movement in the Inchgotrick Fault, and to a much less extent on the Dusk Water Fault, did much to control the pattern of deposition. The Inchgotrick Fault probably marked the limits of marine transgression and bounded a block of uplifted older sediments into which major channels were cut. Deltas built out from the coast north-westward with distributary channels which did not extend beyond the Dusk Water Fault. This pattern of sediment distribution is shown diagrammatically in fig. 8.19.

Post-Lower Linn Limestone: Following deposition of the Lower Linn Limestone the pattern of sedimentation is as follows:-
North of the Dusk Water Fault line sedimentation was deltaic with locally three marine horizons preserved, the Upper Linn, Diddup and Corsankell Limestones. Both the Diddup and Corsankell Limestones are laterally removed by erosion and replaced by channel-fill sandstones, probably of Passage Group age. South of the Dusk Water Fault channel-fill deposits possibly of Passage Group age occur above the Lower Linn Limestone. South of the Inchgotrick Fault the thin Upper Limestone Group sediments have been uplifted above sea level and pedogenesis has produced a series of seat beds. This pattern of sediment distribution is shown diagrammatically in fig. 8.20 and in section in fig. 8.21.


Diagramatic representation of
sediment distribution pattern
pre-Lower Linn Limestone
uplifted blocks of Lower Limestone Group
sediments cut into by alluvial channels
Inchgotrick Fault scarp-
barrier to marine transgression
marine limestones,
calc. mudstones & mudstones
channels grading into
deltaic complex
Dusk Water Fault
deltas building out
over Inchgotrick Fault
S
N



Diagramatic representation of sediment distribution pattern post-Lower Linn Limestone


Stratigraphic changes across
the Dusk Water Fault
Passage
Group
Volcanic Formation
U. Linn Lst.
L. Linn Lst.
Third Post Lst.
Index Lst.
Limestone Coal Group
Lower Limestone
Group
Scale
metres
0
10
20
30
40
LINE OF DUSK
WATER FAULT
Sst units
Base of major
erosive units
NW
SE

Chapter 9 Passage Group

9.1 Introduction

This chapter describes the strata within the Passage Group, especially the distinctive bauxitic clay lithologies and discusses lateral variation in both thickness and lithology. Extensive use has been made of old borehole data held in the records of the IGS, particularly in relation to formations which have not been drilled during the course of this study.

9.2 Stratigraphic boundaries of the Passage Group

The problems of defining the boundaries of the Passage Group are discussed briefly in chapter 2.13. The base is taken, by definition at the Castlecary Limestone and the top, at the *Gastrioceras subcrenatum* Marine Band. Neither of these horizons has been identified in the Dalry Basin and the stratigraphic boundaries are chosen within limits set by the available fossil evidence.

The base of the Passage Group is taken where Upper Limestone Group 'type' sediments with cycles containing marine limestones give way to seatearths and sandstones with occasional marine mudstones, more typical of Passage Group sedimentation (see chapter 8.2). The absence of the Castlecary Limestone from the Dalry Basin precludes a biostratigraphic definition for the top of the Passage Group, however, it can be clearly identified on a lithostratigraphic basis.

The Ayrshire Bauxitic Clay Formation is defined in chapter 2.13 as "that sequence of strata immediately overlying fresh basaltic lavas of the Passage Group, characterised by the presence of bauxitic

clay and related rock types. Interbedded sediments such as coals, seatclays and mudstones are also included within the formation". The bauxitic clay lithologies are peculiar to this part of the sequence and define a lithostratigraphic unit which can be readily identified in both borehole and outcrop sections. Wilson (1922), who made the first detailed study of the bauxitic clays, regarded them as having developed by the in situ weathering of basaltic lavas and recognised that they represent a significant break in sedimentation. While the concept of the development may have, in parts, to be modified (see chapter 9.9), the top of the Ayrshire Bauxitic Clay Formation has proved a useful lithostratigraphic boundary and is taken as the top of the Passage Group in the Dalry Basin.

Within the Passage Group of the Dalry Basin two distinctive lithostratigraphic formations are defined, the Ayrshire Bauxitic Clay Formation and the Passage Group Volcanic Formation (chapter 2.13 and fig. 2.2). This leaves a group of sediments at the base of the Passage Group outwith the formal lithostratigraphic formations and whose characteristics do not fit the criteria for definition as a lithostratigraphic formation. These sediments are here described under the heading "lower sedimentary beds".

9.3 Passage Group - "lower sedimentary beds"

The "lower sedimentary beds" are the basal beds of the Passage Group, sandwiched between the Passage Group Volcanic Formation and sediments ascribed to the Upper Limestone Group. North of the Dusk Water Fault these sediments were recorded in the Diddup Borehole (table 8.2 and fig. 8.2) and in boreholes drilled

to prove fireclay in the area around Monkcastle /NS 28 47/, the details of which are held in confidence by IGS. The sequence in the Diddup Borehole is 25.4 m thick consisting largely of sandstone with siltstone and mudstone bands. A mudstone band at 50.40 m contains some shell traces. Towards the top of the sequence roots become more abundant and seatearths are developed.

North of Diddup in the Monkcastle area, seatbeds dominate the sequence and here fireclay is being actively mined. Additionally thin coals and mudstone bands with Lingula sp. make up a total thickness only slightly less than that in the Diddup Borehole. In outcrop, the sequence in the Caaf Water at Pinnoch Point is similar to the sequence developed in the Monkcastle Boreholes. Sandstones and seatbeds occur with thin marine mudstone bands (Richey 1930). Southwards towards Diddup seatbeds are less abundant and in the stream section at Glen Burn /NS 2608 4395/ the outcrop is largely sandstone with siltstone bands.

Palynological investigations of assemblages from the sediments in the Diddup Borehole (Owens, pers. comm.) place the strata immediately below the lavas within the KV miospore zone, confirming that these beds are, in part at least, of an age appropriate to their being included within the Passage Group.

South of the Dusk Water Fault the 'lower sedimentary beds' of the Passage Group occur in three IGS boreholes, at Hullerhirst, Montgreenan and Kilmaurs (see tables 8.3 to 8.5 and figs. 8.3 to 8.5). The sequence in the Hullerhirst Borehole is lithologically similar to that at Diddup though only 12.57 m thick. It is dominated by sandstones with occasional thin mudstone bands, one of which at 16.12 m has a poorly preserved marine fauna. Rooty

horizons occur towards the top of the sequence.

The sequence in the Kilmaurs Borehole shows an upward-fining series of sandstones with occasional thin siltstone bands from 13.67 m to rockhead. No fossiliferous beds occur within the sequence at Kilmaurs to confirm an age appropriate to their being included within the Passage Group. In the Montgreenan Borehole the 5.15 m of strata immediately below the Passage Group Volcanic Formation are considered as being part of the Passage Group. These strata consist of fine-grained sandstones with mudstone bands, generally greenish-grey in colour with red and yellow mottling. The "lower sedimentary beds" are poorly exposed south of the Dusk Water Fault with the exception of a short section in the Lugton Water /NS 3380 4485/ where basaltic lavas of the Passage Group Volcanic Formation rest on about 2.0 m of cross-bedded sandstone which passes down into 3.0 m+ of dark grey mudstone.

9.4 "Lower sedimentary beds" - environment of deposition

The evidence presented in chapter 9.3 demonstrates that the strata thicken northwards across the Dusk Water Fault accompanied by lateral facies changes resulting from active subsidence in the area to the north of the Dusk Water Fault. The seatbed, sandstone, siltstone, mudstone sequence of the Diddup Borehole seems to continue the marine to deltaic pattern of sedimentary environments established in the Upper Limestone Group though the marine sediments are now less common and much thinner. The pattern of sediment distribution northwards to the Monkcastle area can be interpreted in a similar way though here seatbeds are much more common.

South of the Dusk Water Fault the thinner developments may be interpreted as deltaic sedimentation with occasional marine

transgressions. The sediments in the Kilmaurs Borehole, however, are different consisting of sandstones fining-upwards from a pebbly basal unit and in sharp erosive contact with the underlying mudstones. These sediments most probably represent the infilling of a distributary channel.

It is known that in the Monkcastle area up to four marine bands may occur but the arenaceous nature of the sediments, the degree of lateral variation in lithology and the poor preservation of the faunas precludes correlation. In turn the lack of good correlation plus the limit of the preserved strata makes an assessment of the environment of deposition impossible in any but the broadest terms.

9.5 Passage Group Volcanic Formation

The rocks of the Passage Group Volcanic Formation are geographically widespread (Richey 1930, fig. 25). Outwith the mainland area including the Dalry Basin and adjacent areas (fig. 9.1), the Passage Group Volcanic Formation fringes the Ayrshire coast southwards to Stranraer and extends westwards to Ballycastle in Northern Ireland and Machrihanish in Kintyre. The isopachs for the development in and around the Dalry Basin are based on data assembled by Richey (1930) and modified to take account of more recent drilling. It shows the lavas as forming a general dome structure centred just north of Troon but with thicknesses affected by contemporaneous movements along the Inchgotrick and Dusk Water faults. The formation generally consists of a uniform pile of basaltic lavas of Dalmeny type but both borehole sections and outcrops show that the sequence can be interbedded with

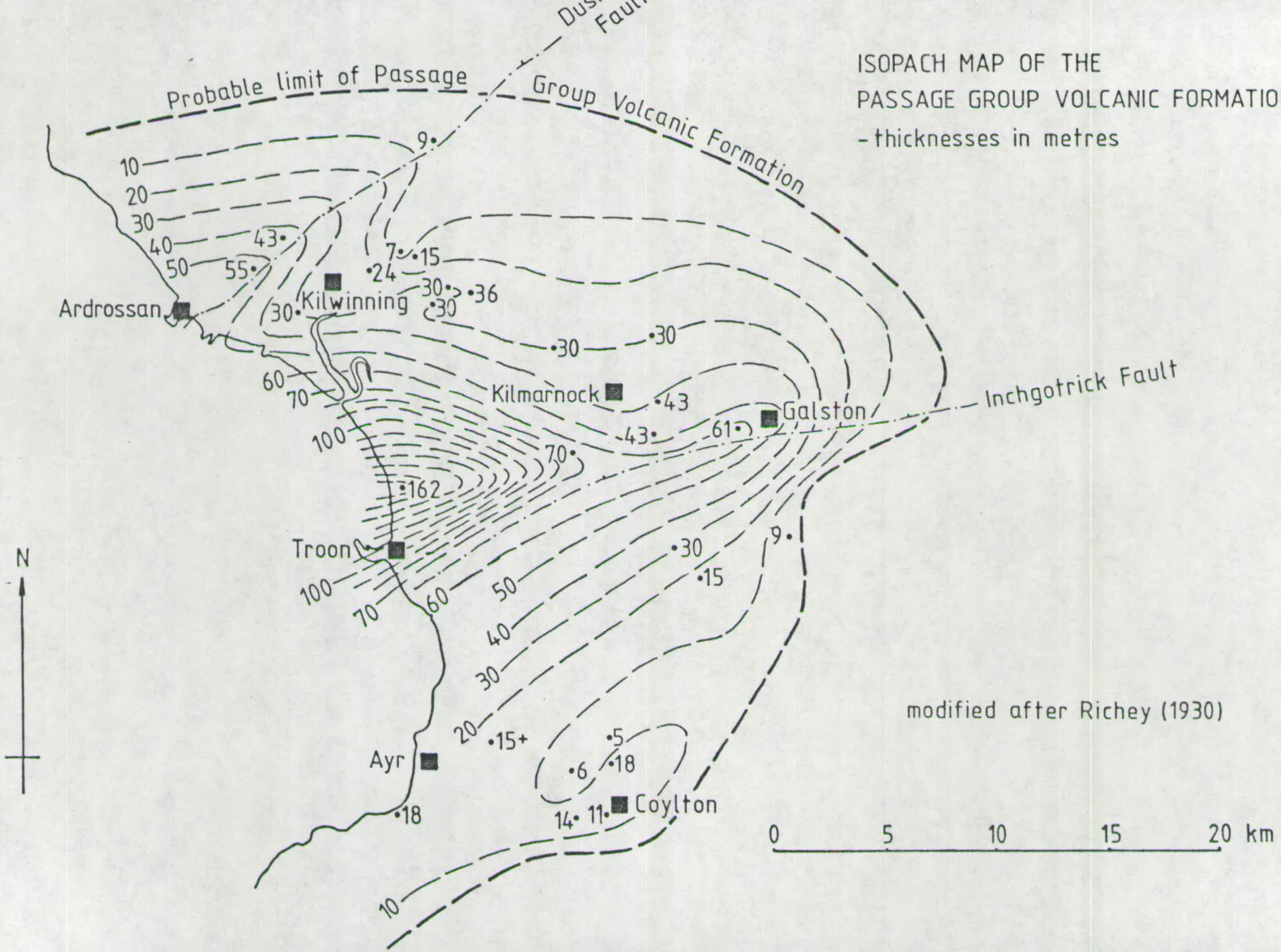

ISOPACH MAP OF THE
PASSAGE GROUP VOLCANIC FORMATION
- thicknesses in metres
Probable limit of Passage Group Volcanic Formation
Inchgotrick Fault
Ardrossan
Kilwinning
Kilmarnock
Galston
Troon
Ayr
Coylton
N
0 5 10 15 20 km
modified after Richey (1930)

Fig. 9.1

sediments. In the Diddup Borehole sediments within the lavas have yielded a miospore flora from the KV zone (Owens, pers. comm.).

The source of the Passage Group lavas has not been identified and is assumed to be beneath the lavas themselves, or else outwith the mainland area. Geochemical studies on these lavas (Macdonald et al, 1977) show that they do not fit into the increasingly silica under-saturated trend established in the Dinantian and early Namurian, and they initiate a second cycle which extends on into the Permian with increasing silica under-saturation. Macdonald et al suggest that the initiation of a second cycle in Passage Group time may have resulted from the high level fusion of mantle material.

9.6 Ayrshire Bauxitic Clay Formation - history of research

The Ayrshire Bauxitic Clay Formation has been defined in chapter 2.13. The distinctive bauxitic clay lithology was first described by John Smith in 1895 though it was not until 1922 that a detailed description was published by G V Wilson. Wilson emphasised the massive structure, conchoidal fracture, unusual density and induration of the bauxitic clay and the variety of textures ranging from fine-grained to oolitic, pisolitic and coarsely clastic. He also noted that the rock is "bauxitic in the chemical sense of containing more Al_2O_3 than can be accommodated with SiO_2 to give kaolinite". From its association with altered basalts of Namurian age, he concluded that it developed from these lavas partly as a residual crust and partly as a transported sedimentary deposit derived from erosion of that crust. He believed both types were later subjected to diagenetic changes involving silicification of some of the bauxitic minerals to form a second generation of kaolinite.

Subsequently, Lapparent (1936) identified boehmite and diaspore in selected samples. Although these aluminium oxyhydroxide minerals proved very much subordinate to that of kaolinite he agreed with Wilson's use of the term bauxitic clay. A number of authors (Bosazza 1947, Keller 1967, Robertson 1971 and Loughnan 1978) have drawn attention to apparent similarities between the bauxitic clay and the flint clays of North America, South Africa, Australia and elsewhere and have suggested that the bauxitic clay of Ayrshire is in effect a typical flint clay. If this is correct, Wilson's mechanisms for the formation of the bauxitic clay assume greater significance in that the origin of flint clays has long been a contentious issue. Controversy is centred primarily on whether these flint clays are allochthonous or autochthonous in origin.

9.7 Ayrshire Bauxitic Clay Formation

The Ayrshire Bauxitic Clay Formation crops out along the margin of the Westphalian, Coal Measures coalfield (fig. 9.2). It is best developed along the northern outcrop extending from Saltcoats /NS 24 41/ on the coast, westwards to Cunninghamhead /NS 38 41/ with only small isolated outcrops elsewhere, and no development south of the Kerse Loch Fault. Everywhere it occurs above basaltic lavas of Namurian, Passage Group age.

