Geology and land-use planning: Great Broughton-Lamplugh area, Cumbria

Part 1. GEOLOGY

Technical Report WA/92/54

Onshore Geology Series

British Geological Survey

BRITISH GEOLOGICAL SURVEY

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BRITISH GEOLOGICAL SURVEY

TECHNICAL REPORT WA/92/54
Onshore Geology Series

Geology and land-use planning: Great Broughton-Lamplugh area, Cumbria

Part 1. GEOLOGY

B Young and M P Boland

Maps and diagrams in this book use topography based on Ordnance Survey mapping.

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PREFACE

This report is one of two which presents the results of a survey of the geology of the Great Broughton–Lamplugh area of Cumbria. This volume, Part 1, describes the geology of the area in detail. A separate volume, Part 2, reviews the geological factors relevant to land-use planning and development.

The district is covered by 1:10 000 sheets NY 03 SE, NY 02 NE and SE and lies within 1:50 000 geological sheets 22 (Maryport) and 28 (Whitehaven). The district was first surveyed at the six-inch scale by T V Holmes, R Russell and J C Ward and published in 1892 on the one-inch scale as Old Series Quarter Sheets 101 NW and 101 SW. Some revision of these sheets was undertaken in 1894 by J G Goodchild and Sir A Strahan with assistance by J D Kendall, and new editions were published in 1895. A detailed resurvey of the area was carried out between 1921 and 1927 by T Eastwood and E E L Dixon as part of the full revision of one-inch sheets 28 and 22. The new maps were published in 1929 and 1930 respectively as separate solid and drift editions; sheet memoirs were issued in 1931 and 1930.

The present survey, which was jointly funded by the Department of Environment and the British Geological Survey, revised the geological maps and prepared thematic maps designed for use by planners and developers. It was undertaken between 1989 and 1990 by M P Boland (NY 03 SE, NY 02 SE (part)) and B Young (NY 02 NE, NY 02 SE (part)).

Palaeontological work was undertaken by P J Brand. Advice and assistance with establishing the computerised database was given by D J D Lawrence and B Porteous. The maps were drawn by Mrs C Simpson under the supervision of R Parnaby in the Keyworth Drawing Office of BGS. The programme managers were D J Fettes (BGS) and H Mallett and S Cosgrove (DOE).

We are grateful for much help and valuable information provided by British Coal, both the Opencast Executive and deep mines North-western area, Tendley Hill Quarries Ltd, Cumbria County Council and numerous land owners.

Mrs J Dunkley and Mrs S Clothier are thanked for preparing the typescript.

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EXPLANATORY NOTES

This report is one of two which describes the results of a research project funded jointly by the Department of the Environment and the British Geological Survey. The objectives of the project were to provide an up-to-date geological database for the Great Broughton-Lamplugh area as a foundation for land-use and development, effective future geological research and the safeguarding of mineral resources. Part 2 (BGS Technical Report WA/92/55), available separately, describes the applications for land-use planning and development. The results, with particular emphasis on the solid and drift geology, are described here. The present study is the third DOE sponsored applied geological mapping project in Cumbria; previous surveys have covered the Workington and Maryport, and Dearham and Gilcrux areas.

The British Geological Survey has undertaken these studies as part of the programme to maintain its coverage of 1:10 000 scale geological maps of the UK.

Several centuries of coal mining and, in recent decades, an extensive search for coal seams which could be worked opencast, have provided a wealth of geological data for the district. In compiling this report and accompanying maps, data from the following sources were collated and interpreted:

- a detailed geological field survey at 1:10 000
- deep mine coal boreholes and shaft records
- deep mine coal abandonment plans
- opencast coal prospecting boreholes
- opencast coal completion plans
- site investigation boreholes, trial pits and reports
- existing geological maps
- Local Authority data
- geological reports and journals.

The type, quantity, quality and limitations of each of these data sources are discussed.

Computerised databases of borehole and geotechnical information comprising more than 16 000 records (i.e. lines of data) were established. Their structure and value, both current and potential, are described in Appendices A and B of Part 2. Computer-aided and conventional techniques were used to produce the 1:10 000 scale standard geological maps, the 1:25 000 scale thematic maps and the accompanying reports.

All National Grid references in this report lie within the 100 km square NY. Grid references are given to either eight figures (accurate to within 10 m), or six figures for more extensive locations.

Each borehole or shaft registered with BGS is identified by a four-element code (e.g. NY 03 SE/1). The first two elements define the 10 km square of the National Grid in which the borehole is situated (e.g. NY 03); the third element defines the quadrant of that square (e.g. SE), and the fourth is the accession number of that borehole. In the text of the report the borehole/shaft is normally referred to by the last three elements alone (e.g. 03 SE/1).

The word 'district', unqualified, in this account means the whole ground covered by NY 03 SE, NY 02 NE and SE.

The maps were constructed in February 1991. No information subsequent to that date has been taken into account.

LIMITATIONS

This report and accompanying maps have been produced by the collation and interpretation of data from a wide variety of sources. However, the data are not comprehensive and do vary in quality. It is inevitable that this will be reflected in the documents presented; local features and conditions may not be represented and many boundaries may be approximate.

CONFIDENTIALITY

Confidential data, chiefly British Coal Opencast Executive prospecting information, have been taken into account and used in a generalised way during the preparation of the geological maps and this report, but details of specific boreholes are not individually quoted.

Data used in preparing this report and associated maps are lodged at the Newcastle upon Tyne office of the British Geological Survey (Windsor Court, Windsor Terrace, Newcastle upon Tyne, NE2 4HB, tel: 091 281 7088; fax: 091 281 9016). Any enquiries concerning these documents should be directed to that office.

The following reports describe the adjoining areas:

BARNES, R P, YOUNG, B, FROST, D V, and LAND, D H. 1988. Geology of Workington and Maryport. *British Geological Survey Technical Report* No. WA/88/3.

YOUNG, B, and ARMSTRONG, M. 1989. The applied geological mapping of the Dearham and Gilcrux area, Cumbria. *British Geological Survey Technical Report* No. WA/89/70.

EXECUTIVE SUMMARY: GEOLOGY

Introduction

The Great Broughton–Lamplugh district includes part of the Cumbrian coalfield and the northernmost part of the West Cumbrain iron orefield. The east of the district is underlain predominantly by limestones while the low fells in the southeast of the district are formed by resistant, older siltstones and sandstones which form part of the Lake District. Exploitation of these rocks, together with the effects of natural geological processes, has resulted in variable ground conditions throughout the area. Coal mining has left a legacy of spoil heaps, underground workings and abandoned shafts. Areas of variably restored opencast coal workings, clay pits and quarries for sandstone, limestone and siltstone also occur. Natural phenomena such as limestone dissolution may also lead to ground collapse. Thus the availability of comprehensive, up-to-date information on the geological environment is essential for planners, geologists and engineers when considering both issues relating to ground stability and future resource development within the area.

Two sets of maps and accompanying reports have been prepared.

1. Geology report WA/92/54 with text detailing the solid and drift geology of the area.
   3 geological maps at 1:10 000 scale.

2. Land use planning report WA/92/55.
   A series of nine thematic maps at the 1:25 000 scale with accompanying text detailing geological factors for consideration in land use planning.

The study was jointly funded by the department of Environment and the British Geological Survey (BGS). The work was caried out by BGS staff at the Newcastle upon Tyne office. Hydrogeological information was supplied by BGS Wallingford.

Objectives

1) To produce new geological maps of the area incorporating all available geological information.

2) To collect and organise borehole and mine-plan data into a data-base/archive.

3) To identify elements of the geology which are of particular interest to planners and developers and to present this information in a form that is understandable to those not trained in geology or related disciplines.