The variation, within the formation, in sedimentary pattern and thickness is evident from the comparison of the sections (fig. 9.3). At Smithstone, north of the Dusk Water Fault, repeated sequences of bauxitic clay, often carbonaceous, and coal are developed up to a thickness of around 20 m (Plate 9.1a). There is no evidence to suggest that the coals within the formation were ever covered by

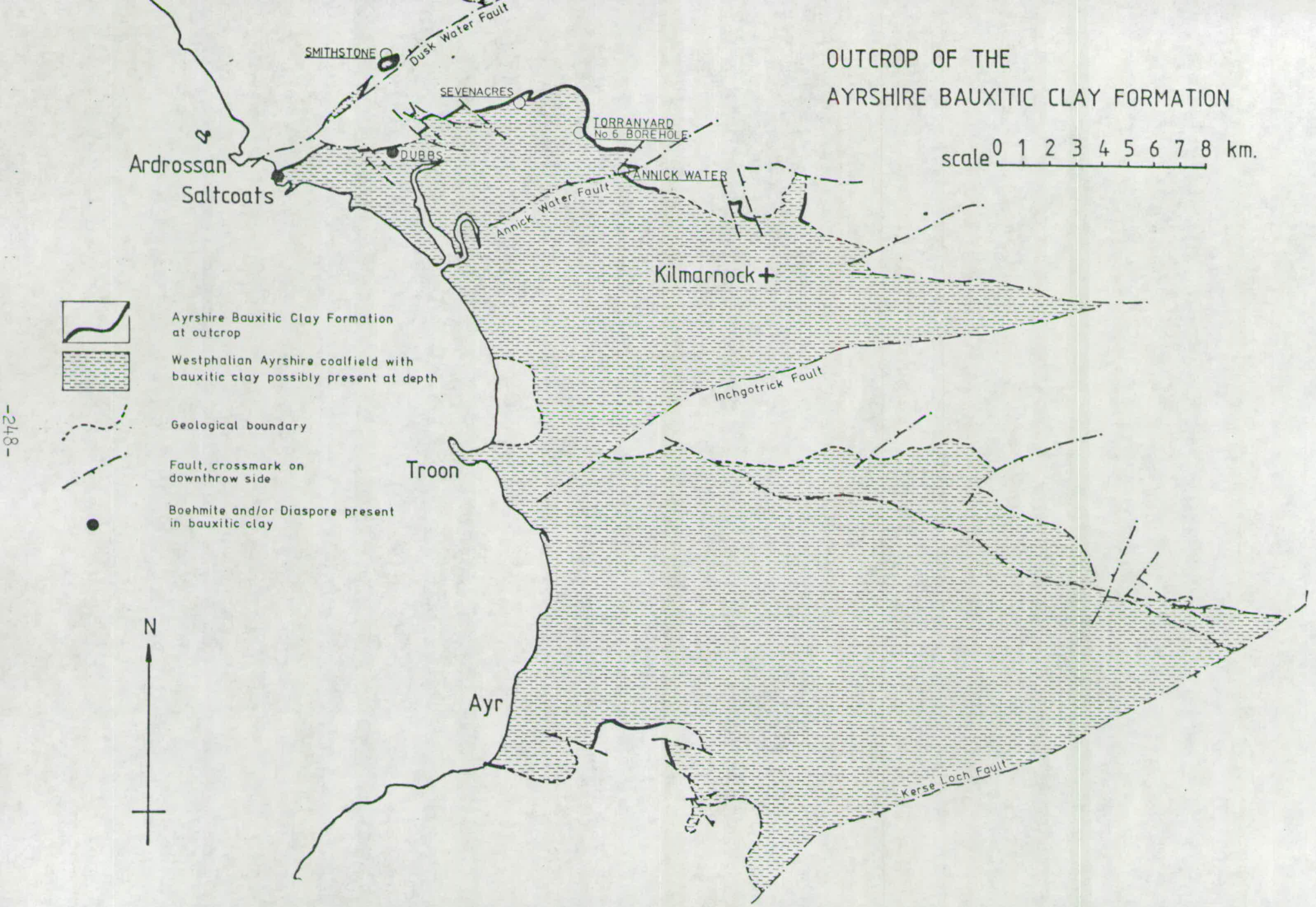
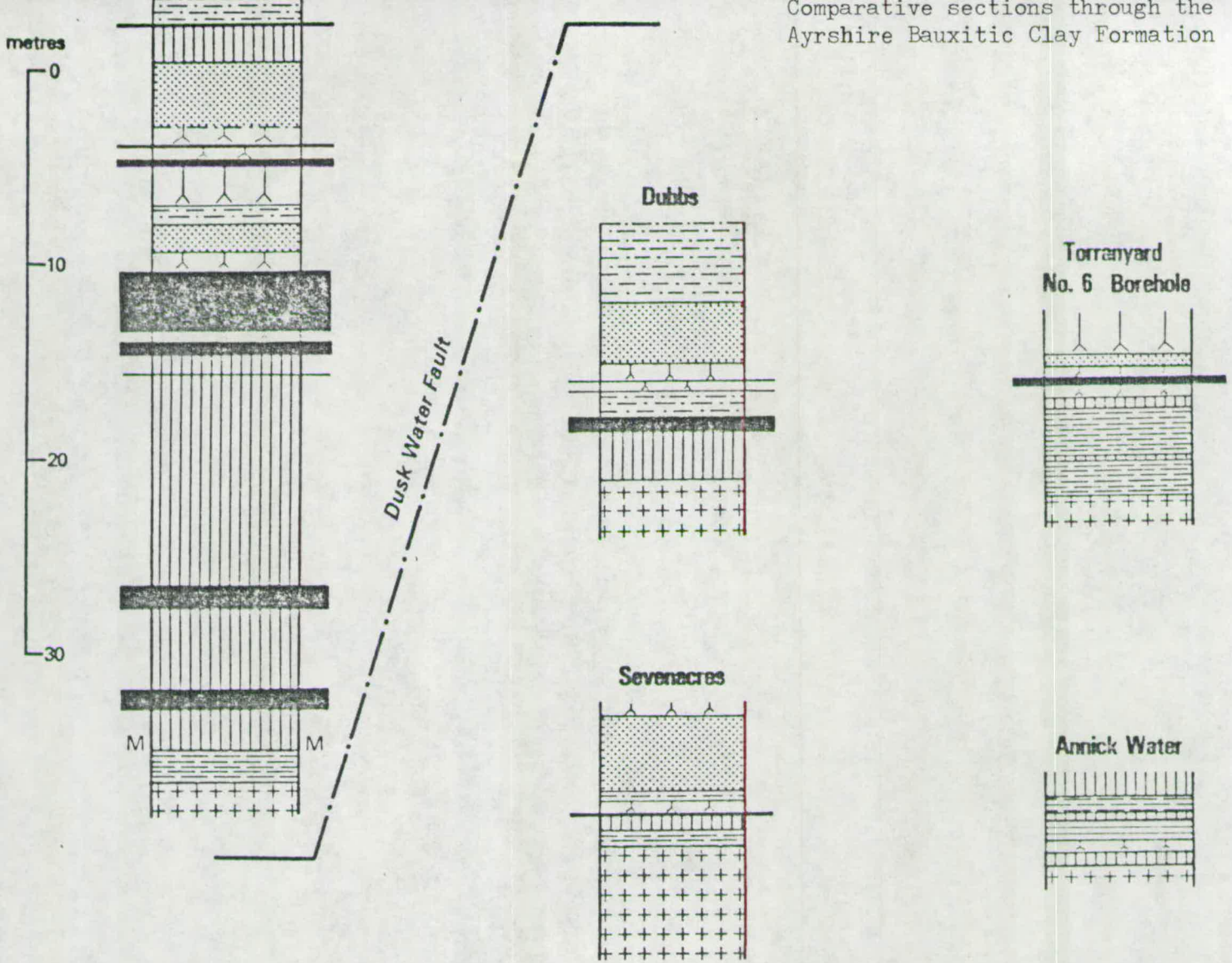

OUTCROP OF THE
AYRSHIRE BAUXITIC CLAY FORMATION
scale 0 1 2 3 4 5 6 7 8 km.
SMITHSTONE
Dusk Water Fault
SEVENACRES
TORRANYARD
No 6 BOREHOLE
DUBBS
ANNICK WATER
Annick Water Fault
Ardrossan
Saltcoats
Kilmarnock
Inchgotrick Fault
Troon
Ayr
Kerse Loch Fault
N
Ayrshire Bauxitic Clay Formation at outcrop
Westphalian Ayrshire coalfield with bauxitic clay possibly present at depth
Geological boundary
Fault, crossmark on downthrow side
Boehmite and/or Diaspore present in bauxitic clay

Fig. 9.2



Comparative sections through the Ayrshire Bauxitic Clay Formation

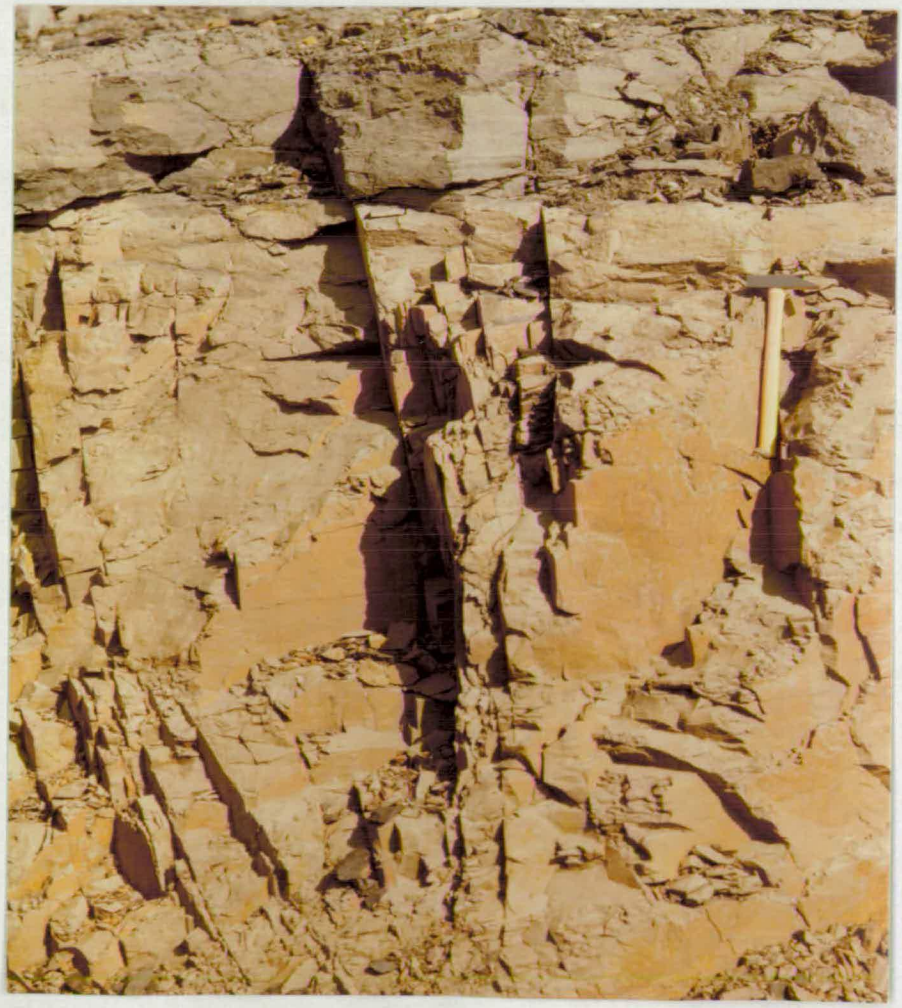
Fig. 9.3

PLATE 9.1

a. Ayrshire Bauxitic Clay Formation at Smithstone showing interbedding of coal and carbonaceous bauxitic clays with the other bauxitic clays.

b. Close-up of bauxitic clay at Smithstone showing characteristic steep jointing. Carbonaceous bauxitic clay occurs at top of section.





hot lava flows or ash falls. A marine band is locally preserved at the base of the bauxitic clay in this area.

South of the Dusk Water Fault at Dubbs the formation is considerably thinner with a bauxitic clay unit of around 4 m in thickness. The transition from bauxitic clay to basaltic lava is never sharp and is often marked by a transitional clayrock lithology rich in sphaerosiderite. The sequence at Sevenacres with the transitional clayrock zone is typical of a large part of the outcrop of the Ayrshire Bauxitic Clay Formation. There may locally be interbedding with other lithologies. In the Torranyard No 6 Borehole a bauxitic clay bed occurs within the clayrock while at Annick Water mudstones with plant fragments and a seatclay occur within the bauxitic clays.

9.8 Torranyard Borehole study

A petrographical, chemical and mineralogical study has been undertaken of the core of the Torranyard No 6 Borehole with colleagues in the University of New South Wales (Monro, Loughnan and Walker, in press). The detailed lithological log of the borehole is given in table 9.1 and fig. 9.4. The results of this study may be summarised as follows:

Petrographical results:

(1) the basal clayrocks contain microlites of kaolinite aligned parallel to the bedding and clasts with original volcanic textures

(2) the lower bauxitic clay contains abundant oolites and pisolites

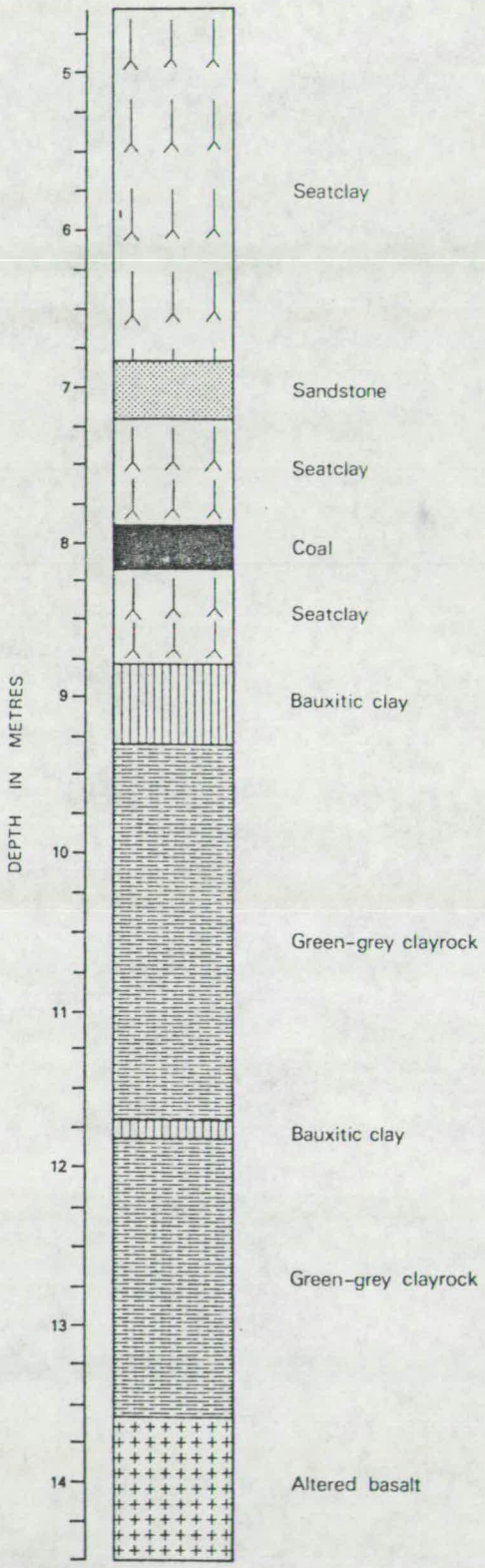
(3) the upper clayrocks also contain microlites of kaolinite aligned parallel to the bedding but do

TABLE 9.1

The Ayrshire Bauxitic Clay Formation in the Torranyard No. 6 Borehole /NS 3575 4373/

	Depth (metres) from	to
Seatclay, medium grey, structureless, abundant sphaerosiderite	4.50	6.83
Sandstone, fine-grained, light grey, compact, tuffaceous	6.83	7.19
Seatclay, dark grey, structureless, ironstone nodules near top becoming black and carbonaceous to base	7.19	7.89
COAL, bright with dull ribs	7.89	8.17
Seatclay, black, carbonaceous, bedded coaly stringers	8.17	8.24
Seatclay, grey, soft, broken	8.24	8.78
Bauxitic clay, light brownish grey, fine-grained some bedding, fragmented material, sub-conchoidal fracture, steep carbonate-coated joints	8.78	9.54
Clayrock, fragmented, grey with dark grey mudstone clasts, bedded, abundant sphaerosiderite	9.54	9.94
Clayrock, fragmented, light greenish grey with abundant sphaerosiderite	9.94	11.70
Bauxitic clay, light brownish grey, fine-grained, fragmented material at top	11.70	11.80
Clayrock, dark greenish grey, abundant sphaerosiderite	11.80	14.00
Basalt, greenish grey, soft, weathered	14.00	14.50

Section of the Torranyard No. 6 Borehole



not contain clasts with original volcanic textures

(4) the upper bauxitic clay is rich in oolites and pisolites towards the top and contains coarse angular clay clasts resembling the underlying clayrocks.

Chemical results:

(1) mobile elements, sodium, potassium and yttrium are depleted in the altered basalts, the clayrocks and the bauxitic clay

(2) other mobile elements, calcium, magnesium, ferrous iron, rubidium, barium and strontium, show an erratic trend down the profile

(3) immobile elements, zirconium and niobium are concentrated to the same degree as aluminium although both are somewhat enriched in the bauxitic clay layers

(4) other immobile elements, titanium, chromium and vanadium show relative depletion within the bauxitic clay layers.