4) To highlight the limitations of interpretations based on the existing data-set and to indicate the need for further specialist advice in relation to specific planning proposals or objectives.

Methodology

The work involved the collation and interpretation of data from many different sources: a specially commissioned 1:10 000 scale field geological survey together with an examination of coal exploration boreholes, deep mine and opencast coal abandonment plans, site investigation boreholes and reports, existing geological maps and memoirs and other archival material held by third parties. Computerised databases of borehole and geotechnical information were established.

Conclusions

This report provides the first comprehensive description of the geology of the district for over half a century. The wealth of information available has been used to undertake a complete revision of the geological maps. The biostratigraphy has been compared with that of the adjacent district. Where necessary, palaeontological speciments have been reexamined.

Emphasis is placed on a description of the Carboniferous stratigraphy, in particular the nature and distribution of the individual rock units, including limestones, sandstone and coal seams. The igneous rocks present within the district are described and there are accounts of the structure and the Quaternary or drift deposits.

In the compilation of the report considerable use has been made of the computerised borehole database established for the project.

This study has attempted to collate and evaluate all relevant geological data. However the maps and reports produced should not be seen as an alternative to a detailed site investigation when planning a development project. The reader is strongly advised always to consult primary sources of data. Where mining is suspected the mine plans and shaft atlases maintained by British Coal and the abandonment plans of non-coal mines held by the Health and Safety Executive should be consulted.

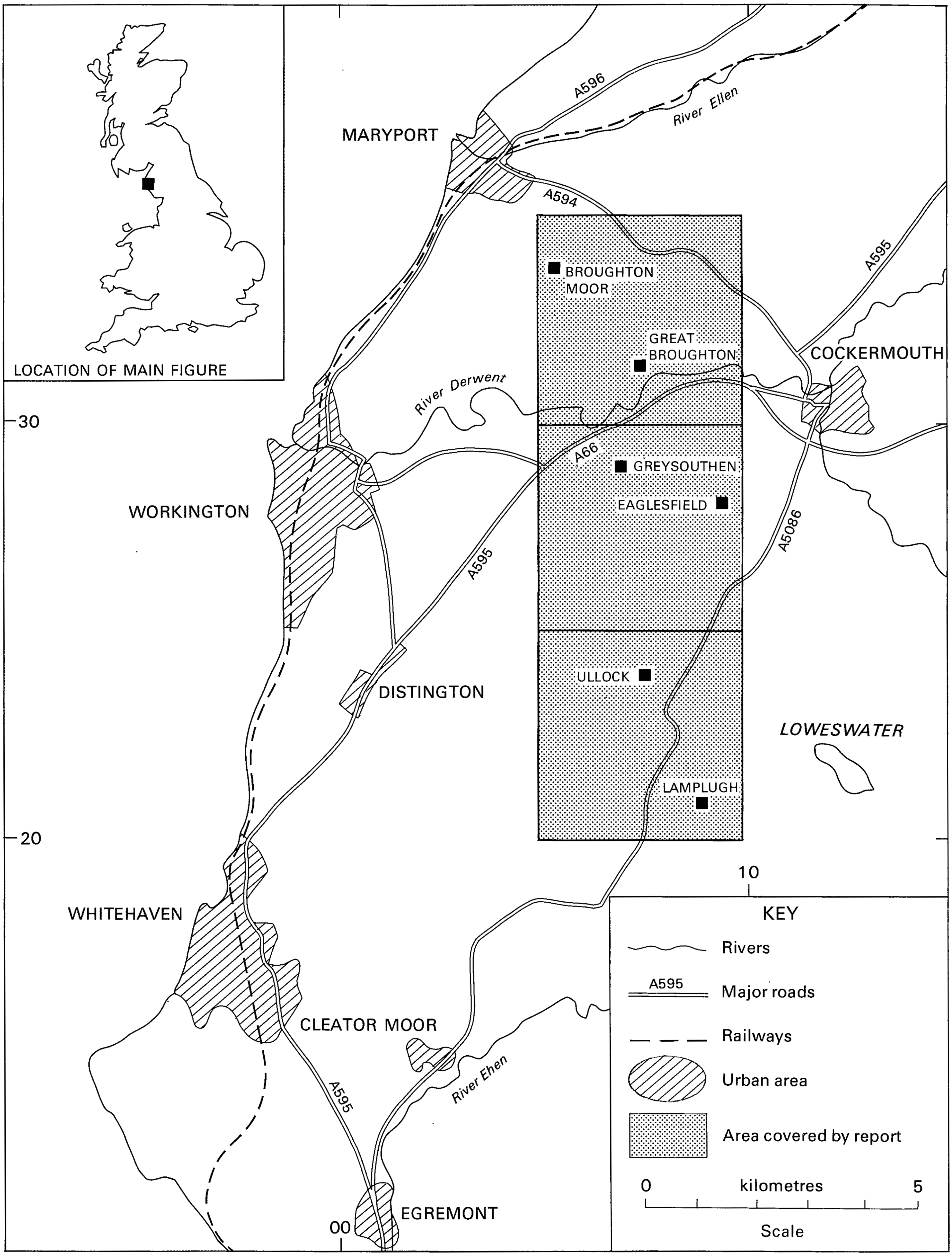


Figure 1 Location map

1. INTRODUCTION

1.1 Geographical setting

Described in this report is a belt of country of some 75 km^2 lying immediately to the west and south west of Cockermouth within the Allerdale and Copeland districts of Cumbria (Figure 1). This is today a predominantly rural area with the population concentrated mainly in the comparatively large villages of Broughton Moor, Great Broughton and Brigham in the north and in the smaller settlements of Eaglesfield, Dean, Branthwaite, Ullock and Lamplugh further south. Scattered farms occur between the villages.

A varied landscape reflects the diversity of the underlying geology. The district includes part of the eastern margin of the Cumbrian Coalfield, the northernmost extremity of the west Cumbrian iron orefield, and extends into the western slopes of the Lake District fells. The western boundary of the Lake District National Park lies less than 1 km east of much of the district, though about 2 km^2 around Lamplugh lie within the Park.

The district is drained to the Irish Sea by the River Derwent and its major southern tributary the Marron. The Derwent rises in the central Lake District draining Derwent Water, Bassenthwaite, Crummock Water, Buttermere and Loweswater. The Marron rises about 1 km south-west of Lamplugh and drains much of the district and the adjacent western slopes of the Lakeland fells.

The area north of the Derwent Valley and much of that to the south towards Branthwaite and Lamplugh consists of rather rolling drift-covered country with numerous predominantly NE–SW drumlin ridges. This land reaches almost 120 m above OD north of the Derwent near Broughton Moor: south of the Derwent altitudes of a little over 140 m above OD are reached between Eaglesfield and Dean. The broad flat floor of the Derwent valley rises from 32 m in the west to 38 m in the east. Although generally heavily concealed by drift deposits, the outcrop of the Carboniferous Limestone may be traced along much of the eastern part of the district from Brigham, through Eaglesfield to Dean and Ullock. In places, most notably on Eaglesfield Crag and near Pardshaw, limestone scars and low crags are prominent landscape features, and such characteristic features of limestone scenery as swallow holes and springs are common locally.

South of Branthwaite, resistant outcrops of Coal Measure sandstones give rise to the steep sided plateaux features of Branthwaite Edge and Dean Moor which reach altitudes of over 180 and 215 m above OD respectively. East of Mockerkin and Lamplugh the ground rises sharply to the north-western Loweswater Fells at 248 m above OD at Mockerkin How and 409 m at Owsen Fell.

Apart from the rough upland grazing which characterises the higher ground of Dean Moor, Mockerkin How and Owsen Fell, much of the district is given over to pastoral farming with small areas under arable cultivation.