Mineralogical results:

(1) neither quartz nor illite occur in the bauxitic clay or clayrocks

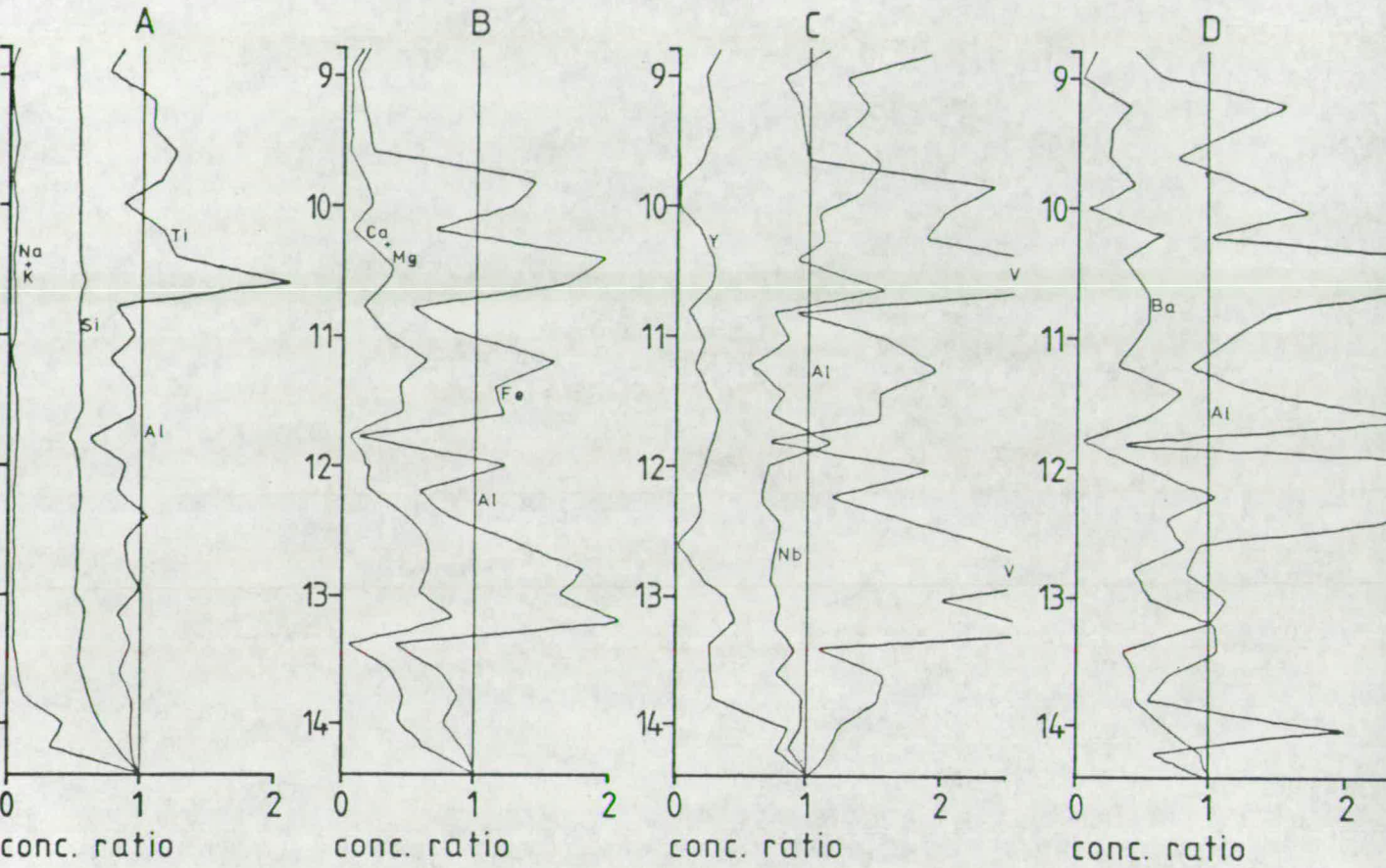
(2) siderite is the most abundant ferruginous mineral

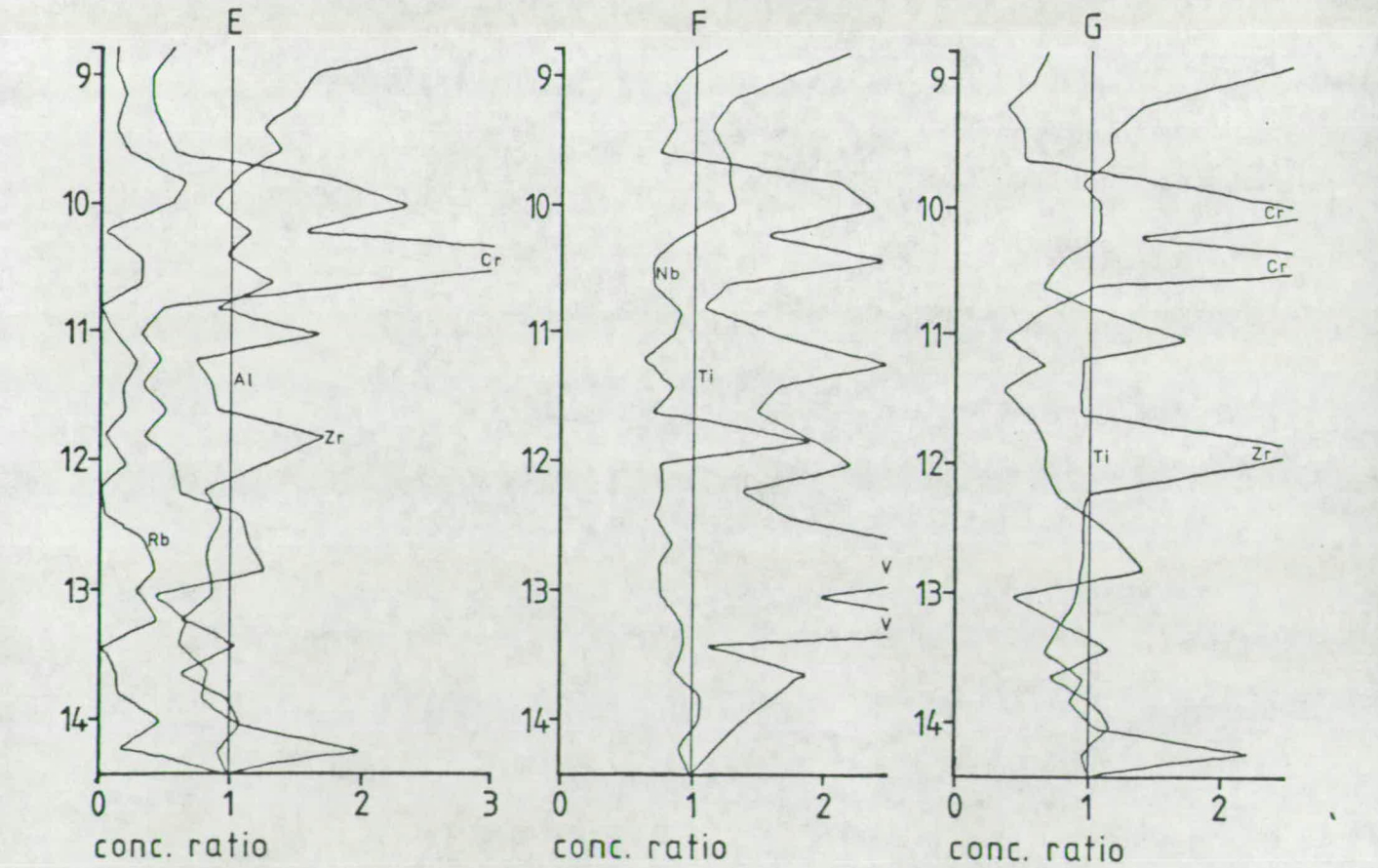
(3) kaolinite is the dominant constituent of the bauxitic clay, clayrocks and altered basalts.

The chemical results are also displayed graphically in fig. 9.5 A to E where the concentration ratios relative to

CONCENTRATION RATIOS

plotted against depth from surface - Torranyard No 6 Borehole





aluminium are plotted against depth and in fig. 9.5 F and G where concentration ratios are plotted relative to zirconium. The chemical data show two profile patterns related to mobile elements, a depletion profile (Na, K, Y) and an erratic profile (Ca, Mg, Fe, Rb, Sr, Ba). The latter may result from re-introduction of these elements from groundwater. The profiles from immobile elements indicate that either enrichment or depletion may occur within the bauxitic clay layer.

In a recent review of the titanium dioxide content of the bauxitic clays of Ayrshire, Cameron (1980) quotes a wide range of values from 1.2% to 14.17% TiO_2. He states that TiO_2 levels of around 5.53% may be expected in a residual deposit with an average Al_2O_3 value of 37.31%. He also suggests that the higher TiO_2 values may be due to reworking of the residual deposit with the localised formation of titanium-bearing heavy mineral placers. A reworking mechanism may account for enrichments not only in titanium but also in other immobile elements. Conversely if a reworking mechanism is operating it must also be depleting some areas of immobile elements.

9.9 Bauxitic clay - autochthonous or allochthonous?

Wilson (1922) recognised two modes of occurrence of bauxitic clay, (1) bauxitic clay which formed in situ by the downward percolation of water, and without any mechanical disintegration and (2) bauxitic clay that has been formed as a true sedimentary deposit on the floors of shallow lagoons, i.e. an allochthonous and an autochthonous development. The criteria used by Wilson to recognise an allochthonous origin was the presence of oolites and pisolites.

The study of the Torranyard Borehole core and the observations

of the Ayrshire Bauxitic Clay Formation throughout the area highlight a number of features in addition to the presence of oolites and pisolites which are inconsistent with an *in situ* development of bauxitic clay from basaltic lavas;

a) The presence of a repeated sequence of bauxitic clay and coal at Smithstone.

b) The presence of a marine band preserved locally at the base of the bauxitic clay at Smithstone.

c) The presence of laminated mudstone with plant remains beneath bauxitic clay at Annick Water.

d) The presence of randomly orientated clasts of parallel aligned microlites of disordered kaolinite within the bauxitic clays of the Torranyard Borehole.

e) The presence of anomalously high or low values of immobile elements (having regard for the degree of inhomogeneity which may be present within the original rock).

The factor which is most important in suggesting an *in situ* development is the nature of the lithological junctions. The bauxitic clay generally grades downwards into clayrock which in turn grades into altered basalt. Former sharp junctions may be obscured in a reworked deposit by laterisation after reworking and by the diagenetic processes which have taken place. Where none of the above criteria are evident an *in situ* development is assumed.

Using these criteria the bauxitic clay developed north of the Dusk Water Fault is regarded as being largely allochthonous in origin though some of the basal clayrock lithologies may have developed by the *in situ* weathering of the underlying basaltic lavas. South of the Dusk Water Fault the outcrops are more

extensive, the profiles more varied and the conclusions less positive. Again the basal clayrocks which grade into altered basalts may be an in situ development but, as at Torranyard, there are sections which are largely allochthonous in origin.

9.10 Bauxitic clay - a flint clay

A comparison of the characteristics of the bauxitic clays of Ayrshire and those of flint clays (Keller 1967) is given in table 9.2. In terms of occurrence, sedimentological structures, mineral composition and textural variation the two are virtually indistinguishable, supporting the proposal that the bauxitic clay is indeed a flint clay.

9.11 Bauxitic clay - environment of deposition

Within the Dalry Basin the Passage Group rocks and in particular the rocks of the Ayrshire Bauxitic Clay Formation are preserved in a relatively small area. But the formation of bauxitic clays is a significant factor in the chronostratigraphy and in the interpretation of the environment at this time. Laterites, of which bauxitic clay is a specific type, are residual deposits and as such require significant time to form in any thickness. This occurrence indicates a period of time with little or no sediment input, a disconformity.

Lateritic weathering requires a tropical climate and alternate wet and dry seasons. The development of bauxitic clay during late-Passage Group time would indicate that the climate was then tropical with dry and rainy seasons.

Despite the variation in the thickness of the basaltic lavas

TABLE 9.2

A comparison of various features of the bauxitic clay of Ayrshire with those of a typical flint clay.

	Bauxitic clay of Ayrshire	Flint clay[1]
OCCURRENCE	In generally non-marine strata associated with coal	In non-marine strata, frequently but not invariably associated with coal
STRUCTURES		
Bedding	Coarse and lenticular	Coarse and lenticular
Lamination	Non-laminated, massive	Non-laminated, massive
Induration	Considerable compared with associated strata	Considerable compared with associated strata
COMPOSITION		
Dominant	Kaolinite, well-ordered	Kaolinite, generally well-ordered
Accessories	Siderite, anatase (Boehmite and diaspore recorded elsewhere)	Diaspore, boehmite, quartz, siderite, anatase, illite
TEXTURES	Cryptocrystalline, oolitic, vermicular, brecciated	Variable. Cryptocrystalline, oolitic, brecciated, vermicular

[1] From Keller (1967)

the topography at this time was low as only local reworking of the weathered crust has taken place. The variable thickness of basaltic lavas appears to have been accomodated by tectonic movements. The proximity of an area of sea is indicated by the presence of marine bands though their local distribution would suggest that the limits of incursions are sinuous. The presence of oolites and pisolites would indicate shallow possibly lagoonal bodies of water into which reworked material would be washed and in which the oolites and pisolites would form. The presence of standing bodies of water are also indicated by the presence of log mats of Sidullaria which are seen at Smithstone.

Chapter 10 Analogues

10.1 Introduction

In each of the preceeding chapters, the sediments of the Dalry Basin have been considered within their stratigraphic context. In this chapter the sediments are discussed from the point of view of their various environments of deposition and compared with possible ancient and modern analogues.

a) Volcanic detritus: Both the Kirkwood Formation (see chapter 3) and the Ayrshire Bauxitic Clay Formation (see chapter 9) have been derived from basic igneous rocks. A two-stage process of weathering and transportation is inferred. Analogues of the weathering processes are considered in tropical areas of recent basic volcanic activity, in the Hawaiian Islands where the topography is steep and the Deccan peninsula of India where the topography is low. Analogues of the transport characteristics displayed in the Kirkwood Formation are sought in the fluvial clastic deposits of the Devonian rocks of the Catskill Mountains, USA and the Old Red Sandstone of south Wales.

b) Deltaic environments: Sequences which are interpreted as deltaic are described from the Limestone Coal Group (see chapter 7), the Upper Limestone Group (see chapter 8) and possibly from parts of the Lower Limestone Group (see chapters 4 and 6) of the Dalry Basin. Many potential analogues may be cited and the characteristics of the Dalry Basin sediments are first compared with the general characteristics of river-, tide- and wave-dominated deltas. These are typified by the Mississippi, Gulf of Papua and Rhone deltas respectively and an analogue may be sought here. Comparisons are also made with contemporaneous sedimentation in the north of England and in the Kincardine Basin in the eastern Midland Valley of Scotland.

c) Linear clastic shoreline: The demarcation between the deltaic environment and that of the linear clastic shoreline is imprecise. The sequence of sediments in part of the Calciferous Sandstone Measures has been suggested as being part of a shoreline rather than deltaic deposition. This suggestion is tested against modern linear clastic shorelines on the east coast of the USA and against an ancient analogue in the Lower Silurian sediments of south-west Wales.

d) Shallow marine sedimentation: Sediments of shallow marine origin are present in the Upper and Lower Limestone Groups and within the Calciferous Sandstone Measures. In addition evidence has been cited to indicate exposure of the Dockra Limestones in the Dalry Basin. Analogues for these sediments and for the later alteration are considered from the Great Bahama Bank, Florida and the Guatamala and Honduras shelf.

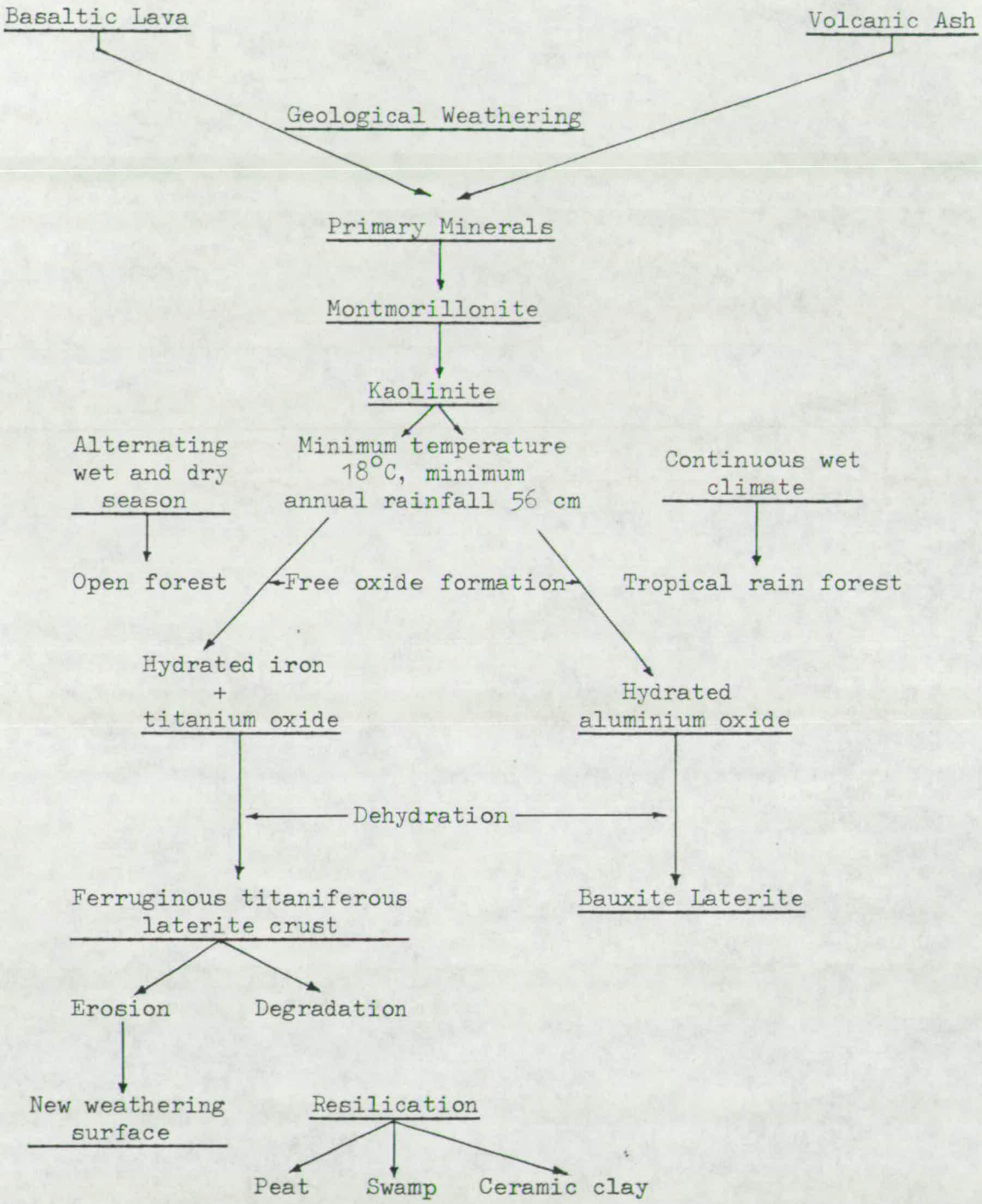
10.2 Volcanic detritus

The volcanic detritus characteristic of the Kirkwood Formation of the Calciferous Sandstone Measures and the Ayrshire Bauxitic Clay Formation of the Passage Group result from the interaction of two processes, weathering and transportation.

The weathering of basic igneous rocks to give kaolinitic, iron-rich sediments is the process of lateritisation. The steps in the weathering of a basaltic lava under tropical conditions are summarised in table 10.1. While in the Kirkwood Formation the processes have progressed only as far as to give montmorillonite or kaolinite, in the Ayrshire Bauxitic Clay Formation kaolinite has formed with, in places, breakdown to give boehmite and diaspore.

Valeton (1972) distinguishes two types of bauxitic deposit, a

TABLE 10.1



From Sherman (1952)

'slope type' which forms lens-shaped bodies, is zoned in the downslope direction and is characterised by the presence of gibbsite and diaspore and the 'plateau type' which are developed along well-drained valley sides as the lateral equivalent of plateau laterites. The slope-type deposits occur on the steep topography of the Hawaiian Islands while the plateau-type deposits occur in the Deccan peninsula of India.

The plateau type bauxites of the Deccan have a marked and characteristic profile (Valeton, 1972, fig. 47) consisting of a thin red clay on a lateritic iron crust with a mottled zone below resting on a bauxite with a transitional saprolite zone separating it from the fresh basalt. Neither the Kirkwood Formation nor the Ayrshire Bauxitic Clay Formation is characterised by such a profile though within the latter there is some differentiation into a bauxitic clay, an intermediate clay rock and fresh basalt. While lateral reworking and transportation could mask profile development there is little evidence to suggest that a 'plateau type' development is a good analogy for the genesis of the volcanic detritus of the Dalry Basin.

The bauxites developed in Hawaii (Sherman 1958) are characterised by lateral differentiation into facies or catena caused by the downslope movement of groundwater. The upper slope (Halii series) consists of ferruginous bauxites low in SiO_2 but high in Al_2O_3 and Fe_2O_3. Circulating water is impeded in the bottom slope and resilicification of gibbsite occurs (Puhi series). In the intermediate zone (Haiku series) there has been both segregation of gibbsite and ferruginous aggregates and precipitation of gibbsite in layers. Abbot (1958) records lenses or cavities up to 15 cm in length

of nearly pure bauxite formed on the upper slope of the channel of the River Wailu by lateral feed. Enrichment in aluminium is also recorded by Sherman (1958) on pitching lava flows on the islands of Maui and Hawaii where rainfall is high, with good groundwater circulation. Lenticular bodies form in hollows in the lava topography which consist of nearly pure gibbsite.

Rainfall is also particularly important in the redistribution of iron. In conditions of steady tropical rainfall iron is leached from the profile and removed entirely. During alternating wet and dry seasons ferrous iron leached in the wet season is oxidised in the dry season and precipitated as extremely insoluble ferric oxides. The abundant but patchy distribution of ferric iron in the bauxitic clays of Ayrshire suggests a similar mode of formation.

The weathering process which has resulted in the sediments of the Kirkwood Formation is similar to that giving the slope type bauxites of the Hawaiian Islands though the sediments of the Kirkwood Formation show features of transportation and are less severely weathered. Vegetation plays an important part in stabilising modern volcanic slopes preventing erosion of the weathering products. The role of any vegetation which may have been present on the Lower Carboniferous lava slopes of the Dalry Basin is not known.

The Ayrshire Bauxitic Clay Formation has also similarities with the slope type bauxites of the Hawaiian Islands. The lateral variation in the deposit with lenses bearing bauxitic minerals (Wilson 1922) is analagous to the development of aluminium-rich bauxites in hollows in the Hawaiian lavas. While there is profile differentiation which could be akin to that developed in plateau type

bauxites it has been suggested (Monro, Loughnan and Walker, in press) that these may be attributed to reworking.

The suggestion that much of the Ayrshire Bauxitic Clay Formation has been transported comes from indirect evidence of nature of clasts, presence of fossils etc. No sedimentary structures are preserved which indicate how the material was transported. Within the Kirkwood Formation are conglomeratic horizons which fine upwards into clay sized particles. The weathering process has also contributed to a net lowering of the present grain size of the beds.

The characteristics of the Devonian fluvial sediments of south Wales and those of the Catskill Mountains, USA, have been summarised by Selley (1970). He emphasises a generalised fining-upward sequence consisting of a basal conglomeratic channel floor deposit followed by cross-bedded sands, point bar deposits overlain by fine-grained overbank flood plain sediments.

In the Kirkwood Formation coarse conglomerate beds with an erosive base are readily recognised as channel floor deposits. The fine sand bands may be attributed to point bar or levee deposits while the fine silts and muds may be considered as overbank floodplain deposits. The presence of root casts within the fine-grained sediment also points towards this interpretation.

The sediments in the Kirkwood Formation, now dominantly argillaceous, may have been coarse-grained at the time of transportation before weathering reduced the overall grain size. Equally the supply of detritus from the weathering of the lavas may have been dominantly argillaceous.

10.3 Deltaic environments

The original definition of a delta (Herodotus, c430 BC) was of a triangular area at the mouth of a river. This term was broadened and re-defined by Lyell (1854) as "alluvial land formed by a river at its mouth". This definition recognised the continuum that exists between the delta as a triangular area at the mouth of a delta and a linear clastic shoreline. The nature of the delta depends on the interaction of three processes, wave action, tidal action and river action. Galloway (1975) suggests that the delta type may be defined by plotting on a ternary diagram a measure of the effects of each of these three processes. This gives a triangular diagram with the areas from each apex corresponding to river, wave or tidal dominated deltas.

River dominated deltas: These deltas generally have the traditional triangular or lobate morphology developed by the seaward progradation of sediment from the river mouth without redistribution by wave or tidal action. The velocity of the river water and its sediment carrying capacity is much reduced when it leaves its channel and the main sediment load is deposited in the delta front area. A distributary mouth bar consisting of the most coarse-grained detritus forms, the sediment deposited becoming more fine-grained seawards towards the pro-delta area where clays and fine silts are deposited from suspension. Channels and subaqueous levees may also occur in this delta front environment. Within the delta plain area, distributary channels, often with subaerial levees, bring sediment to the delta front. Between the channels marsh and fine-grained overbank deposits occur.

The river-dominated delta is dynamic. Channels may silt up

and be abandoned, sub-aerial levees may be breached and another delta lobe built out in another place. The area between delta lobes then becomes an inter-distributary bay being slowly filled with fine-grained sediment.

Wave-dominated deltas: These deltas differ from those described above in that wave action is continually reworking the mouth bar deposits into a series of superimposed coastal barriers. These sand bodies tend to parallel the coastline rather than build out from it and the morphology of such a delta is linear rather than lobate.

Tide-dominated deltas: In these deltas also there is a continual reworking of the mouth bar deposits, in this case by tidal action. A series of linear or digitate ridges are formed parallel to the direction of the tidal currents. Where longshore currents are particularly strong the area of principal sediment deposition may be displaced someway down current from the river-mouth or may become completely dispersed along the shoreline. In the latter case no delta may be recognisable.

Carboniferous deltaic sedimentation in north England: Two types of deltaic facies have been recognised in the Dinantian and Namurian sediments of northern England, a Yoredale facies and a Millstone Grit facies (Ramsbottom, 1974). The Yoredale facies sediments are deposited on marine limestones in cycles beginning with pro-delta laminated silts and clays coarsening upwards into ripple and cross-bedded sands deposited at the delta front and in distributary channels and capped by coal and rooty beds formed in the swamp environment of the delta plain. A study of the sedimentary history of a single delta lobe (Elliott, 1975) supports this rather simplistic

model in general terms though adding to the detail of environmental interpretation.

The Millstone Grit facies is deposited on basinal marine mudstones beginning with a series of turbidites becoming progressively more proximal upwards followed by delta front sediments with channels infilled with turbiditic sandstones and finally the delta plain with mudstones, siltstones and minor channel sequences.

Namurian deltaic sedimentation in central Scotland: Studies have been made in central Scotland of sediments of similar age to those of the Dalry Basin. These include the strata of the Limestone Coal Group below the Black Metals (Read, 1965) and the strata of Upper Limestone Group between the Upper Hirst Coal and the Plean No 1 Limestone (Read et al 1971). The sequence described from the Limestone Coal Group is considered by Read as having been deposited during a period of widespread marine transgression with much of the complex lithological variation due to the interaction of subsidence and sedimentation. Much of the more arenaceous sediment below the Black Metals is considered deltaic with sedimentation suggested as being analagous to a 'small-scale' Mississippi-type delta.

The Upper Limestone Group sequence in one cycle between the Upper Hirst Coal and the Plean No 1 Limestone is studied by Read et al using trend-surface analysis. They suggest that analogues of these sediments may be found in various parts of the Mississippi delta and conclude that deposition occurred in a delta prograding from the north-west, north and east in a series of short-lived, small-scale delta lobes or crevasse systems.

Sedimentation in the Dalry Basin: Similarities may be seen between the patterns of sedimentation of the Upper Limestone Group

and Limestone Coal Group of the Dalry Basin and sequences of sediments in modern deltas, the Yoredale deltaic facies of northern England and the Namurian sediments of central Scotland. All are marked by a distinct upward -coarsening sequence of sediments with delta plain coals and seat beds and channel deposits. Rapid alternations of environment are also seen which are interpreted as delta shifting or crevassing. The presence of rooty beds and coals at the top of the deltaic cycles in the Dalry Basin suggest that reworking of the delta top by either wave or tidal action is not an important factor. No turbiditic sediments characteristic of the Millstone Grit delta facies of northern England have been found in either the Limestone Coal Group or the Upper Limestone Group sediments of the Dalry Basin.

The sandstone and siltstone bodies in the Lower Limestone Group have also been considered as being of deltaic origin (chapter 6.8) although the geometry of the bodies is linear. Scrutton (1960) notes that the Mississippi delta in 1874 consisted of a series of fingers of sand close to the main distribution channels and represent the early constructional phase of the delta (bird's foot delta). A linear morphology is also thought to have resulted from a river-dominated deltaic environment in Upper Carboniferous sediments in north Devon (Elliott 1976).

The scale of any delta will depend not only on how it forms but for how long it has existed. The delta complexes of the Limestone Coal Group and Upper Limestone Group were at least as wide as the present Midland Valley (70 km) while those of the Lower Limestone Group were more local. An individual delta lobe of the Mississippi may be as little as 10 km wide but over the past 5,000 years seven partially overlapping lobes have built the deltaic complex till it is now around 200 km wide (Shirley, 1966).

10.4 Linear clastic shorelines

Deltas are formed where rivers supply more sediment than can be redistributed by marine or wave action. Where such redistribution does take place, linear clastic shorelines form.

They may be formed with either a rising or a falling sea level. Regressive shorelines usually consist of a series of sand ridges side by side, each of which represent the position of a former beach face. The vertical sequence consists of silt and clay passing up into fine sand with shell fragments and thence into fine-grained cross-bedded sand with roots at the top. This sequence has no similarities with any sequence in the Dalry Basin.

The mechanisms associated with a transgressive sequence are summarised by Elliott (1978). Two mechanisms are considered. The first involves shoreface retreat of the barrier island system where sediment is eroded from the upper shoreface and redeposited in the lower shoreface-offshore area or in lagoons as washover fans (Swift 1975). The second mechanism 'in-place drowning' involves the barrier remaining intact until the wave breaker zone reaches the top of the barrier when sedimentation jumps landward into the inner margin of the lagoon (Sanders and Kumer, 1975). Because of their relatively thin nature and because of the poor preservation potential in a transgressive environment these sediments are rarely recognised in the geological record.

Modern transgressive sequences, eastcoast Canada and USA: The sequences in a clastic shoreline environment with a rising sea level may be examined on the eastern seaboard of Canada and the USA. Fischer (1961) records the present day distribution of sediment along the New Jersey coast with lagoonal sedimentation separating a barrier island from the land. During transgression there is a

landward shift of both the lagoonal and the barrier island facies which may involve the complete destruction of the barrier island system and its replacement by offshore sands. Fischer compares these sequences with a cycle from the Pennsylvanian Cherokee Group of south-eastern Kansas where barrier sands rest unconformably on older sediments. This phase is considered transgressive and is followed by a regression phase of barrier beach and lagoonal sedimentation.

A study of the sediments of the Bay of Fundy in Newfoundland, Canada (Swift 1968) also highlights the erosive element at the base of a transgressive clastic shoreline sequence. Swift also recognises a three-fold facies division, lagoon-barrier complex-open marine, though the sediment sequence may be modified during the transgression. Comparisons are made with the Cretaceous, Peedee and Black Creek Formations of the Carolina coastal plain where a disconformity marks the base of a transgressive sequence. Here, however, much of the record of the facies sequence appears to be missing.

The barrier and lagoonal complex of Rhode Island is unusual in that sediment supplied to the barrier island is relatively low (Dillon 1970). This factor is considered by Dillon to be significant in allowing the barrier island complex to migrate landwards. Its base remains at a shallow depth, resulting in erosion of the entire seaward side. Barrier islands supplied with abundant sediment are considered more likely to remain stationary even with a rising sea level until the volume of sediment required to extend the base area is greater than the sediment supply. The barrier island then flounders as in the 'in place drowning' mechanism.

Silurian transgressive barrier islands, south-west Wales:

Barrier islands preserved in a Lower Silurian transgressive

sequence are described from south-west Wales (Bridges 1976). A Lower Silurian eustatic rise in sea level caused the landward migration of a belt consisting of lagoonal-barrier island-offshore marine sediments on to a volcanic terrain of basaltic lavas. Lenses of volcanic detritus similar to that of the Kirkwood Formation of the Dalry Basin are locally preserved immediately above the lavas. This is followed by a lagoonal facies consisting of intercalated mudstones and siltstones with a restricted marine fauna. The succeeding barrier sand facies consists of well sorted, bioturbated sandstones with occasional pebbles and a low faunal content. Finally the open marine facies consists of sandstones and mudstones with a rich and diverse marine fauna.

Sedimentation in the Dalry Basin: The examination of modern clastic shorelines shows that transgressive shorelines are characterised by erosion and modification of older sediments. It seems inevitable that no sub-areal part of the barrier complex will be preserved and preservation of other parts will depend on the degree of protection. The sequences described from the south Wales Silurian are comparable with the sequences associated with the Upper Old Mill Limestone and the Lower Old Mill Limestone. While the dune phase can generally be recognised in modern barrier island complexes it has not been recognised in either the sediments of the Dalry Basin or in those of the Lower Silurian of south Wales. An analogy of the preserved sequences in the Dalry Basin may thus be readily made with the south Wales rocks (including transgression on to a volcanic terrain), the mechanism of formation is probably best sought from the study of the sediments of the Bay of Fundy. The restricted nature of the outcrop of these sediments in the Dalry Basin makes more detailed comparison invalid.

10.5 Shallow marine environments

Much has been written on carbonate sedimentation in shallow marine environments since Sorby (1851), including detailed work on present day environments in the Bahamas (Agassiz, 1894, 1896). The potential of these sediments as oil reservoirs has further stimulated work. Reviews of sedimentation in these environments are common, Selley (1970), Wilson (1975), Sellwood (1978), James (1979).

The range of facies within the shallow marine environment have been described (Wilson 1970, 1974, 1975) and are summarised in table 10.2.

Within the Dalry Basin the shallow marine environments give rise to the following lithofacies:

1. Dark grey limestones and calcareous mudstones - occurring throughout the Upper Limestone Group, within the Broadstone and Wee Post limestones and within the 'Lugton' facies of the Dockra Limestone of the Lower Limestone Group.
2. Light grey bioclastic limestones - occurring within the 'Trearne' facies of the Dockra Limestone, Lower Limestone Group and the Upper and Lower Old Mill limestones, Calciferous Sandstone Measures.
3. 'Restricted fauna' limestones - occurring locally at the top of the Dockra Limestone, Lower Limestone Group and locally within the Lower and Upper Old Mill limestones, Calciferous Sandstone Measures.

The dark grey argillaceous limestones are thought to have been deposited below normal wave base, they are often well bedded and while the fauna is in places quite diverse, often it is not abundant. Limestones, particularly in the Lower Limestone Group, are frequently affected by root penetration. It is difficult to discriminate between the sediments of Wilson's open neritic and his open platform environments though the better fit appears to be the latter.