Three major roads cross the district, the A594 Maryport–Cockermouth, A66(T) Whitehaven–Cockermouth and A5086 Egremont–Cockermouth. In addition a complex network of unclassified roads connects the villages, most of which lie away from the main roads. A number of railways formerly served the district for both passenger and colliery traffic. All have long been dismantled. The course of the former Cockermouth–Workington line is followed through much of the district by the realigned A66 trunk road.

In common with much of the Cumbrian Coalfield, the district has a long history of coal production. All underground mining ceased many years ago though opencast extraction continues today at the Fox House site in the north-west of the district and opencasting is expected to commence at the Broughton Lodge site in 1992. Prospecting of future sites was underway at a number of sites throughout the district during the survey.

Iron ore was worked underground at a few places. Clay ironstone from the Coal Measures was extracted, mainly last century, in the Branthwaite area. Hematite was mined from the Carboniferous Limestone near Lamplugh and trials were made last century for the same ore in the Eaglesfield area.

Limestone has been extracted from numerous quarries, with the largest at Broughton Crags, Brigham and Eaglesfield. Tendley Hill Quarry at Eaglesfield is the only active limestone quarry in the district today.

Several sandstone units have provided stone, mainly for local use, although none has been worked for many years.

Other mineral products recorded from the district include very small amounts of sand, gravel, brick and tile clays, the latter believed to have been obtained from the Coal Measures.

With the demise of the extractive industries the district has resumed its essentially agricultural character. The former colliery villages of Broughton Moor and Great Broughton now serve mainly as dormitories for Workington, Cockermouth and beyond. Greysouthern, Eaglesfield, Dean and the district's other villages are dominantly farming settlements, in some cases with several farms within the same village. Many of these villages are becoming increasingly popular as residential areas for the urban centres of west Cumbria.

1.2 History of geological research

Systematic geological investigation of the area began late last century with the Geological Survey six-inch scale mapping carried out by T V Holmes, R Russell and J C Ward. Vertical Section sheets, compiled by Russell, were published in 1886 and the first one-inch scale Geological Survey maps, Old Series Quarter Sheets 101 NW and 101 SW, were published in 1892. Some revision of these sheets was undertaken in 1894 by J G Goodchild and Sir A Strahan, with some assistance by J D Kendall, and new editions were published in 1895.

A detailed resurvey of the area was carried out between 1921 and 1927 by T Eastwood and E E L Dixon as part of the full revision of Geological Survey one-inch Sheets 28 (Whitehaven) and 22 (Maryport). The new maps were published in 1929 and 1930 respectively as separate solid and drift editions; sheet memoirs were issued in 1931 and 1930 (Eastwood, 1930; Eastwood et al., 1931). A new sheet of vertical sections, Sheet 95, compiled by Dixon, Eastwood and Smith, was published in 1931.

The latest resurvey began in 1985 with the first of three research projects funded jointly by the Department of the Environment and the British Geological Survey. This work has involved not only the production of new geological maps but a range of thematic maps illustrating aspects of particular importance in land-use planning. To date 1:10 000 scale geological maps have been published covering the areas around Maryport, Workington, Dearham and Gilcrux, together with a variety of 1:10 000 and 1:25 000 scale thematic maps showing such elements as rockhead elevation, drift thickness, extent of shallow mining etc. Accompanying reports have also been published (Barnes et al., 1988; Young and Armstrong, 1989).

Despite its long history as a coal producer the Cumbrian coalfield has, perhaps surprisingly, attracted comparatively little research compared to other coalfields. Aspects of the stratigraphy, mainly arising from Geological Survey investigations, include, in addition to the memoirs already noted, papers by Garwood (1913), Smith (1921), Trotter and Hollingworth (1927), Jones (1957), Taylor (1961) and Mitchell, Taylor and Ramsbottom (1978). Descriptions of the Lower Carboniferous rocks include works by Edmonds (1922), Garwood (1913), George et al. (1976), Mitchell et al. (1978) and Stabbins (1969). Aspects of the Skiddaw Group rocks have been the subject of papers by Jackson (1978), Molyneux and Rushton (1988) and Fortey et al. (1989).

Several authors have made reference to the Quaternary geology of west Cumbria though the most recent synopsis is that by Pennington (1978). Much has been published on the hematite iron orefield of west Cumbria, the northernmost deposits of which occur within the present district. Early contributions on this topic include those by Kendall (1873-75; 1893). Smith (1924) published an exhaustive description of the orefield and Dixon (1928) and Trotter (1945) discussed the origin of the mineralisation.

In the present study the results of these earlier works, together with more recent information from boreholes and mining, have been critically reviewed and re-correlated. All available mine plans have been examined and the ground has been resurveyed in detail.

2. GEOLOGICAL SUMMARY AND GEOLOGICAL HISTORY

The geological succession in the Great Broughton–Lamplugh district is summarised in Table 1. The solid geology of the district is shown in Figure 2.

Ordovician rocks of the Skiddaw Group crop out in a small area in the extreme south-east though these are likely to be present throughout the district beneath the Carboniferous sediments.

During Ordovician times the area which was to become northern England lay south of the contemporary equator beneath a wide ocean known to palaeogeographers as the Iapetus Ocean. To the north of this was the continental mass of Laurentia, including much of what is now Canada and Greenland. South of Iapetus were two separate land areas, separated by the Tournquist's Sea; Gondwana in the south-west comprising the area destined to become Africa and much of mainland Europe, and Baltica in the south-east which was to develop into modern Scandinavia. Great thicknesses of sediment, mainly silts, muds and sands accumulated both on the floor and margins of the ocean. Instability of deposits on the southern margin gave rise to turbidity currents which carried large volumes of sediment northwards towards the centre of

Table 1 Geological Succession in the Great Broughton–Lamplugh area.

SYSTEM		STRATUM NAME	MAIN LITHOLOGIES	APPROX THICKNESS (m)
RECENT		PEAT	Peat	?up to 1.5
		ALLUVIAL FAN DEPOSITS	Silt, sand and gravel	?up to 4
		LACUSTRINE DEPOSITS	Clay and silt	?up to 2
		ALLUVIUM	Clay, silt and gravel	?up to 5
		RIVER TERRACE DEPOSITS	Silt, sand and gravel	?up to 4
PLEISTOCENE		GLACIOFLUVIAL DEPOSITS	Sand and gravel	?up to 5
		TILL OR BOULDER CLAY	Stony and locally sandy clay	locally in excess of 30
GREAT UNCONFORMITY—FOLDING, FAULTING, UPLIFT, EROSION				
CARBONIFEROUS	UPPER	COAL MEASURES	Mudstones, siltstones	320
		HENSINGHAM GROUP	Mudstones, siltstones and sandstones with a few coals and limestones	140
		CHIEF LIMESTONE GROUP	Mainly limestones with interbedded sandstones, mudstones and siltstones	200
	LOWER	COCKERMOUTH LAVAS	Olivine basalts and tholeiitic andesites	25
		BASEMENT BEDS	Mainly mudstones in this area, conglomerates and sandstones in adjacent areas	?up to 13
GREAT UNCONFORMITY—FOLDING, FAULTING, UPLIFT, EROSION				
ORDOVICIAN	SKIDDAW GROUP	KIRKSTILE FORMATION	Mainly mudstones	1200
		LOWESWATER FORMATION	Mainly sandstones	800
		WATCH HILL FORMATION	Mainly sandstones	250–600
		BITTER BECK FORMATION	Mainly mudstones	>600

the ocean to be deposited as beds of greywacke sandstone, siltstone and silty-mudstone. Slumping of semi-compacted sediments down sub-marine slopes produced distinctive fold structures in parts of the sequence.