TABLE 10.2

Facies	Lithology	Color	Grain type and depositional texture	Bedding and sedimentary structures	Terrigenous clastics admixed or interbedded	Biota
Basin (euxinic or evaporitic) a) Fine clastics b) Carbonates c) Evaporites	Dark shale or silt, thin limestones (starved basin); evaporite fill with salt	Dark brown, black, red	Lime mudstones: fine calcisiltites	Very even mm lamination: rhythmic bedding: ripple cross lamination	Quartz silt and shale: fine grain siltstone:cherty	Exclusively nektonic-pelagic fauna preserved in local abundance on bedding planes
Open shelf (undaform) Open marine neritic a) Carbonates b) Shale	Very fossiliferous limestone interbedded with marls: welll segregated beds	Grey, green, red, brown	Bioclastic and whole fossil wackestones: some calcisiltites	Thoroughly burrowed: thin to medium: wavy to nodular beds: bedding surfaces show diastems	Quartz silt, siltstone, and shale: well segregated beds	Very diverse shelly fauna preserving both infauna and epifauna
Toe of slope carbonates	Fine grain lime-stone: cherty in some cases	Dark to light	Mostly lime mudstone with some calcisiltites	Lamination may be minor: often massive beds: lenses of graded sediment: litho-clasts and exotic blocks. Rythmic beds	Some shales, silt, and fine grained siltstone	Bioclastic detritus derived principally from upslope
Foreslope a) Bedded fine grain sediments with slumps b) Foreset debris and lime sands c) Lime mud mounds	Variable, depending on water energy upslope;sedimentary breccias and lime sands	Dark to light	Lime silt and bioclastic wackestone-packestone: litho-clasts of varying sizes	Slump in soft sediments: foreset bedding:slope bioherms: exotic blocks	Some shales, silt, and fine grained silt-stone	Colonies of whole fossil organisms and bioclastic debris
Organic (ecologic) reef a) Boundstone mass b) Crust on accumulation of organic debris and lime mud: bindstone c) Rafflestone	Massive limestone-dolomite	Light	Boundstones and pockets of grainstone: packstone	Massive organic structure or open framework with roofed cavities: lamination contrary to gravity	None	Major frame building colonies with ramose forms in pockets; in situ communities dwelling in certain niches
Sands on edge of platform a) Shoal lime sands b) Islands with dune sands	Calcarenitic-oolitic lime sand or dolomite	Light	Grainstones well sorted: rounded	Medium to large scale crossbedding: festoons common	Only some quartz sand admixed	Worn and abraided coquinas of forms living at or on slope few indigenous organisms
Open platform (normal) marine, limited fauna) a) Lime sand bodies b) Wackestone-mudstone areas, bioherms c) Areas of clastics	Variable carbonates and clastics	Dark to light	Great variety of textures: grainstone to mudstone	Burrowing traces very prominent	Clastics and carbonates in well segregated beds	Open marine fauna lacking (eg echino-derms, cephalopods, brachiopods): molluscs, sponges, foram algae abundant patch reefs present
Restricted platforms a) Bioclastic wackestone, lagoons and bays b) Litho-bioclastic sands in tidal channels c) Lime mud-tide flats d) Fine clastic units	Generally dolomite and colomitic limestone	Light	Clotted, pelleted mudstone and grain-stone; laminated mudstone; coarse litho-clastic wackestone in channels	Birdseye, stromatolites, mm lamination, graded bedding, dolomite crusts on flats. Cross-bedded sand in channels	Clastics and carbonates in well segregated beds	Very limited fauna, mainly gastropods, algae, certain foraminifera (eg miliolids) and ostracods
Platform evaporite a) Nodular anhydrite and dolomite on salt flats b) Laminated evaporite in ponds	Irregularly laminated dolomite and anhydrite, may grade to red beds	Red,yellow,brown		Anhydrite after gypsum; nodular, rosettes,chicken-wire and blades; irregular lamination; carbonate caliche	Windblown,land derived admixture clastics may be important units	Almost no indigenous fauna, except for stromatolitic algae

From Wilson (1978)

The Trearne facies of the Dockra Limestone can never be generally described as a 'reef' or organic build-up in that bedding is nearly always preserved. The exception is at Dockra Quarry /NS 363 524/ where the limestone is apparently massive with biohermal structures. This is a unique locality and one which, due to flooding, is inaccessible for detailed study. The'Trearne'facies more generally is a light coloured bioclastic limestone with little or no clastic material present. Cross-bedding is locally preserved though the bioclastic components are heterogeneous in size and may have not been moved very far. The restricted fauna which Wilson ascribes to the platform-edge sands relates to a supposed high energy environment but if this were less, organisms could thrive on the substrata though not in sufficient numbers to build up into a 'reef'. The'Trearne'facies of the Dockra Limestone may be transitional between Wilson's 'reef' and his platform-edge sand environments. The Upper and Lower Old Mill limestones are crinoidal in character, fining upwards into mudstones. These sediments may well compare with Wilson's platform-edge sands but in a transgressive sequence they will be replaced upwards by sediment deposited below wave base.

The 'restricted fauna' limestones include the development at the top of the Dockra Limestone characterised by the presence of ostracods and algal oncolites, the marginal algal developments in the Lower Old Mill Limestone and the red fossiliferous mudstones in the Upper Old Mill Limestone. Possibly the most significant factor in both Wilson's restricted platform and platform evaporite environments is the nature of the fauna. The sediment type will vary with local conditions and in the restricted platform environment Wilson quotes a wide range of facies. Evaporite minerals are not

recorded from the Dalry Basin but the reddened top of the Dockra Limestone suggests exposure to sub-areal weathering. Environments of deposition of the 'restricted fauna' limestones in the Dalry Basin are comparable with Wilson's restricted platform environment but a sub-areal environment without precipitation of evaporite is also present.

Modern tropical shelf areas are classified by Sellwood (1978) into those which are rimmed by reefs and those which are open. Of the open shelves two types are distinguished, those with appreciable volumes of clastic sediment and those where the clastic input is relatively small. Clastic-influenced open shelves occur along the Atlantic shelf of southern North America. Rapid transgression has meant that most of the sediments here are reworked Holocene deposits (Milliman et al, 1972). There is a facies zonation which parallels the coast based on the dominant grain type, the bioclastic content ranging from near-shore molluscs to off-shore planktonic foraminifera. In the eastern Gulf of Mexico a similar facies zonation has been established (Ginsburgh et al, 1974). Quartz sand is here the most in-shore sediment becoming finer-grained off-shore. The bioclastic content also changes from near-shore molluscs to off-shore planktonic foraminifera.

The sediments of the Dalry Basin show little of the bioclastic zonation typical of the environments described above neither laterally nor vertically. The sequence associated with the Lower and Upper Old Mill limestones may be comparable in that clastic sands are succeeded by crinoidal sand which becomes more muddy upwards.

A clastic-free open shelf occurs off the Yucatan penninsula, an area of shelf adjacent to a low undulating karstic plain with no

surface drainage. Thin carbonate deposits overly older sediments. No comparison can be made with the Dalry Basin sediments which are characterised by the abundance of clastic sediment.

The Bahama/Florida platform is typical of the shelf environment rimmed by 'reef' deposits. This, once continuous shelf is now submerged and divided into the Bahama Platform and the Florida Platform. The Great Bahama Bank, a part of the Bahama Platform, has a complex lithofacies distribution (Purdy 1963). A belt of dominantly muddy sediments is located close to Andros Island while reef and coraline algae deposits are found around the platform edge. Elsewhere on the platform top oolites are common. Pellet mud and mud lithofacies, occuring in the more sheltered areas of the platform, are subject to fluctuating salinity and exposure within the intertidal zone. The fauna recorded is sparse in both numbers and variety but algae are common particularly as crusts within the top 15 cm of the high water tidal zone and in the supratidal marshes (Hardie, 1977). Here the distribution of algae record the progressive Holocene sea-level rise. The mud content of the oolitic lithofacies is low, a function of the high energy environment.

The area of southern Florida is dominated by an arcuate string of islands which separate the reef tract from Florida Bay. The reef tract is a complex of actively-growing coral with sand shoals. Hurricanes, common in the area, are an important factor in the break-up and redistribution of this material. The back-reef lagoon is a more sheltered environment with a rock pavement or patch reefs in the seaward zone and a landward zone carpeted by sediment-trapping Thalassia grass. Florida Bay is a broad, very shallow area extending from the coastal mangrove swamps to the back-reef lagoon. The

sediment within the bay consists of grass-covered mud banks rising to within 30 cm of water surface. The faunas are, like those of the muddy facies of the Bahamas, tolerant to hypersaline conditions and are restricted in both number and variety.

The shelf of Guatamala and Honduras is around 480 km long and from less than 2 to 29 km wide. Three major depositional areas have been recognised (Ginsburg and James, 1974), the barrier platform, the shelf lagoon and an inshore area influenced by terrigenous sediment. The barrier platform has a steep seaward face and consists of corals and coralline algae. Behind the barrier platform is a deep shelf lagoon with water up to 60 m deep. Pinnacle reefs occur but the dominant sediment type is a lime mud with a transitional calcarenite facies close to the reef. Shorewards there is an increase in the proportion of mud which is derived from a network of coastal rivers. Wave action within the lagoon is of sufficient energy to generate a series of spits and bars.

Reconstructions of the early Carboniferous plate dispositions (Smith et al 1973) places the Dalry Basin in the tropical regions of the southern hemisphere. The climate which existed then may have been similar to that existing today in the areas around Florida, the Bahamas etc. It is difficult to propose analogues between most of the marine limestones of the Dalry Basin and the Bahama Bank or Florida, but the particular lithologies of the 'Trearne 'facies of the Dockra Limestone may be comparable. There is a vast difference in scale but the Trearne facies does have a shallow-water or exposed development, it does suggest that the biota has acted as a sediment trap and it does have development of local reef structures.

The Guatamala and Honduras shelf is morphologically very

different from the area of sedimentation in the Dalry Basin. There are, however, similarities in the types of sediment which have accumulated. Both are dominated by argillaceous carbonate sediments deposited below wave base but with wave action generating shoals of bioclastic sand. Reefs may also occur building up to or close to water surface. These sediment types occur in the Lower and Upper Limestone Group of the Dalry Basin.

10.6 Post-script

The quest for analogues both modern and from the geological record is fraught with danger. While certain characteristics may be closely matched there is no such thing as the perfect analogue. Rather they must be used as a guide in the construction of hypothetical models which can be refined or discarded as the geological database expands.

Chapter 11 Tectonics and cyclicity

11.1 Introduction

The sedimentary record in the Dalry Basin given in the previous chapters highlights the importance of tectonism and cyclicity in determining the spatial pattern of sediment distribution. In this chapter the tectonic evolution of the Midland Valley and possible controls for the cyclicity in sedimentation are discussed.

11.2 Midland Valley evolution - the traditional view

The pre-plate tectonic concept of the evolution of the Midland Valley has been discussed by Kennedy (1958) and George (1960). Kennedy postulated a compressional rift model. He considered the Highland Boundary Fault as having been initiated in a post-Arenig but pre-Caradocian orogeny when intensely folded geosynclinal sediments were thrust over a more gently folded belt. The Southern Upland Fault, he considered as having developed in the late-Silurian as a steeply thrust frontal zone of the main Southern Upland fold belt.

Kennedy's synthesis is primarily structural. He does not make the fullest use of the stratigraphical variation within the Midland Valley and beyond.

The model postulated by George (1960) takes greater account of stratigraphic variation across the Midland Valley and differs markedly from that of Kennedy. George considered that there is no evidence to suggest that the Highland Boundary Fault was initiated during a pre-Arenig period. A comparison of sequences on either side of the Highland Boundary Fault, particularly in Tyrone, has led George to consider that this fault was initiated as a normal fault

downthrowing to the north.

The Southern Upland Fault is considered by George as having originated no earlier than late-Silurian but facies contrasts within these rocks may signify the beginning of associated tectonism. The occurrence of Lower Old Red Sandstone sediments in a syncline trending south-west from St Abb's Head and Eyemouth suggests to him that the Southern Upland Fault was then no barrier to depositional continuity and that this structure was most probably initiated in mid-Devonian times.

Within the Midland Valley itself George draws attention to the fault-bounded Pentland anticline and the graben structure between it and the Southern Upland Fault. He considers that this minor graben with thick, sharply folded Lower Old Red Sandstone sediments within it can be traced southwards to beyond Dalmellington where its northern margin is marked by the Straiton Fault.

During Carboniferous time George considered that sedimentation along the northern margin of the basin was in the main not tectonically but erosively determined with overstep of Carboniferous strata into the Highlands in deeply eroded areas. The Southern Upland Fault, however, he considers as having a marked influence on sedimentation particularly in the Sanquhar and Thornhill areas. He also observed that the Inchgotrick Fault influenced sedimentation during the Lower Carboniferous acting as a margin to a block area. George does not discard the hypothesis that Carboniferous sedimentation outside Ayrshire may have been fault controlled but emphasises the effect of volcanic episodes on sedimentation.

George highlights the complexity of the evolution of the Midland Valley in the history of movement along the Highland Boundary Fault

and in the 'block and basin' structures within the Midland Valley graben proper. What is missing is the 'driving mechanism' to account for these complexities and for that we must look to the plate tectonic concepts.

11.3 Midland Valley evolution - a Caledonian plate tectonic view

Models for the evolution of the Scottish Caledonides in plate tectonic terms have been proposed by many authors (Dewey, 1969, 1971; Fitton et al, 1970; Mitchell et al 1975; Philips et al, 1976; Stone, 1980) but these only consider the early initiation of the Midland Valley structure to mid-Devonian times. Thereafter its history must be interpreted from a study of Hercynian plate dispositions and by using evidence from the initial basin fill, the Old Red Sandstone (Bluck, 1978, 1980), Carboniferous volcanism (Macdonald, 1975; Macdonald et al, 1977; Francis, 1979) and the evolution of an adjacent structure - the Northumberland Basin (Leeder, 1971, 1974, 1976).

Dewey (1969, 1971) envisaged oceanic crust subducted north-westward beneath continental crust along a line trending north-east to south-west through Glen App. On the consuming plate margin a trench formed within which sediments were stacked up by successive overthrusting to form an accretionary wedge. By late-Llandoverian time this had become 'Cockburnland', an area of erosion supplying sediment both to the north and to the south. He suggested that the highlands were a volcanic, high heat flow region with the Highland Boundary Fault marking the line of the volcanic front and that the Midland Valley was a non-volcanic sedimentary wedge between volcanic front and trench. The Midland Valley therefore first appears as a

sedimentary basin in late-Llandovarian time bounded by 'Cockburnland' to the south and the Highland Boundary Fault to the north. The Southern Upland Fault developed, according to Dewey, around early Devonian time.

Dewey's model therefore envisaged a Midland Valley basin bounded to the north-west by a south-easterly downthrowing normal fault and to the south-east initially by an emergent land mass and subsequently by a normal fault downthrowing to the north-west, the Southern Upland Fault.

This model corresponds in many respects with the 'Andean' type continental margin (Dickenson, 1981) where the Midland Valley is represented by a forearc basin. However the 'Andean' model does envisage thrusting along the northern margin of the forearc basin and some evidence of this type of structure along the Highland Boundary Fault has been recorded (Armstrong et al, 1970). It is difficult to envisage the formation of a tensional graben geometry under the compressional forces of a plate subducting north-westward. Isostacy from the erosion of the Highland and Cockburnland areas and deposition within the Midland Valley could initiate the required vertical movements as could the intrusion of granitic batholiths in the Highland and Southern Uplands, but the model is not entirely satisfactory with respect to the Midland Valley.

Fitton and Hughes (1970) proposed a rather different plate model based on petrochemical evidence from the Ordovician lavas of the Lake District and Wales. Oceanic crust subducted south-eastwards along a line trending north-east to south-west through Moffat. Partial melting of this plate as it moved deeper into the crust gave rise to progressively more alkaline volcanism southwards with tholeitic

northern Borrowdale Volcanics, calc-alkaline southern Borrowdale Volcanics and alkaline volcanism in Wales.

Later authors have set this geographically incomplete model in broader regional context.

Mitchell and McKerrow (1975)considered that the development of the Midland Valley and the Southern Uplands could be explained by analogy with the Burma orogen. The model proposed is very similar to that of Dewey (1969) but differing in that oceanic rather than continental crust is considered as underlying the Midland Valley. Mitchell et al also considered that an extinct Benioff zone where oceanic crust was subducted beneath continental crust occurs to the north of the Highland Boundary Fault. They recognised the complex structural history of the Highland Boundary Fault but suggest that, by analogy with the late-Cenozoic subsidence of the Eastern Trough of Burma, the evolution of the Midland Valley graben from early Devonian times was related to incipient rifting. Isostacy from the erosion of the Highlands and Southern Uplands and deposition within the Midland Valley is considered as the mechanism triggering subsidence.

The model of Mitchell et al does not explain the observations of Fitton et al nor does it provide a mechanism other than isostacy for the later rifting in the Midland Valley.

Phillips et al (1976) attempted to reconcile the contrasting models of Dewey and Mitchell et al with that of Fitton et al. They envisaged three subduction zones. The first (Sd 1) in the north-west Highlands corresponds to the Caledonian front and is the site of east south-easterly subduction of a Lewisian foreland plate beneath continental crust containing an ensialic Dalradian basin.

The second (Sd 2) lying to the south of the Southern Uplands is the north-westerly subducting margin of the oceanic Iapetus crust while the third (Sd 3), to the north-west of the Lake District, is the south-easterly subducting margin of the same Iapetus crust. Phillips et al derive directions of plate movement from tectonic trends and suggest oblique subduction on Sd 1 and Sd 2 causing sinistral strike-slip fault movement along the Great Glen Fault. Likewise oblique subduction on Sd 2 and Sd 3 would cause an earlier closure of the Iapetus Ocean in the north-east then in the south-west from late Ordovician to early Devonian times with resultant strike-slip faulting along the suture.

While Phillip's model does not discuss directly the evolution of the Midland Valley it places its evolution at a time following the oblique collision of two continental masses with considerable strike-slip movement along the suture.

Stone (1980) draws an analogy between the Midland Valley and the West Peruvian trough and suggests that the northern margin of the Iapetus Ocean was 'Andean' in type, with an andesitic volcanic belt (the Lower Old Red Sandstone volcanics of the Siddlaw Hills) within the fractured continental crust.

The models for the early evolution of the Midland Valley still leave three questions without a satisfactory answer.