During Ordovician and Silurian times convergence of the Laurentian, Gondwanan and Baltic plates brought about a progressive narrowing of Iapetus culminating in its closure along the line known as the Iapetus suture in late Silurian times. Some early folding and faulting of these sediments resulted from these movements though the main deformation of the Skiddaw Group, including the development of cleavage, occurred in early Devonian times.

The age of a small stock-like mass of microdiorite intruded into the Skiddaw Group in the Eaglesfield area is unknown. This is one of a group of similar, and presumably related, small intrusions which occur widely in the Cockermouth and Embleton area, a short distance to the east of the present district. They are likely to postdate the main deformation and cleavage of the Skiddaw Group. Their relationship to the Carboniferous rocks is unknown, though no intrusive rocks cut the Carboniferous of this part of Cumbria. A Devonian age is probably most likely for this intrusion.

Apart from the Eaglesfield microdiorite, there are no rocks within the district representative of either the Silurian or Devonian systems. A period of uplift and very considerable erosion predated the onset of Carboniferous deposition.

In Lower Carboniferous times the area formed part of a shallow tropical sea on the northern and eastern flanks of the newly submerged Lake District. The earliest Carboniferous deposits in the Cockermouth district a very short distance outside of the present area, are a group of conglomerates and coarse sandstones formed by the accumulation of debris eroded from the adjacent uplands of what is now the Lake District. These Basement Beds, which are of local distribution, are absent at outcrop in the district though they occur in places at depth.

Within this part of Cumbria the Cockermouth Lavas, at or very near the base of the Carboniferous, record a local, probably short-lived volcanic episode. The main outcrop of lavas lies to the north east of the district though they may underlie a considerable area in the north of the district.

Much of the Lower Carboniferous sequence records almost continuous marine deposition. Throughout much of the period limestones, many of which contain abundant shell, coral, crinoid and foraminiferal debris, were deposited. Beds of mudstone and sandstone reflect temporary incursions of non-marine conditions. This non-marine influence becomes more dominant during Namurian times as recorded by the sequence of mudstones and sandstones which exhibit abundant evidence of fluviatile and deltaic environments. Equatorial swamp forests developed locally producing a few generally thin coal seams, especially in later Namurian times. By late Carboniferous, Westphalian or Coal Measures times the non-marine environment was well established with frequent widespread development of coal-forming swamps. By then marine incursions were restricted to rare short-lived episodes recorded in a few marine bands.

Throughout much of Carboniferous times subsidence kept pace with sedimentation though there is evidence that northern Cumbria lay astride a contemporaneous WSW–ENE 'hinge line' which follows very approximately the northern margin of the Lake District and can be traced across eastern Cumbria and through the Tyne Gap on the northern margin of the Pennines. Relatively greater subsidence of the basin north of this line allowed the accumulation of much greater thicknesses of sediment than on the more stable area, to the south. Much of the district appears to lie well within this more stable area, although the Carboniferous sequence in the south gives evidence of the proximity of this pivotal area.

Towards the close of the Carboniferous period uplift and folding took place. A period of sub-aerial, possibly tropical, weathering in very late Carboniferous or earlier Permian times led to extensive reddening of the Coal Measures, with perhaps locally the oxidation and destruction of some coal seams.

Permo-Triassic sediments were no doubt deposited across much, if not the whole, of west Cumbria. No rocks of this age are preserved within the present area though small outliers are present in the district immediately to the south.

Post Triassic faulting was followed, probably during Cretaceous or Tertiary times, by a widespread episode of mineralisation which deposited very large quantities of hematite in west and south Cumbria and adjoining parts of the Lake District.

There is no record of further geological events until the Quaternary. During this period a late-Devensian glaciation deposited an extensive mantle of boulder clay (till) with local accumulations of sand and gravel. Post glacial deposits include alluvial flats adjacent to modern rivers and streams, lacustrine deposits and small areas of peat.

3. ORDOVICIAN ROCKS

3.1 Introduction

Rocks of the Skiddaw Group, which form a wide outcrop in the central Lake District, crop out in the extreme south-east of the district and are likely to be present beneath the Carboniferous rocks.

3.2 Classification

The Skiddaw Group, of Ordovician age, is the oldest group of rocks in the Lake District. The deposits range in age from Tremadoc to Llanvirn. In the Caldbeck area the Skiddaw Group is unconformably overlain by the Llanvirn age Eycott Volcanic Group (Millward and Molyneux, 1991). To the south, the Skiddaw Group is unconformably overlain by the Borrowdale Volcanic Group of Llandeilo to Caradoc age. Neither the Eycott Volcanic Group nor the Borrowdale Volcanic Group crop out in the district.

The Lower Palaeozoic rocks of the Lake District underwent deformation during the Acadian orogeny in Lower Devonian times.

3.3 Conditions of deposition and sedimentology

The Skiddaw Group comprises greywacke sandstones, siltstones and silty mudstones which were mainly deposited by turbidity currents. Deposition took place on the north-westt margin of the Avalonian–Cadomian plate (Webb and Cooper, 1988). The turbidites show a southerly derivation.

3.4 Stratigraphy

The stratigraphy of Skiddaw Group has been divided into two distinct sequences by Cooper and Molyneux (1990). Each sequence is restricted to a separate belt, the boundary between the two belts being the ENE–WSW trending Causey Pike Fault. The Great Broughton–Lamplugh district lies within the northern belt, the stratigraphy of which is described here. The Bitter Beck Formation of upper Tremadoc to lower Arenig age is the oldest unit within the northern sequence. It consists of laminated siltstone and mudstone. This formation has a minimum thickness of 600 m.

The overlying Watch Hill Formation, which is between 250 and 600 m in thickness, also of upper Tremadoc to lower Arenig age, is dominated by lithic greywackes. These pass upwards into laminated mudstone and siltstone of the Hope Beck Formation. This formation is estimated to be approximately 700 m thick.

The Loweswater Formation, estimated to be around 800 m thick and of Arenig age, consists of quartz-rich greywacke sandstone turbidites, in which characteristic sedimentary structures are well developed. The youngest formation within the sequence is the Kirkstile Formation. This is up to 1200 m thick and of upper Arenig to lower Llanvirn age. It is dominated by laminated mudstone and siltstone with some beds of greywacke sandstone.

Palaeontological control, mainly by means of graptolites and microfossils, is important for differentiating the finer-grained formations.

Skiddaw Group fossils collected from the cores of the Dean No. 6 borehole [0762 2497] include: *Didymograptus sparsus(?)* and *Eoglyotograptus dentatus*. The fauna is probably of upper Arenig, *D.hirundo* zone age.

3.5 Details of stratigraphy

KIRKSTILE FORMATION

This is exposed in a small quarry on Mockerkin How [0995 2275] and a number of smaller exposures to the north and west. The Kirkstile Formation here is a dark grey mudstone or siltstone. Laminations on the 1 mm scale strike approximately east–west and dip at up to 40^{o} to the south.

LOWESWATER FORMATION

The Loweswater Formation is best exposed in two quarries, one on High Hows [0965 2016] and the other on Owsen Fell [0962 2116]. The beds are typically grey to green in colour and show an upward fining from fine- to medium-grained sandstone to mudstones. The thin- to medium-bedded sandstones have erosive bases and contain rip-up clasts. Bedding is the right way up on High Hows.

3.6 Structure

Open to close, north-vergent upright folds with wavelengths of approximately 2 m are seen at Mockerkin How. Two cleavages appear to be present, a steep spaced fabric and a shallower dipping fabric (Strike 156^{o}: Dip 60^{o} NE). This second fabric appears to be related to a prominent crenulation lineation which can be seen on the bedding surfaces. This fold style is repeated in the quarry on Owsen Fell, although fold wavelengths here are only 2 cm in size.

A number of displacement surfaces may be seen affecting rocks of the Loweswater Formation at High Hows [0965 2016] and Benthow Wood [0932 2179]. At Benthow Wood a shallowly dipping surface marked by a 10 cm wide gouge zone shows a thrust sense as indicated by the sense of rotation of bedding towards the structure. On High Hows, a 2 cm wide zone of veined mudstone (Strike 019^{o}: Dip 55^{o} W) is related to the offset of sandstone beds. The age of these structures is unknown.

4. INTRUSIVE IGNEOUS ROCKS

Within the Lake District, various minor intrusions were emplaced between Late Ordovician and early Devonian times (Rundle 1979). The composition of the intrusions is largely medium- to high-K calc-alkaline, although low-K tholeiites and alkaline rock types are also present.

The minor intrusions of the western Lake District have been subdivided into distinct groups based on their field and petrographic characteristics (Eastwood et al. 1968; Firman 1978).

A dyke of quartz microdiorite cuts the Skiddaw Group at Eaglesfield. This rock is comprised of euhedral feldspar laths up to 3 mm long showing both simple and polysynthetic twinning. The rock is dominated by elongate laths, up to 5 mm in length, which have been replaced by a pale brown, high birefringence mineral of uncertain identity. These are probably pseudomorphs after hornblende. Quartz grains are also present. Secondary minerals include sericite and calcite.

Although classified as a tonalite on BGS 1:25 000 sheet NY 12, the above petrography suggests that quartz microdiorite better describes this rock.

5. CARBONIFEROUS ROCKS

5.1 Introduction

Carboniferous rocks crop out over the greater part of the district. With the exception of the very highest parts of the Coal Measures, representatives of the complete west Cumbrian Carboniferous sequence are present throughout.

5.2 Classification

In the pages which follow the Carboniferous sequence will be described in ascending order of the four major lithostratigraphic divisions recognisable within the district. These are outlined in Table 2 alongside previous lithostratigraphical classifications which have been applied to this and the immediately adjoining areas. A brief consideration of these classifications is worthwhile in order to appreciate something of the evolution of current understanding of West Cumbrian Carboniferous lithostratigraphy.

Everywhere in west Cumbria the Carboniferous succession rests unconformably on older rocks. Locally a small thickness of Basement Beds, comprising conglomerates and sandstones with some shales, is present at the base. In the Cockermouth area these include the Cockermouth Lavas. Both the lavas and the Basement Beds are overlain by a Lower Carboniferous sequence which is dominated by limestone and which earlier authors, e.g. Eastwood (1930), Eastwood et al. (1931) and Eastwood et al. (1968) have included within the 'Carboniferous Limestone Series'.

Overlying the predominantly limestone succession is a generally poorly exposed, and thus poorly known, group of beds thought to consist mainly of mudstone, siltstone and sandstone. A prominent sandstone immediately above the First Limestone is known as the Hensingham Grit from its type locality near Whitehaven. In the Maryport and Whitehaven areas Eastwood (1930) and Eastwood et al. (1931) applied the term Hensingham Group to these beds with the Hensingham Grit at the base. In their lithostratigraphical classification these authors placed the Hensingham Group, the limestone sequence, from First to Seventh Limestone, the Basement Beds and where present the Cockermouth Lavas, in the Carboniferous Limestone Series. Eastwood et al. (1968) excluded the Hensingham Group from the Carboniferous Limestone Series in the Cockermouth area. The limestones of the Cockermouth area were subdivided into the Upper and Lower Chief Limestone Groups, the boundary being drawn within the Fourth Limestone. Young and Armstrong (1989, Fig. 5) adopted a broadly similar classification in the revision of the Dearham and Gilcrux area. In an attempt at correlation with the thicker Lower Carboniferous sequence of north Cumbria these authors adopted the terms Lower Liddesdale Group for the beds up to the base of the Fourth Limestone and the Upper Liddesdale Group for the succession from Fourth to Second Limestone. As Young and Armstrong (1989) adopted an essentially chronostratigraphical approach to their treatment of the Dearham and Gilcrux sequence, the Namurian First Limestone was separated from the main Dinantian limestone succession.

Despite the attractions of the primarily chronostratigraphical approach of Young and Armstrong this study has shown that a classification similar to that of Eastwood et al. (1968) better fits the sequence in the present district. Accordingly in this report we place all of the limestone sequence, from First to Seventh Limestone, within the Chief Limestone Group (Table 3, Figure 3).

As has already been outlined, the authors of the Whitehaven memoir chose to regard the Hensingham Group as part of the Carboniferous Limestone Series. In the Maryport memoir Eastwood (1930) had difficulty in correlating the Hensingham Grit and immediately overlying beds with the 'Millstone Grit' elsewhere in northern England. His solution was to infer the presence of an unconformity within the Hensingham Group. The beds beneath this unconformity were placed within the Carboniferous Limestone Series; those above were tentatively assigned to the 'Millstone Grit'. This problem was further discussed by Eastwood et al. (1968) in the Cockermouth memoir. Here the Hensingham Group was regarded as entirely within the Upper Carboniferous and was taken as synonymous with the 'Millstone Grit' of the Pennines.

Young and Armstrong (1989) retained the term Hensingham Group for the sequence from the base of the Hensingham Grit to the base of the Coal Measures at the Subcrenatum Marine Band. This usage is followed in this report.

In earlier interpretations of the Cumbrian coalfield Eastwood (1930) and Eastwood et al. (1931) recognised a two-fold division of the Coal Measures with a lower unit, the Productive Measures, believed to be overlain unconformably by a group of red sandstones known as the Whitehaven Sandstone. Taylor (1961) showed that over much of Cumbria the Whitehaven Sandstone comprised parts of the Middle Coal Measures reddened by late Carboniferous or early Permian weathering. His work did not support the presence of an unconformity at this level and the term Whitehaven Sandstone was abandoned. In the Cockermouth memoir (Eastwood et al. 1968) and in subsequent descriptions of the coalfield, including this report, the three-fold division into Lower, Middle and Upper Coal Measures has been followed. Details of the palaeontological basis for this classification and for the definition of the base of the Coal Measures are given below.

Table 2 Lithostratigraphical Classification of the Carboniferous Rocks.