1. What is the nature of the basement beneath the Midland Valley? The early models of Dewey and Fitton and Hughes imply oceanic crust beneath the Midland Valley, however geophysical studies (Bamford et al, 1977; Powell, 1970) in association with petrographic studies of xenoliths within Carboniferous vents (Upton et al, 1976; Graham et al, 1978) suggest a continental basement. Magnetotelluric

and magnetovariational studies (Hutton et al, 1980), however, are inconclusive about the nature of the basement beneath the Midland Valley.

2. What is the nature and history of the bounding faults? The Highland Boundary Fault in particular has a long history with the orientation of the fault plane and the direction of movement not known for certain. The presence of Old Red Sandstone and marine Carboniferous strata south of the Southern Upland Fault suggests that 'Cockburnland' was a faulted eroded highland.

3. What is the role of strike-slip faulting? The Phillips model suggests strike-slip movement along the Iapetus suture and inevitably the effects of this stress pattern will also be felt throughout the fracture belt. Recent work in the Old Red Sandstone (Bluck, 1978, 1980) indicates the importance of these movements.

11.4 Midland Valley evolution - Old Red Sandstone evidence

The most recent plate tectonic models (see chapter 11.3) suggest closure of the Iapetus Ocean by mid-Devonian times. The sediments deposited both during and after this closure may therefore hold evidence as to the early evolution of the Midland Valley. Recent work on both the Upper and the Lower Old Red Sandstone of the Midland Valley (Bluck, 1978, 1980) summarises the history of sedimentation of these rocks. The Lower Old Red Sandstone crops out in two strips, one adjacent to the Highland Boundary Fault, the Strathmore Syncline and the Sidlaw Anticline, and the other adjacent to the Southern Upland Fault.

The Lower Old Red Sandstone is 9 km thick in the Strathmore Syncline (Armstrong et al, 1970). Thickness variations which have been recognised are thought to result from the south-westerly overstep

by successively younger sediments (Patterson and Harris, 1969). Thick conglomerates interstratified with sandstones occur along the Highland border with finer grained sediments on the eastern side of the Strathmore Syncline interstratified with a major lava pile. Bluck (1978) considers that the coarse conglomerates adjacent to the Highland Boundary Fault were deposited as alluvial fans deriving material from the rising Highland massif. The finer sediments of the south-eastern limb of the Strathmore Syncline he considers as being deposited in braided streams flowing south-west.

A similar pattern of sedimentation occurs in the second strip of outcrop adjacent to the Southern Upland Fault, though the marked south-westerly thinning is only demonstrated in the Pentland Hills (Mykura, 1960). Conglomeratic alluvial fans, thinning towards the north-west, occur adjacent to the Southern Upland Fault while finer grained sediments, deposited in braided streams flowing south-westwards, occur in the Maybole area.

Bluck (1979) concludes that during Lower Old Red Sandstone times the margins of the sedimentary basin were not far from the present positions of the Highland Boundary and Southern Upland Faults. A Middle Old Red Sandstone age (George, 1960) for the major movement on the bounding faults presents the difficulty of accommodating up to 9 km of Lower Old Red Sandstone strata. Bluck considers that secondary minor fractures, sourcewards of the main Highland Boundary and Southern Upland Faults, were responsible for defining the margins of the basin and that these would now be largely eroded with uplift. He considers that the Strathmore Basin extended south-westerly with time and that the throw of the basin-bounding faults would decrease in that direction.

The Upper Old Red Sandstone rests unconformably on Lower Old Red Sandstone in the Midland Valley and it is generally assumed that most if not all of the Middle Old Red Sandstone is missing. The Upper Old Red Sandstone consists of four main lithological divisions, (1) a basal conglomerate, (2) pebbly sandstones, (3) breccia and conglomerate, and (4) sandstone with calcrete (Bluck, 1980). A fifth unit occurring locally at the base of the Upper Old Red Sandstone in the northern Firth of Clyde consists of sandstones considered to be in part aeolian and in part a fluvial overbank deposit. Bluck (1980) considered Upper Old Red Sandstone deposition to have occurred in two embayments, the Midland Valley and Kintyre embayments separated by an upland ridge trending north north-west to south south-east.

Bluck's detailed studies in the west of the Midland Valley suggest that the two embayments developed different dispersal patterns, to the south-west in Kintyre and to the north-east in the Midland Valley proper. Bluck envisages extension of the depositional basin by sinistral strike-slip faulting along the Highland Boundary fault and step faulting withinthe basin. He considered (p 75) that "... basin development in the Clyde is only a local expression of a wider structural event which encompasses most of Midland Scotland ...".

Bluck presents a useful model to account for the distribution of Upper Old Red Sandstone sediments using a tectonic regime (strike-slip faulting) previously suggested from plate tectonic models (Phillips et al, 1976). However, the development of these basins can only be satisfactorily established when time-horizons are recognised. The concept of strike-slip faulting as a control of sedimentation within the Upper Old Red Sandstone may have a continuing role into the Carboniferous.

11.5 Midland Valley evolution - evidence from Carboniferous volcanism

The Dalry Basin was the site of two major volcanic events resulting in the eruption of the Clyde Plateau Volcanic Formation and the Passage Group Volcanic Formation. Both events have influenced subsequent sedimentation (see chapters 3 and 9) but these and other volcanic events are the effects of deeper crustal processes which influence the evolution of the Midland Valley.

An association between volcanism and faulting in the Midland Valley has been suggested by the line of necks along the Campsie Fault (Craig et al, 1975), in the complex history of the Ardross Fault (Francis et al, 1970) and in the thickness variation in the Clyde Plateau Volcanic Formation (Hall, 1974, also see chapter 3). Petrochemical studies of the Carboniferous lavas (Macdonald, 1975; Macdonald et al, 1977) indicate two cycles of magma generation. The first occurring from early Carboniferous to mid-Namurian times is considered as having evolved in a tensional tectonic regime with normal faulting while the second, from late-Namurian to Permian times is ascribed to a compressional environment with intermittent tension and continued normal faulting.

Francis (1978) attempts to set Carboniferous volcanism within a plate tectonic setting. By early Carboniferous times the Iapetus Ocean had closed and two continental masses were welded into one. The Carboniferous volcanism is therefore considered as a mid-plate phenomenon. Volcanism in this tectonic environment is frequently considered to result from mantle plumes. These are however stationary and as the crustal plate moves so does the volcanic centre. There is no evidence to suggest migration of volcanic centres during

the Carboniferous. Within the Dalry Basin alone major volcanism has occurred in the early Carboniferous and in the Passage Group with minor sporadic activity during the Limestone Coal Group.

Volcanism appears to be intimately connected with the structural evolution of the Midland Valley but the actual mechanism has not been resolved. The dynamics of the continental margin lying some way to the south (see chapter 11.6) may relate. From petrochemical studies a simple tectonic regime can be suggested to include the first of Macdonald's cycles, but the second cycle with compression intermittently relieved demands a more complex model.

11.6 Midland Valley evolution - a Hercynian plate-tectonic view

With the closure of the Iapetus Ocean taking place in mid-Old Red Sandstone times (see chapter 11.4) the evolution of the Midland Valley during Upper Old Red Sandstone and Carboniferous times is influenced by Hercynian plate dispositions. Like the Caledonian models discussed earlier (chapter 11.3) authors have at various times postulated many combinations of plate movement and direction of subduction which have been summarised by Francis (1978). Many of the earlier models (Johnson, 1973; Floyd, 1972) feature northerly subduction along a line through Cornwall. More recent work, however, (Lorenz et al, 1976; Lorenz, 1976) suggests south-easterly subduction with closure of the mid-European ocean during Westphalian times.

The implications on the evolution of the Midland Valley are that south-easterly subduction at the plate margin could generate tensional stresses within the plate during Dinantian and Namurian times and that the continental collision during the Westphalian could result in compression. These implications can then be compared

favourably with the stress pattern suggested by the petrochemistry of the lavas (see chapter 11.5).

11.7 Midland Valley evolution - evidence from an adjacent structure

The evolution of the adjacent Northumberland Basin (Leeder, 1971, 1974, 1976) is in many ways analogous to that of the Midland Valley being aligned along a similar north-east to south-west trend, part-bounded by major fault structures and characterised by early Carboniferous volcanism.

Leeder (1971) considers that the evolution of the Northumberland Basin is related directly to volcanism. Partial melting in the upper mantle, with associated dilation and uplift, is considered to have occurred shortly before the end of Upper Old Red Sandstone times. As evidence of this uplift Leeder cites the widespread occurrence of concretionary cornstones towards the top of the Upper Old Red Sandstone. With a tensional stress regime established over the swell, a half-graben faulted on the southern margin was established. Following eruption of the lavas and crustal depression within the half-graben coastal alluvial plains and deltas built out down the southerly-facing palaeoslope.

The presence of cornstones, cited by Leeder as evidence of uplift, may also result from other means. A period of non-deposition when the sedimentation in a valley has reached equilibrium would result in pedogenesis and the formation of cornstones.

However, a further line of evidence from the Dalry Basin lends support to Leeder's hypothesis. Red sandstone with cornstones, which have been eroded in places, lie immediately below the lavas of the Clyde Plateau Volcanic Formation. At Meikle Busbie /NS 238 459/

for example lavas rest on a surface cut in a major cornstone bed. Erosion, together with cornstone development, may be better evidence of uplift. A tectonic history of the Midland Valley similar to that of the Northumberland Basin would fit with the conclusions of Macdonald et al (1977) (also see chapter 11.5) relating to the tectonic environment during generation of the Dinantian lavas.

In a later paper Leeder (1976) applies his Northumberland model to other basins including the Midland Valley, in the Devonian to Carboniferous block and basin system. The outstanding unanswered question, however, is the mechanism which causes the initial partial melting in the mantle. Leeder used a Johnson (1973) plate tectonic model with northwards subduction in the region south of Brittany, but did not relate this to the partial melting.

11.8 Midland Valley evolution - a summary

The evidence discussed previously suggests that the Midland Valley was initiated prior to and during the closure of the Iapetus Ocean under regional compressive stress. The Highland Boundary Fault, and possibly other north-east to south-west trending structures, were initiated as thrusts within a depositional basin lying between an uplifted Highlands and 'Cockburnland'. Oblique closure of the Iapetus Ocean involved strike-slip faulting along the suture and probably similar movements along the north-east to south-west trending structures. Subsequent Hercynian plate movements, together with isostatic effects from erosion of the Highlands and Southern Uplands and deposition in the Midland Valley, and swelling from partial melting in the mantle, caused tension within the welded continent. Normal faults developed along the margins and within the Midland

Valley resulting in a conventional rift structure. Within this major structure minor block and basin areas are also developed.

11.9 Tectonics in the Dalry Basin

Within the Dalry Basin the role of tectonics in determining the pattern of sediment distribution was noted by Richey (1930) in relation to the Inchgotrick Fault and to a lesser extent the Dusk Water Fault. Evidence presented in this thesis has substantiated these ideas by tracing thickness changes and by identifying missing strata across these faults. It has also become apparent that in addition to these two faults other north-easterly trending faults are involved, such as the Annick Water Fault.

The model envisaged for sedimentation adjacent to the Inchgotrick Fault suggests that this fault did, during Limestone Coal Group and Upper Limestone Group times, have a northwards facing fault scarp which acted as a barrier to some of the marine transgressions of the Upper Limestone Group. The area south of the Inchgotrick Fault may well have been an upland area characterised only by channel-fill deposition throughout the Limestone Coal Group and well into Upper Limestone Group times.

The Inchgotrick Fault marks the northern margin of a block area, the southern margin of which is marked by the Kerse Loch Fault and the 'Line of Steep Measures' in central Ayrshire (Eyles et al (1949). The long history of the Inchgotrick Fault is demonstrated by the fact that it coincides with the southern limit of the Clyde Plateau Volcanic Formation (see chapter 3.2). Its influence therefore extends back to at least early Carboniferous times.

The Dusk Water Fault has a similar early history. Geophysical

evidence has demonstrated thickness changes in the Clyde Plateau Volcanic Formation across it (Hall, 1974) and contemporaneous fault movements have been suggested as an explanation. However, Hall has also suggested that these movements were to the south. Downthrow to the north is detected by thickness variations (see chapter 7.6) during Limestone Coal Group times but it is during the latter part of the Upper Limestone Group that the fault has its greatest effect on sediment distribution. In the post-Lower Linn Limestone period the Dusk Water Fault marked the northern margin of a block area characterised by channel-fill deposits. The marine transgressions associated with the Upper Linn, Corsankell and Diddup Limestones appear to have extended no further than the Dusk Water Fault (see figs 8.19 and 8.20). This fault may therefore have been marked by a northerly facing fault scarp during this period.

It can be clearly demonstrated that a block-and-basin pattern was influencing the sediment distribution in the Dalry area. Tectonism similarly influences Lower Old Red Sandstone sedimentation at the eastern end of the Midland Valley between the Pentland Anticline and the Southern Upland Fault (see chapter 11.2). The extent of this tectonic pattern on sediment distribution elsewhere in the Midland Valley remains to be investigated.

11.10 Cyclicity - the descriptive approach

Phillips as early as 1836 first recognised the 'Yoredale-type' cycle of limestone-shale-sandstone-coal in the north of England. Similar cycles were later found to be common within the Upper Visean and Namurian sediments throughout northern England and Scotland. Early work on the 'Yoredale-type' cycles was largely descriptive but

mechanisms for generating these cycles were proposed. Hudson (1924) suggested uplift of the source area while Brough (1928) suggested intermittent, jerky subsidence; recurrent, sharp uplifts in the source area and climatic changes from humid to arid.

By the 1950s the concept of the 'standard' or 'ideal' cycle had emerged (Dunham, 1950). He emphasised that parts of the ideal cycle may be missing and that the total thickness of the cycle and that of the individual lithologies within it may vary. By doing so, Dunham highlighted the recurring problem of defining a cycle. A cycle of sedimentation may be detected on all scales from the microscopic, such as varves, to the magascopic where changes may be apparent over systems. Differing scales of cycles may be caused by different mechanisms.

The deltaic origin of much of the clastic sediment within the 'Yoredale-type' cycles was recognised by Moore (1958, 1959, 1960) who suggested an interaction between a shallow epicontinental sea and a large delta. Lateral variation and to some extent repetition of cycles was attributed to delta crevassing.

Johnson (1960, 1961) studied the variation in the lithologies of observed cycles as compared with Dunham's 'ideal' cycle. He concluded that lithological differences may be explained by deposition in different parts of a major delta complex.

Zone 1	Nearshore facies	coal-sandstone-shale
Zone 2	Yoredale facies	coal-sandstone-shale-limestone
Zone 3	Open sea facies	shale-limestone
Zone 4	Open sea facies	limestone

Duff et al (1967) in reviewing cyclical sedimentation also highlighted the variability which may occur in dominant lithology especially in

the Scottish Carboniferous. Here however the differing cycle types are related to the broad lithostratigraphic groupings.

11.11 Cyclicity - the mathematical approach

It appears to be an inherent human characteristic to create order out of chaos (Zeller, 1964). It is therefore easier for the geologist to 'recognise' cycles than for him to be aware of a random distribution of lithologies. Attempts have been made to consider lithological sequences objectively and, if possible, quantitatively, that some of this human bias may be removed, including the problem of the cycle scale.

Pioneer work in this field (Duff and Walton, 1962) attempted, by the application of statistical techniques, to determine and define a 'modal' cycle and to erect a composite succession. Pearn (1964) suggested that a statistical comparison may be made between the 'modal' cycle and the 'ideal' cycle for a particular sedimentary environment, allowing the fit one with another to be tested.

Transition matrix analysis assesses the probability of one lithology being overlain by another. The method avoids defining a top or bottom of a cycle and allows closely related cycles to be considered together. Analysis of this type has been used extensively in studies of the Namurian sediments of central Scotland (Read and Dean, 1967, 1968; Read, 1969). A Markov-process model is used in which the occurrence of a rock type is determined only by that rock type which immediately precedes it. This is a first-order Markov chain. Should the succession of lithologies be in random order then the sequence may represent a series of independent events. A simplified version of transition matrix analysis (Selley, 1970)

has been used in this thesis.

The relationship between the cycle characteristics and migrating facies belts (Potter and Blakeley, 1968) indicates that a strong 'memory' is present where there is a regular migration of clearly defined facies belts and that the 'memory' lessens as the migration pattern becomes more complicated. In a deltaic environment it would be expected that the complex migration of a delta would generate short 'memory' cycles. These cycles would be less clearly defined and would have a tendency to have 'minor' cycles within them.

Much of the work done on cyclicity in the Scottish Carboniferous relates to coal-bearing cycles of deltaic origin; little has been done on the relationship between the clastic, deltaic part of these cycles and the marine sediments. Belt (1975) attempted to define cycles of Visean and early Namurian age in Fife from limestone through a clastic sequence to seatclays and coals. His approach was largely an attempt to define a 'modal' cycle in the Duff and Walton vein and would have been greatly helped by the application of transition matrix analysis.

11.12 Controls of cyclicity

The mechanisms for controlling cycles is still a controversial subject. As in all 'good' controversies the initial definition is still not clear. What is meant by a cycle? Duff and Walton (1962) defined the cycle as "... a group of rock units which tend to occur in a certain order and which contains one unit which is repeated frequently through the succession." In discussions of the mechanisms controlling cyclicity however authors have considered

cycles on all scales from the varve to the mesothem.

Mechanisms have been reviewed (Wells, 1960; Duff et al, 1967) and may be considered under four main headings; climatic control, eustatic control, tectonic control, sedimentary control.

Climatic control: Climate may control cycles in one of two ways. Firstly ocean water may be locked up as land ice during glaciations causing a net lowering of sea level which fluctuates with the waxing and waning of the glaciers. Secondly, changes in the weather pattern may occur on a cyclical basis related to astronomical phenomena. The effects of glaciations will be discussed later with other eustatic controls.

Attempts have been made to relate changing weather patterns to the sun spot cycle. The length of this cycle and its relationship with weather patterns is, however, not established. Broad climatic changes in the geological record have been attributed more to changes in latitude due to plate movement than to a change in the climatic pattern.

Outwith the glacial aspect it is not possible to relate cycles of sedimentation to climatic change.

Eustatic control: Worldwide changes in sea-level may result from one of two phenomena. There may be a change in the volume of water in the oceans or else the volume of the confining oceans may themselves change. Changes in the volumes of water in the oceans occurs during glaciations when large volumes of ocean water are locked up as land ice. The main glacial periods in the geological record are the late-Precambrian, the Carboniferous-Permian and in the Quaternary. The Gondwana glaciation during the Carboniferous and into the Permian has been discussed by Crowell (1976) who

supports the original suggestion of Wanless (1950) that sedimentary cycles in the Carboniferous result from waxing and waning of ice centres in Gondwana. Crowell stated that the record of the Gondwana glaciation indicated many ice centres waxing and waning irregularly over a 90 m.y. period. He suggested that the onset of cyclicity in the late-Visean can be matched with the start of glaciation and the end of cyclicity with the end of glaciation in the mid-Permian.

Glaciation undoubtedly occurred in Gondwana during the Carboniferous and into the Permian and ossilation of world-wide sea-level must result from the waxing and waning of these glaciers. However, cycles of sedimentation also occur elsewhere in the geological record apparently unrelated to glaciation anywhere. Additional factors are necessary in the cyclic process.

With the configuration of plates which existed through Carboniferous time, with subduction and ocean closure, it seems probable that the size of the ocean basins was changing and that changes in sea-level could result. Such controls have been invoked to account for cyclicity in the Jurassic (Hallam, 1963). Measurements of movements of the ocean floor summarised by Duff et al (1967) suggest that changes in the volumes of the ocean basins give sea-level changes the rates of which are much slower than would result from glaciation. As the Carboniferous cycles are characterised by relatively rapid repetition of lithological sequences, change in the volume of ocean basins is unlikely in itself to control cyclicity.

Tectonic control: Tectonism has been proposed as the controlling mechanism of Carboniferous cyclic sedimentation (Bott and Johnson, 1966). This proposal resulted from a mantle flow theory put forward

by Bott (1964). Bott linked subsidence within the depositional basin to isostatic uplift in the source area. Mantle material flowing into the uplifted area, he suggested, is derived from neighbouring areas causing local subsidence. This subsidence Bott considered as taking place in a series of short repeated steps separated by relatively long periods of quiescence.

Bott's theory is based on the initial assumption that cycles are typically 100 ft (30 m) thick. This figure is derived from an 'ideal' cycle of Westoll(1962) based on a relatively small development in the Tyne trough. However, Bott's general concept is useful as a hyopthetical model.

Bott and Johnson cited one example from the Midland Valley to illustrate tectonic control of cyclicity; Read (1961) demonstrated the splitting of a single coal seam at the margins of a small basin into fifteen small sedimentary cycles. While this is good evidence of tectonism, it relates to regional subsidence rather than faulting and is rather different from the style of tectonism envisaged by Bott. The regional subsidence may however be a feature of deeper crustal faulting.

Subsidence initiated by sediment load as suggested by Dunham (1950) and Westoll (1962) is considered unacceptable by Bott and Johnson as the subsidence caused by a given thickness of sediments will always be less than that thickness. However, sediment is being deposited in the basin and the isostatic effect of that load must have an effect on the relative position of land and sea and hence on the sediment distribution pattern. Within Ayrshire there is evidence of block and basin structures in the Carboniferous but the effects of these appear to relate more to the broad lithostratigraphic

sequence than to the individual cycle.

Sedimentary control: Sedimentary control of cyclicity is favoured by Duff et al (1967). There are two aspects to this control, the first relates to delta growth while the second relates to the role of organic accumulation (peat). Studies of deltaic complexes and particularly the Mississippi delta (Scruton, 1960) showed that delta growth is complex with channelling, crevassing and sub-delta growth taking place at different times in different parts of the delta complex. Duff et al suggested that the lithological sequence obtained from the Mississippi delta may be matched with many Carboniferous cycles. Bott and Johnson (1966) however suggested that these cycles in the Mississippi delta result from Quaternary sea-level changes. Deltaic deposits are generally lacking in lateral continuity. Compaction of a body of deltaic sediment will be uneven, a phenomena which might cause subsequent delta shifting.

The role of organic accumulations has been emphasised by Duff (1967). He suggested that peat accumulation may not go on indefinitely and its thickness might be self-controlling. As the peat accumulates so the soil conditions on which the organic matter grows become less favourable and the vegetation becomes sparser and smaller until accumulation no longer keeps pace with subsidence and the area is flooded.

Sedimentary control of cyclicity is particularly attractive where deltaic conditions can be clearly identified. However, the problem remains that without some other additional mechanism subsidence induced by the sedimentary load itself will not maintain the repetition of the cycles.

A review of the literature in the context of the Carboniferous

sequences in the Midland Valley would indicate that here cyclicity cannot be attributed to a single cause. A number of factors can be identified both local and remote which should have an influence on the cyclicity. The problem remains to quantify the effects of those factors and to demonstrate how they change in a regional sense through Carboniferous time.

11.13 Cyclicity in the Dalry Basin

Cyclicity in one form or another is apparent in all the major lithostratigraphic groups in the Dalry Basin. The lithological characteristics of these cycles vary. The analysis of the cycles in the Lower Limestone Group both above and below the Dockra Limestone (see chapters 4.4 and 6.7) show similar patterns within generally upward-coarsening trends in the clastic sediments. The complexity of the cyclical patterns may relate to the interplay between the open marine, prodelta and interdistributary bay environments in an area of low topographic relief. In both the Ardrossan and Muirlaught Boreholes there is no clear relationship between the clastic part of the cycle and the rest. Both these boreholes lie in the same tectonic block between the Dusk Water Fault and a parallel fault, 3 km to the north. The Ardrossan Borehole also showed an anomolously thick development of sandstones. Clastic sedimentation in this area may have been initiated by 'independent' tectonic events rather than by the sedimentary processes of a regional prograding delta.

In the Limestone Coal Group a clear cycle can be defined (see chapter 7.8) which coarsens upwards from mudstone, siltstone, sandstone, seatclay to coal. The 'strong memory' of one lithology for the previous lithology may, as suggested by Potter and Blakely (1968),

relate to a regular migration of facies belts. In the case of the Limestone Coal Group a delta complex advancing without significant channelling or crevassing.

The cycles in the Upper Limestone Group (see chapter 8.7) are less well defined than those of the Limestone Coal Group. The successions appear to show two types of cycle, an upward-coarsening, deltaic cycle and an upward-fining channel fill cycle. Though a thick channel fill deposit occurs in the Kilmaurs Borehole, this type of cycle only appears as a significant influence in the analysis of the Hullerhirst Borehole. Here, although channel fills are less thick, they occur more frequently in the succession.

Control of cyclicity in the Dalry Basin will result from the interaction of three factors, eustacy, tectonism and sedimentation. Eustatic changes in sea level have been suggested by Ramsbottom (1973, 1977) and these related to the Carboniferous stages. As discussed in chapter 2.6 the time scale on which these eustatic sea-level changes have been established is considerably longer than that which relates to the individual lithological cycles. At the same time there is not sufficient data to determine sea-level changes in the detail which might be reflected in individual lithological cycles. Within the Dalry Basin a broad-scale cyclicity relates to the change from dominantly marine conditions in the Lower Limestone Group to the dominantly deltaic conditions in the Limestone Coal Group, a cycle repeated from the Upper Limestone Group into the Coal Measures. This type of 'major' cycle appears to be on a time scale similar to that for the eustatic sea-level changes suggested by Ramsbottom.

Isopach maps suggest contemporaneous fault movements in the

Limestone Coal Group, Upper Limestone Group and locally in the Lower Limestone Group. The effects of tectonism however appear to be in the defining of areas of deposition, in influencing local lithofacies and in the control of the overall thickness of sedimentation. The rapid alternations which occur in the Lower Limestone Group between marine conditions with limestone deposition and terrestrial conditions with formation of seat beds and coals may have been controlled by slight regional uplift. The time scale of these changes is too rapid to be related to the proposed eustatic sea-level changes and too little clastic sediment was being deposited to cause either subsidence or the complex interplay of sedimentary environments in a major delta. With a constantly rising sea-level however and low magnitude, pulsed regional uplift, the observed sequences could be generated.

Sedimentary control of cyclicity appears dominant in the Limestone Coal Group and in the Upper Limestone Group. Repetitions of coarsening upwards clastic sequences, the individual beds of which cannot be traced laterally over a wide area, relate more readily to the complexity of data switching, crevassing and channelling in a delta complex than by external control. Some external influence however in the form of regional subsidence is required to maintain the base level for continued sedimentation (see Johnson and Bott, 1967, p 425).

Chapter 12 History of sedimentation in the Dalry Basin and conclusions

12.1 History of sedimentation in the Dalry Basin

The main features of the history of sedimentation in the Dalry Basin are summarised in table 12.1 and fig 12.1. A pattern of changes in depositional environment emerges on two scales, minor depositional cycles involving 10-20 m of sediment and major depositional cycles involving around 200 m of sediment. As has been discussed in chapter 11 control of this cyclicity comes generally from the interaction of eustacy, tectonism and sedimentation. The regular asymmetric cycles of the Limestone Coal Group are considered as being controlled by the rates of sediment supply in a deltaic environment while the rapid alternations between marine and terrestrial conditions below the Top Hosie Limestone may result from the interaction of eustatic sea-level changes with regional tectonism. A further factor which may influence sediment distribution in the Dalry Basin is volcanism which occurs at the beginning of the sequence in the form of the Clyde Plateau Volcanic Formation and at the end as the Passage Group Volcanic Formation.

12.2 Calciferous Sandstone Measures - conclusions

Volcanism had an important influence on sedimentation in the Calciferous Sandstone Measures of the Dalry Basin. It resulted in a) mass flow of material from the mantle/lower crust to the surface causing a tectonic imbalance; b) change in the surface topography; and c) provision of a lithologically distinct sediment source. Much of the tectonic imbalance appears to have been accommodated during eruption. The presence of only thin and impersistent beds of

Event No	Relative sea level movement	Rock type	Environment	Tectonism	Lithostratigraphic Unit
11	Fall	Mudstone and seat beds	Silting up of former marine area with lagoonal muds, colonisation by plants, roots locally penetrate underlying limestones with partial solution and reprecipitation in nodules	?regional uplift	
12		Sandstones and siltstones	Local erosion removes strata to Wee Post Limestone, deposition of coarse grained deltaic on channel fill sediments	?regional uplift	
13		Coal	Colonisation by plants, accumulation of plant debris in swamp conditions		
14	Rise	Marine limestones and calcareous mudstones	Shallow marine conditions over a wide area, rich marine fauna	?regional subsidence	Dockra Limestone
15	Rise	Bioclastic limestones	Organisms thriving in centre of Dalry Basin build on each other till sediment within wave base winnowing of fines, becoming argillaceous laterally		Dockra Limestone - 'Trearne' facies
16	Fall	Ostracod/algal limestone	Area of organic build-up close to intertidal zone with faunal change formation of algal oncolites by wave action	?regional uplift	Top of Dockra Limestone
17	Fall	Iron-rich crust	Local exposure of Dockra Limestone, solution in fresh groundwater leaving reddened crust with cavities filled by kaolinite, silica reprecipitates at water table as chert nodules, plant colonise limestone pavement	?regional uplift	Top of Dockra Limestone
18	Fall	Mudstones and seat beds, local siltstones and sandstones	Silting up of marine area with lagoonal muds, colonisation by plants, local deltas building with coarser clastic sediments	?regional uplift with local contemporaneous faulting	
19	Rise	Mudstones, calcareous mudstones and limestones	Complex relationship of marine and lagoonal conditions over a wide area		Lower part of Hosie Limestone Formation
20	Fall	Mudstones, seat beds and coal	Silting up of marine-lagoonal complex, colonisation by plants and accumulation of plant debris, small local deltas formed		Hosie Fireclay position

TABLE 12.1 (cont'd)

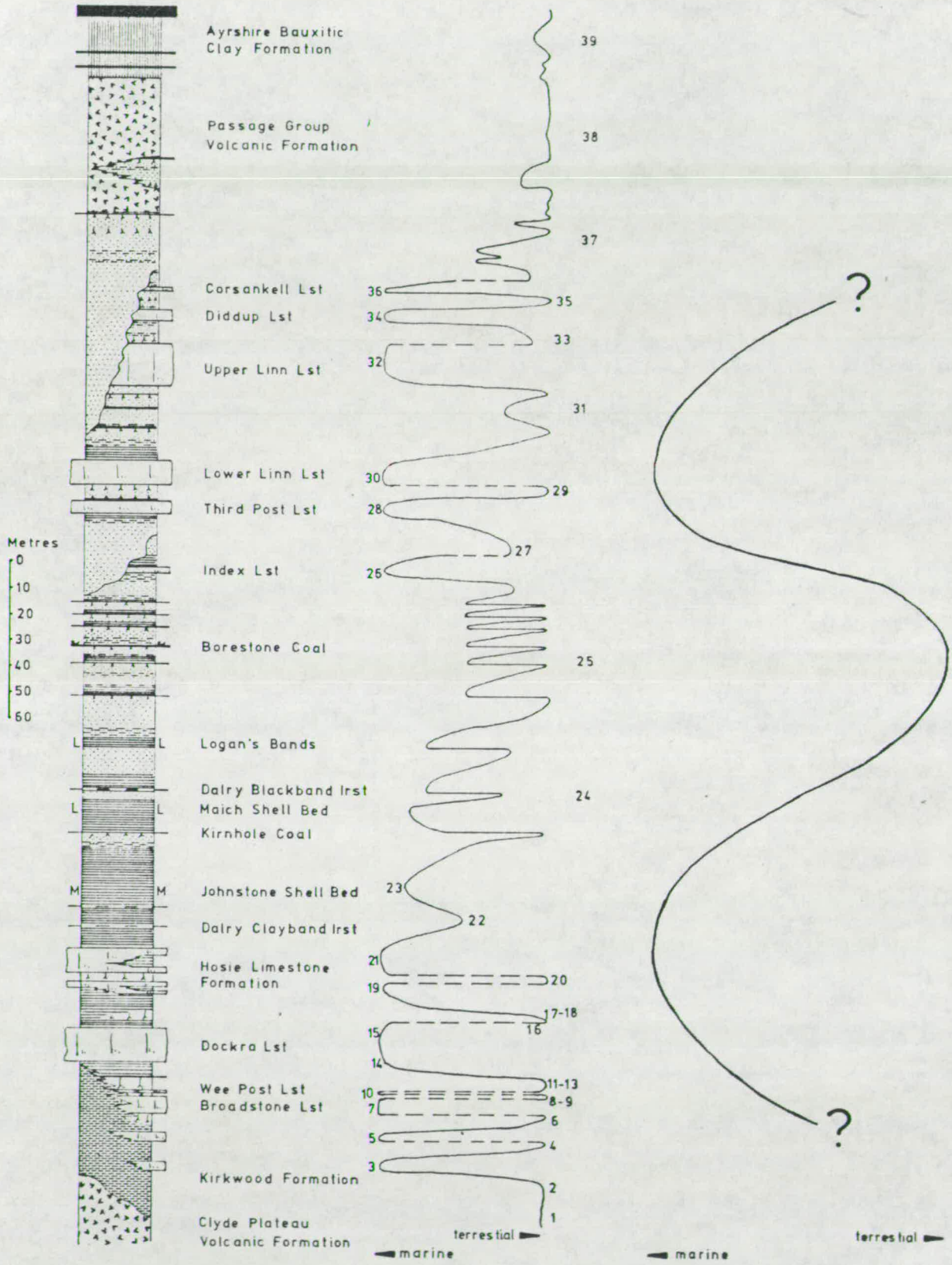
Event No	Relative sea level movement	Rock type	Environment	Tectonism	Lithostratigraphic Unit
21	Rise	Mudstones, calcareous mudstones and limestones	Complex relationship of marine and lagoonal conditions over a wide area		Lower part of Hosie Limestone Formation
22	Slow fall	Mudstones and ironstones	Widespread lagoonal conditions, ironstones formed diagenetically .		
23	Rise	Mudstones	Marine conditions, deposition of mud with rich marine fauna		Johnstone Shell Bed
24	Slow fall	Mudstones, locally sandstones, siltstones, coals	Lagoonal muds with abundant Lingula sp., small local deltas formed, with accumulation of plant debris, marine conditions maintained	Slower relative subsidence in tectonic block between Dusk Water and Annick Water Faults, greater thicknesses accumulated to the north and south of this block	Maich Shell Bed
25	Slow fall	Mudstones, siltstones, sandstones, seat beds abd coals	Advance of delta complex from the north east accumulation of plant debris on delta top		Borestone coal etc.
26	Rise	Limestones	Shallow marine environment covers Dalry Basin to north of Inchgotrick Fault; south of Inchgotrick Fault channelling (event 9) continues or else there is a disconformity or hiatus in sedimentation	Effects of movement on Inchgotrick Fault continue	Index Limestone
27	Fall	Mudstones, siltstones, sandstones	Resumption of deltaic sedimentation, channelling occurs frequently in area south of Inchgotrick Fault locally removing the Index Limestone, widespread rooty beds		
28	Rise	Limestones, calcareous mudstones	Shallow marine environment cover Dalry Basin north of the Inchgotrick Fault		Third Post Limestone
29	Fall	Mudstones, siltstones, sandstones and seat beds	Resumption of deltaic sedimentation, local channelling, colonisation of delta tops and filled channel by plants		
30	Rise	Limestones, calcareous mudstones	Shallow marine environment covers entire area both north and south of the Inchgotrick Fault depositing limestones	Effects of movement of Inchgotrick Fault cease	Lower Linn Limestone