MARYPORT MEMOIR (Eastwood 1930)	WHITEHAVEN MEMOIR (Eastwood et al., 1931)	COCKERMOUTH MEMOIR (Eastwood et al., 1968)	DEARHAM & GILCRUX REPORT (Young & Armstrong 1989)	THIS REPORT
<u>COAL MEASURES</u> Whitehaven Sandstone Series ~~~~~unconformity~~~~~ Productive Coal Measures	<u>COAL MEASURES</u> Whitehaven Sandstone Series ~~~~~unconformity~~~~~ Productive Coal Measures	<u>COAL MEASURES</u> Upper Coal Measures Middle Coal Measures Lower Coal Measures	<u>COAL MEASURES</u> Middle Coal Measures Lower Coal Measures	<u>COAL MEASURES</u> Upper Coal Measures Middle Coal Measures Lower Coal Measures
		------- non-sequence	--------	
<u>MILLSTONE GRIT SERIES</u> (Possibly present) unconformity	<u>MILLSTONE GRIT</u> probable unconformity	<u>MILLSTONE GRIT SERIES</u> (= HENSINGHAM GROUP) Hensingham Grit at base	<u>HENSINGHAM GROUP</u> (Hensingham Grit at base)	<u>HENSINGHAM GROUP</u> (Hensingham Group at base)
<u>CARBONIFEROUS LIMESTONE SERIES</u> Hensingham Group (Hensingham Grit at base) First Limestone Second Limestone Orebank Sandstone Group Third Limestone Fourth Limestone Fifth Limestone Sixth Limestone Seventh Limestone Cockermouth Lavas Basement Conglomerate	<u>CARBONIFEROUS LIMESTONE SERIES</u> Hensingham Group (Hensingham Grit at base) Chief Limestone Group First Limestone Second Limestone Orebank Sandstone Group Third Limestone Fourth Limestone Fifth Limestone Sixth Limestone Seventh Limestone Basement Beds	<u>CARBONIFEROUS LIMESTONE SERIES</u> Upper Chief Limestone Group First Limestone Second Limestone Orebank Sandstone Third Limestone Fourth Limestone (upper part) Lower Chief Limestone Group Fourth Limestone (lower part) Fifth Limestone Sixth Limestone Seventh Limestone Cockermouth Lavas Basement Conglomerate	<u>FIRST LIMESTONE</u> <u>UPPER LIDDESDALE GROUP</u> Second Limestone Orebank Sandstone Third Limestone Fourth Limestone <u>LOWER LIDDESDALE GROUP</u> Fifth Limestone Sixth Limestone	<u>CHIEF LIMESTONE GROUP</u> First Limestone Second Limestone Orebank Sandstone Third Limestone Fourth Limestone Fifth Limestone Sixth Limestone Seventh Limestone <u>COCKERMOUTH LAVAS</u> <u>BASEMENT BEDS</u>
~~unconformity~~~~~~~~~~~	~~~~~~ unconformity~~~~~~~~~~~	~~~~~~ unconformity~~~~~~~~~		~~~~ unconformity~~~~~~~

6. CARBONIFEROUS ROCKS: 2 BASEMENT BEDS AND COCKERMOUTH LAVAS

6.1 Introduction

The base of the Carboniferous sequence is not exposed within the district. Mapping indicates that throughout much of the district the Carboniferous rocks have a faulted contact with the Ordovician Skiddaw Group. Only in a very small area in the Derwent Valley near Brigham and in the extreme south near Lamplugh do the lowest Carboniferous beds come to outcrop, although the actual contact is everywhere concealed by drift deposits.

Elsewhere in west Cumbria a group of Basement Beds locally overlies the sub-Carboniferous unconformity. In the Cockermouth area Eastwood et al. (1968, p.150) describe up to 30 m of conglomerate where Ordovician volcanic rocks underlie the Carboniferous, although they note that when Basement Beds overlie the Skiddaw Group they are either much thinner or absent. In the Whitehaven area Eastwood et al. (1931, p 63) record a variable thickness of Basement Beds, comprising mottled shales, mudstones, grits and conglomerates up to almost 9 m thick, though they are generally much thinner, and commonly absent. Reddening of the underlying Skiddaw and Borrowdale Volcanic Group rocks is common in the Whitehaven district. Following the customary practice within the west Cumbrian iron ore field the Basement Beds of the Whitehaven area, which when present lie directly beneath the Seventh Limestone, are commonly referred to collectively as the Seventh Shale.

Between Brigham, in the north east of the present area, and Bothel some 13 km to the north east, a group of basic lavas, the Cockermouth Lavas, occur within the Basement Beds sequence (Eastwood, 1928; Eastwood et al. 1968). The lavas are mainly olivine basalts though MacDonald and Walker (1985) have described tholeiitic andesites. Perhaps as many as six flows have been recognised with an aggregate thickness of up to 100 m (MacDonald & Walker 1985). Over much of their outcrop the lavas are underlain by conglomerates and locally beds referrable to the Basement Beds overlie them, separating the lavas from the Seventh Limestone. In places, including the present district, the lavas rest directly upon Skiddaw Group rocks.

Detailed mapping of the Great Broughton–Lamplugh area has provided no evidence for the presence of Basement Beds at outcrop. Indeed in the Derwent valley there are grounds for believing that the Cockermouth lavas directly overlie the Watch Hill Grits within the Skiddaw Group. Around Lamplugh the Seventh Limestone appears to rest directly on the Skiddaw Group. The logs of several boreholes in this area also record Seventh Limestone in contact with the Skiddaw Group though it is not always clear from the surviving records whether the junction is a structural or stratigraphical one. Basement Beds have been noted in boreholes at Gatra [02 SE/19] and Streetgate [02 SE/62].

6.2 Classification

The precise age of the Basement Beds of west Cumbria was unknown until comparatively recently. Indeed Eastwood et al. (1968, p.150) remarked that the Basement Conglomerate of the Cockermouth district "... is almost certainly of Carboniferous age ...". Butcher (personal communication p.171 in Mitchell et al, 1978) reported the presence of CM Zone spore assemblages of Courceyan age from Basement Beds both above and below the Cockermouth lavas at Blindcrake and Redmain, about 4 km east of Dovenby in the north of the district.

6.3 Conditions of deposition and sedimentology

The broad pattern of Carboniferous depositional history and the developing picture of contemporary palaeogeography have been outlined above.

Eastwood et al. (1931, p 64) cited evidence from the Whitehaven area for continental weathering of the pre-Carboniferous land surface composed of Skiddaw and Borrowdale Volcanic Group rocks. During the advance of the Lower Carboniferous sea, abundant weathered debris was redistributed, accumulating in hollows on the submerged land surface. A feature of the conglomerates of the Basement Beds both in the Whitehaven and Cockermouth areas (Eastwood et al. 1968, p.150) is the local derivation of the contained clasts. Sandstones and mudstones also occur within the basement beds, no doubt reflecting quieter intervals in which supplies of coarse debris were reduced.

The Cockermouth Lavas record a volcanic episode during deposition of the Basement Beds. Their position, close to the southern margin of the Solway-Northumberland trough, suggests that this volcanism was associated with the initiation of the 'trough'. Leeder (1982) has drawn attention to the association of this magmatic activity within an area believed to contain the remnants of the Iapetus suture and in which stretching of the crust, basin subsidence and rifting resulted in volcanism. MacDonald and Walker (1985, p.142) suggested that the Cockermouth Lavas were erupted quietly from a fissure or line of vents aligned approximately along the present outcrop. The presence of well developed 'bole' or soil horizons between flows (Eastwood et al. 1968, p.152) indicates contemporary sub-aerial weathering. It is thus likely that the Cockermouth Lavas were erupted either subaerially or into the very shallow waters of the advancing Lower Carboniferous sea.

An upward passage from Basement Beds to Seventh Limestone, noted by Eastwood et al. (1968) probably records the progressive and eventually complete submergence of the area.

6.4 Details

Sediments referable to the Basement Beds are recorded from boreholes at Gatra and Streetgate (boreholes 02 SE/19 and 02 SE/62). At Streetgate, 12.6 m of brown shale is recorded at the bottom of the borehole. This shale is interpreted in the borehole log as being the shale which elsewhere overlies slate, presumably of the Skiddaw Group, though slate was not reached in this borehole. At Gatra 4.5 m of shale overlies a 'red and grey shale' interpreted as being Skiddaw Group; no fault was recorded between this and the overlying 'grey shale'. These shales above the Skiddaw Group are interpreted as being equivalent to the Seventh Shale of the Whitehaven area.

The outcrop of Cockermouth lavas is confined to the area between Brigham and Papcastle, east of the Ewanrigg Fault. Fine-grained, green, amygdaloidal basalt lavas are exposed in the bed of the River Derwent at Stodhole Beck [0988 3114]. Identification of individual flows was not possible.

The primary mineralogy and texture of the lavas is largely obscured by secondary replacement. Original mafic phenocrysts are pseudomorphed by fine-grained chlorite and serpentine, while iron oxide rims define an original fracture pattern in the grains. The presence of olivine and/or augite phenocrysts in unaltered Cockermouth Lavas has been described by MacDonald & Walker (1985). Plagioclase phenocrysts, up to 9 mm in size, are also present. The feldspar laths may be partially included with the pseudomorphed mafic grains, indicating an original subophitic texture. The feldspars are commonly saussuritised. Replacement by both carbonate and chlorite may also be seen. Opaque minerals, possibly ilmenite and/or magnetite which occur as randomly orientated bladed or skeletal crystals, are abundant.

The amygdales which are developed in parts of the lava are irregular or elongate and may be up to 5 mm in length. They exhibit a zonal infill of alternating layers of calcite and fine-grained quartz. The final phase of infill is represented by coarse-grained calcite or quartz.

7. CARBONIFEROUS ROCKS: 3 CHIEF LIMESTONE GROUP

7.1 Introduction

Rocks of the Chief Limestone Group crop out in an almost continuous belt along the eastern side of the district (Figure 2). Near Mockerkin the continuity of the outcrop is interrupted by displacement along the Mockerkin Fault. The top four limestone units are generally well-exposed between Great Broughton and Pardshaw and have been exploited in numerous quarries. Extraction of the First limestone continues today on a large scale at Tendley Hill Quarry. Elsewhere drift deposits conceal much of the Chief Limestone Group outcrop. Details of the stratigraphy of the drift-covered areas and of the lowest beds of the sequence are derived almost entirely from the records of boreholes.

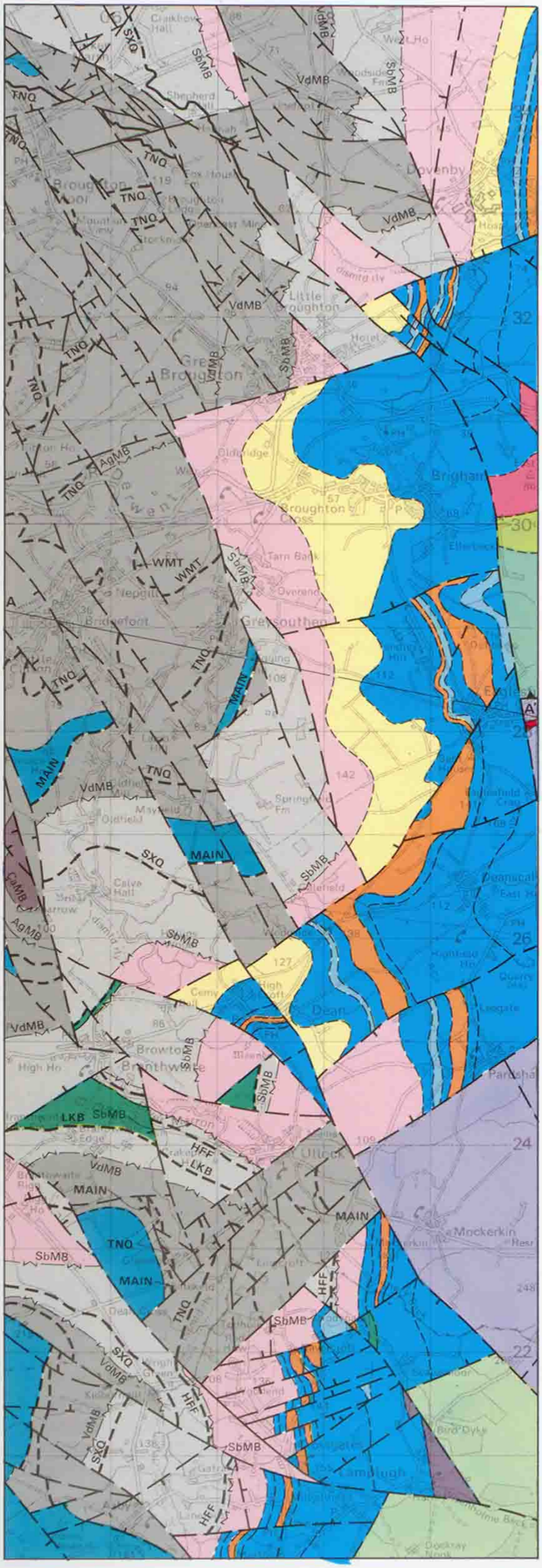
Where free of superficial deposits the limestones give rise to distinctive landscape features. On Eaglesfield Crags and NE of Pardshaw the Fourth Limestone typically forms terraced hillsides with low limestone crags alternating with grass-covered slack features marking the outcrop of interbedded mudstones. The First and Second Limestones form similar lines of crags north of Eaglesfield. Swallow holes are associated with most of the limestones. These are most abundant, or at least most easily recognised, in areas where drift or overlying solid formations are absent or thin. South-west of Eaglesfield, swallow holes into the First Limestone are especially abundant and in places these penetrate several metres of drift and Hensingham Grit above the limestone (see Section 12-11). The thin soils on the bare limestone outcrops support a characteristic limestone grassland flora.

7.2 Classification

The lowest part of the West Cumbrian Carboniferous sequence is dominated by limestone (Figure 3). Individual limestone formations have long been recognised and are named in descending order as the First Limestone, Second Limestone

Table 3 Chronostratigraphical and lithostratigraphical classification of the Chief Limestone Group

<table>
<tr><th colspan="3">CHRONOSTRATIGRAPHY</th><th colspan="2">LITHOSTRATIGRAPHY</th></tr>
<tr><td rowspan="8">CARBONIFEROUS</td><td>NAMURIAN</td><td></td><td>First Limestone</td><td rowspan="8">CHIEF LIMESTONE GROUP</td></tr>
<tr><td rowspan="7">DINANTIAN</td><td rowspan="5">Brigantian</td><td></td></tr>
<tr><td>Second Limestone</td></tr>
<tr><td>Orebank Sandstone</td></tr>
<tr><td>Third Limestone</td></tr>
<tr><td></td></tr>
<tr><td>Asbian</td><td>Fourth Limestone</td></tr>
<tr><td>Holkerian
?Arundian</td><td>Fifth to Seventh Limestone</td></tr>
</table>



CARBONIFEROUS

- MIDDLE COAL MEASURES
  - Upper Coal Measures, undivided
  - Middle Coal Measures, undivided
  - Sandstone in Middle Coal Measures
- LOWER COAL MEASURES
  - Lower Coal Measures
  - Sandstone in Lower Coal Measures
- HENSINGHAM GROUP
  - Hensingham Group, undivided
  - Hensingham Grit
- CHIEF LIMESTONE GROUP
  - Chief Limestone Group, undivided
  - Sandstone in Chief Limestone Group including Orebank Sandstone
  - Limestone in Chief Limestone Group including First to Seventh Limestone
  - Cockermouth Lavas

ORDOVICIAN

- SKIDDAW GROUP
  - Skiddaw Group, undivided
  - Kirk Stile Formation
  - Loweswater Formation
  - Watch Hill Formation
  - Bitter Beck Formation