TABLE 12.1 (cont'd)

TABLE 12.1 (cont'd)

Event No	Relative sea level movement	Rock type	Environment	Tectonism	Lithostratigraphic Unit
31	Fall	Mudstones, siltstones, sandstones and seat beds	Resumption of deltaic sedimentation, colonisation of delta tops by plants		
32	Rise	Limestones and calcareous mudstones	Shallow marine environment covers area to north of Dusk Water Fault and may encroach from the south on to the area south of the Inchgotrick Fault, south of Dusk Water Fault channelling or a disconformity or hiatus in sedimentation	Movement of Dusk Water Fault, fault scarp acts as barrier to marine sedimentation	Upper Linn Limestone
33	Fall	Siltstones, sandstones and seat beds	Exposure of limestone, early colonisation by plants, small deltas with sandstones and siltstones	?regional uplift	
34	Rise	Limestone	Shallow marine encironment in area to north of Dusk Water Fault, to south continued channelling or a disconformity or hiatus in sedimentation	Dusk Water Fault scarp remains as barrier to marine sedimentation	Diddup Limestone
35	Fall	Mostly sandstone, occasional seat beds	Extensive erosion and channelling north of the Dusk Water Fault, local erosion of Diddup Limestone to south continued channelling or a disconformity or hiatus in sedimentation local colonisation by plants		
36	Rise	Limestone	Shallow marine environment to north of the Dusk Water Fault, to south continued channelling or a disconformity or hiatus in sedimentation	Dusk Water Fault remains as a barrier to marine sedimentation	Corsankell Limestone
37	Fall	Mostly sandstones with siltstones and seat beds	Extensive erosion and channelling north of the Dusk Water Fault, Corsankell Limestone extensively eroded, to south continued channelling or a disconformity or hiatus in sedimentation, local colonisation by plants		
38		Basaltic lavas	Irregular sub-areal topography	Contemporaneous movements on the Dusk Water Fault controlling thickness variation	Passage Group Volcanic Formation
39		Bauxitic clays, clay rock, coal	Lateritic weathering and reworking of weathered material, thick accumulations with periods of non-deposition and accumulation of plant material to north of Dusk Water Fault	Contemporaneous movements on the Dusk Water Fault controlling thickness variation	Ayrshire Bauxitic Clay

Depositional cycles in the Dalry Basin



lithological succession

minor depositional cycles

major depositional cycles

conglomerate above the lavas suggests subdued topography, perhaps modified in places by thicknesses of unconsolidated ash. Lateral thickness variations appear to have been accommodated by differential subsidence with contemporaneous faulting playing an important role. Thickness variations are noted across the Dusk Water Fault while the Inchgotrick Fault scarp all but stopped the southerly extension of the lavas.

The lithological sequences south of the Inchgotrick Fault (the Harelaw and Deaconhill boreholes - see chapter 8.8) indicate events outwith the area of eruption of the lavas. About 10 m of topmost Calciferous Sandstone Measures sediments rest disconformably on mudstones with cementstones which extend down to the Upper Old Red Sandstone. Within the Dalry Basin the lavas rest directly on Upper Old Red Sandstone though northwards around Loch Thorn mudstones with cementstones occur beneath the lavas. Diagrammatic sections (figs 12.2 and 12.3) illustrate what might have been the sequence of events through late-Upper Old Red Sandstone and into early Carboniferous times in the Midland Valley. By analogy with the evolution of the Northumberland trough (see chapter 11.7) a period of contemporaneous instability with doming of the Upper Old Red Sandstone and local fault movement occurred prior to and during eruption of the lavas.

The land surface after eruption ended had little relief but as it subsided it controlled the extent of marine deposition. A ribbon diagram (fig 12.4) through the Dalry Basin demonstrates the 'gulf' in the land surface which confined the early marine deposition and how this influence becomes less significant with each successive transgression.

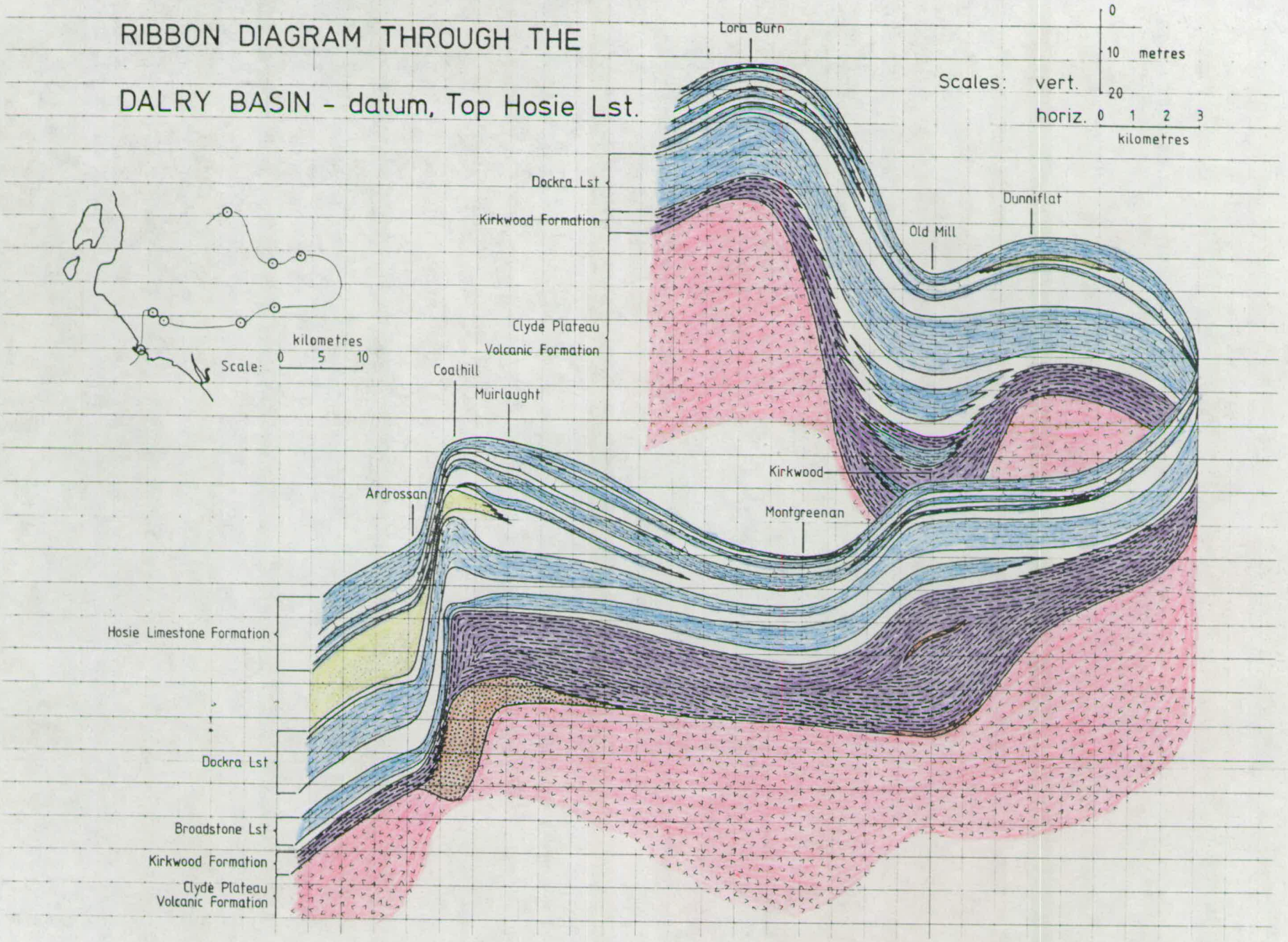

RIBBON DIAGRAM THROUGH THE
DALRY BASIN - datum, Top Hosie Lst.
Lora Burn
Scales: vert. 0 10 metres 20
horiz. 0 1 2 3 kilometres
Dockra Lst
Kirkwood Formation
Clyde Plateau Volcanic Formation
Dunniflat
Old Mill
kilometres
Scale: 0 5 10
Coalhill
Muirlaught
Kirkwood
Ardrossan
Montgreenan
Hosie Limestone Formation
Dockra Lst
Broadstone Lst
Kirkwood Formation
Clyde Plateau Volcanic Formation

Fig. 12.4

The lateritic weathering of the lavas has also provided the distinctive sediment sources for the Kirkwood Formation. These sediments are, in general, considerably thicker than previously estimated by Richey (1930). They are iron-rich. Kaolinite is the dominant clay mineral and montmorillonite also occurs. The Kirkwood Formation was deposited from ephemeral streams and rivers, infilling hollows in the land surface. Lateritic weathering continued after deposition further altering the deposit.

Similarities have been noted between the sediments of the Kirkwood Formation and the slope-type bauxites of Hawaii although the latter are more severely weathered and do not show the transportation characteristics of the Kirkwood Formation.

12.3 Lower Limestone Group - conclusions

The depositional environments of the Lower Limestone Group are dominantly shallow marine. As such the sediments are particularly sensitive to changes in relative sea-level. The area of deposition of the early marine sediments, including those of the Calciferous Sandstone Measures, was controlled by the topography of the lavas but following deposition of the Dockra Limestone the Dalry Basin was completely submerged by each transgression.

The limestones are generally uniformly argillaceous but within the Dockra Limestone two lithofacies can be recognised. The 'Lugton' facies consists of argillaceous limestones similar to the other marine limestones of the Lower Limestone Group while the 'Trearne' facies consists of a variety of types of bioclastic limestone, mud-free and forming a biothermal mound. A local pedogenic horizon, the 'White Post', was formed on the emergent

mounds of the Dockra Limestone with a relative fall in sea-level in the immediate post-Dockra Limestone period. Many of the other Lower Limestone Group limestones also have roots within the topmost beds. These locally significant features clearly arose from only minor changes in relative sea-level.

Despite the tectonic imbalance created by the eruption of the Clyde Plateau Volcanic Formation contemporaneous faulting was slight. Bed-for-bed correlations can be made across most of the major faults. The Inchgotrick Fault may have been dominant at this time taking up all the strain, as does today's San Andreas fault system, but no significant movement took place until late-Lower Limestone Group times.

Clastic sediments, of silt grade or coarser, occur in restricted areas and are relatively thin except at Ardrossan where local contemporaneous fault movements resulted in a thick accumulation. These sediment bodies have upwards-coarsening characteristics typical of deltaic deposits and a digitate morphology. They may be comparable with the bird's foot delta, constructional phase of the early Mississippi delta. Root beds were formed as the lateral equivalents of these coarser clastic sediments which were deposited when much of the rest of the area was subjected to minimal deposition.

Direct analogues of Lower Limestone Group of Lower Limestone Group sedimentation are not readily discernable. Palaeomagnetic studies suggest that the early-Carboniferous Dalry Basin was within tropical latitudes. Shelf sedimentation at the present day on the tropical eastern coast of America is similar in many ways to the sedimentation on the Carboniferous shelf of which the Dalry Basin

was part. The analogy is not perfect, notably in the absence of a volcanic arc, and to match many of the lithologies associated with the 'Trearne' facies, particularly the algal crusts, the Bahama Bank complex is more suitable.

12.4 Limestone Coal Group - conclusions

Sedimentation in the Limestone Coal Group marks a transition from marine to deltaic conditions and mudstones with a marine or lagoonal fauna are progressively replaced by coarser clastic sediments brought in by deltas advancing from the east or north-east.

Lithofacies and isopach maps show that the pattern of sediment distribution is being controlled both by the sedimentary processes in the advancing delta and by contemporaneous movement along the Annick Water and Dusk Water Faults. The analysis of the cyclicity shows a strong upwards-coarsening trend suggesting a simple progradation of deltaic environments.

Similarities have been noted between Limestone Coal Group sedimentation in the Midland Valley and sedimentation in modern river-dominated deltas. Differing delta types, however, are most readily distinguished by their morphology and in ancient deltas this can only be determined with considerable borehole data.

A number of factors have influenced cyclicity (chapter 11.13). In the Limestone Coal Group the dominant factor appears to be the rate of sediment supply within the deltaic environment.

12.5 Upper Limestone Group - conclusions

Sedimentation in the Upper Limestone Group is dominated by the effect of contemporaneous faulting. The Dusk Water and

Inchgotrick Fault scarps acted as barriers to marine transgression and defined areas with differing thicknesses and successions of sediments. North of the Dusk Water Fault there is a full and thick succession between the Index and Corsankell limestones, between the Inchgotrick and Dusk Water Faults the succession is limited to that between the Index and Lower Linn Limestones, while south of the Inchgotrick Fault an attenuated sequence occurs with possibly only the Lower Linn Limestone present. The reason for this upsurge in tectonism is not known.

The pattern of sedimentation in the Upper Limestone Group is cyclical with marine limestones and calcareous mudstones passing up into pro-delta muds, delta front sands and silts and delta top seatbeds and coals. The marine sediments are uniformly argillaceous with little lateral variation. The deltaic sediments differ from those of the Limestone Coal Group in the frequent occurrence of channel-fill deposits and local erosion. The cycles are complex and show that channelling, crevassing and delta switching were important aspects in building the delta. The evolution of a delta in this way can be compared with that of the Mississippi but on a very different scale.

12.6 Passage Group - conclusions

Extensive volcanic activity returned during Passage Group times in the Dalry Basin. As in the Calciferous Sandstone Measures much of the thickness variation in the lava pile is accommodated by differential subsidence and contemporaneous faulting. Eruption of the lavas was followed by a period of tropical lateritic weathering. During this period the kaolinite-rich weathering products were reworked and, with further weathering locally giving rise to bauxitic

minerals, bauxitic clay was formed.

The formation of the bauxitic clay is complex involving considerable diagenetic changes and redistribution of mobile elements. A generally allochthonous origin is favoured for the bauxitic clays though the underlying clayrocks may be derived by in situ weathering. The local strata compare with the slope-type bauxites of Hawaii. The top of the formation also represents a hiatus in sedimentation resulting largely from the presence of the lavas.

The lavas have partly protected the Dalry Basin from marine incursions which occur within the Passage Group elsewhere in the Midland Valley, but rare marine fossils found in the bauxitic clays indicate a proximate marine environment. As in Calciferous Sandstone Measures times the presence of a pile of volcanic rocks has influenced the pattern of sediment distribution.

12.7 Methodology - conclusions

This thesis has used the available geological data, particularly existing borehole data re-assessed and re-interpreted in the light of a drilling programme especially planned for this research. The work has proved the fundamental value of preserving such data. Transition matrix analysis has proved to be a useful tool particularly in those parts of the sequence where cycles are less clear.

12.8 In conclusion

I quoted at the beginning of this thesis:

"Lithostratigraphic analysis of sedimentary basins involves fundamental concepts of tectonics and sedimentation ...".

The detailed examination of a small basin has emphasised the interplay between local tectonics, sedimentation and volcanism. More widespread sea-level changes and climate have also affected the facies in both space and time.

While much of the work on the Carboniferous System in Scotland has been concerned with the description and correlation of strata, this thesis has recorded detailed successions which have been used to identify the depositional environments and the factors controlling sediment distribution through time. However, the test of a true understanding of these controls is in whether their effects can be quantified and the results of these effects measured in the rocks. That is in the future.

In the context of Europe, the Dalry Basin is a fragment but many of the influences on sedimentation identified here will relate to the wider pattern of sedimentation. Even in Scotland questions remain as to the regional effect of volcanism, contemporaneous faulting, strike-slip faulting and so on. Certainly there is a need for a new regional appraisal of sedimentation during the Carboniferous Period. This thesis in making use of the geological data base of borehole information, together with specific drilling programmes and outcrop examination, in constructing isopach maps, in the consideration of lithofacies distribution and in the study of the pattern of cyclicity lays a foundation for future work.

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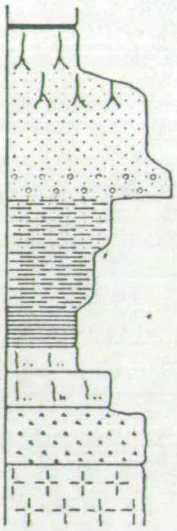
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APPENDIX 1

Key to symbols & ornaments used

BOREHOLE SECTIONS



coal
seatclay
seatearth
sandstone
pebbly sandstone
siltstone
silty mudstone
mudstone
calc. mudstone
limestone
tuff
igneous rock

L	lingula
NMB	non-marine bivalves
M	marine fauna
RM	rich marine fauna
Ost	ostracods
Alg	algae
c	coal
⅄	roots
T	tuffaceous
I	ironstone bands and nodules
•	nodules within limestones
~	eroded surface
— ch	chert nodules

CORRELATION DIAGRAMS



coal
seatclay
seatearth
sandstone
siltstone
mudstone
limestone & calc mudstone
tuff
igneous rock

RIBBON DIAGRAM



limestone
seatclay
mudstone and siltstone
sandstone
tuffaceous mudstone
tuff
basaltic lavas