Quartz, microdiorite

Coal seam

Fault

Thrust

Marine band

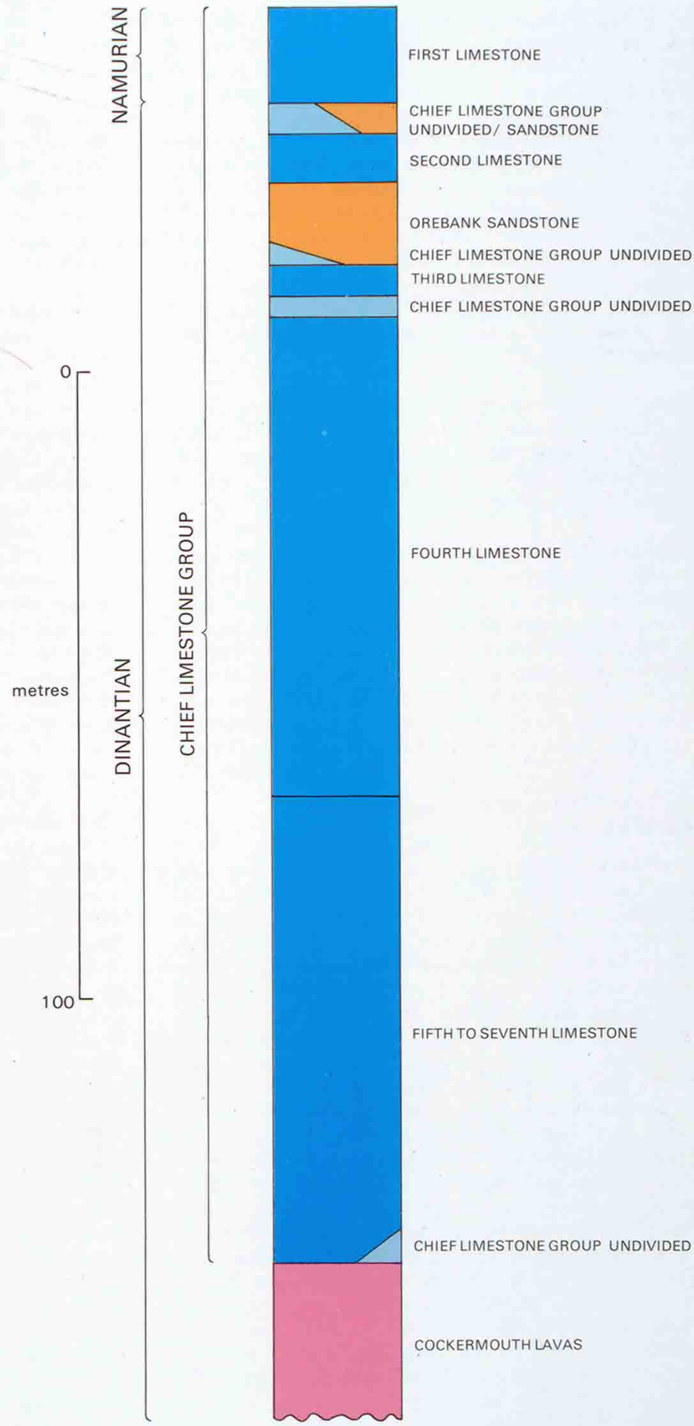
Geological boundary, solid

CaMB	Cambriense (St Helens) Marine Band
AgMB	Aegiranum (Bolton) Marine Band
WMT	White Metal
TNQ	Tenquarters
MAIN	Main
VdMB	Vanderbeckei (Solway) Marine Band
LKB	Lickbank
SXQ	Sixquarters
HFF	Harrington Four Foot
SbMB	Subcrenatum Marine Band

This figure is a simplified portrayal of 1:25 000 scale map 1 which should be consulted for detailed information

Figure 2 Solid Geology map

Figure 3 Generalised vertical section of the Chief Limestone Group



etc. These names were coined in the early days of the west Cumbrian ironore mining when successively lower limestones were encountered in shaft sinking and mine development. Strata between the limestone formations comprise mudstones, siltstones and sandstones. Iron ore mining practice was to refer to most of these clastic beds as 'shale', in most instances irrespective of the dominant lithology. Each 'shale' took its name for the overlying limestone. More specific names were applied to two sandstone formations high in the sequence, the Orebank Sandstone between the Second and Third Limestone and the Little Whirlstone, a sandstone unit within the interval between the First and Second Limestone.

Details of the chronostratigraphical correlation of the Chief Limestone Group are shown in Table 3. These have been taken from Mitchell et al (1978) who presented a synthesis of all available work on the Carboniferous stratigraphy of Cumbria.

Apart from the topmost limestone unit, the First Limestone, the Chief Limestone Group lies entirely within the Lower Carboniferous or Dinantian. Palaeontological evidence indicates that the base of the First Limestone coincides closely to the base of the Namurian division of the Upper Carboniferous. However in view of its obvious lithological similarity to the underlying sequence, the First Limestone is included here within the Chief Limestone Group.

7.3 **Conditions of depositions and sedimentology**

Lower Carboniferous times saw a progressive submergence of the uneven surface of Lower Palaeozoic rocks beneath a tropical sea. There is evidence in adjoining parts of west Cumbria that the pre-Carboniferous surface was exposed to a period of arid or semi-arid conditions immediately prior to its submergence. During early Carboniferous times, the basement structure of northern England was characterised by structurally contrasted areas. Areas of relatively rapid submergence formed 'troughs' or 'basins' between 'blocks' or 'massifs' which subsided more slowly. The boundaries between 'troughs' and 'blocks' were comparatively narrow hinge zones along contemporary fault lines. In northern England the broad Solway-Northumberland Trough extended from the area of the modern Solway Firth across Northumberland and into the present day North Sea. North of this 'trough', in the area which now forms the Southern Uplands, lay a landmass which supplied abundant, though intermittent, supplies of terrigenous sediment throughout Carboniferous times. To the south of the 'trough' an area of relatively buoyant rocks including the partially concealed granites of the Lake District and Pennines formed a 'block' area known as the Manx-Cumbria-Alston Ridge. This extended from the Isle of Man across the Lake District and into the Northern Pennines. The present day Maryport-Gilcrux-Stublick fault line coincides closely with the course of this Carboniferous hinge zone. Further south lay other 'troughs' in the Stainmore and Craven areas. Sedimentation began earlier in the 'troughs' than on the 'blocks', although the whole of northern England was submerged during Dinantian times.

The present district occupies a position close to the northern margin of the Manx-Cumbrian-Alston Ridge. Evidence for the progressive submergence of this ridge is provided by the onlapping unconformity of successively older Carboniferous beds around the margin of the present day Lake District (Mitchell et al 1978).

In northern England the Lower Carboniferous sequence records an interplay of marine and non-marine deltaic influences. A characteristic feature of much of the Lower Carboniferous is the cyclical repetition of lithologies as idealised cyclothems comprising in ascending order limestone, mudstone, sandstone and locally coal. These are interpreted as the products of alternating periods of relatively slow and rapid subsidence. During periods of slow subsidence, delta lakes advanced across the area from the north carrying mud and sand from the Southern Uplands landmass. On occasions deltas were built up to above sea level allowing the development of swamp forests now represented by seatearths and coal seams. With more rapid submergence warm, clear marine water spread from the south overwhelming the deltas and depositing marine limestone. From their extensive development in parts of the Yorkshire Pennines these rhythmic deposits are termed Yoredale cyclothems.

The relative thicknesses of individual lithologies reflects the varying importance of marine and non-marine influences within cyclothems. Within the present district, much of the Chief Limestone Group is dominated by limestone, especially in the lower part of the sequence. Clearly non-marine influences were comparatively weak at this time, especially when compared to adjacent areas in northern and eastern Cumbria. Rhythmic sedimentation within an essentially limestone environment is recorded in the upward sequence of calcareous shale, dark grey limestone and light grey or white limestone. This cyclicity was ascribed by Ramsbottom (1973) to a series of worldwide (eustatic) changes of sea level. In this model, marine transgressions are marked by bioclastic limestone; regressions by algal, dolomitic and fine-grained limestones, shales and sandstones. Emergence is indicated locally by non-sequences, minor unconformities, breccia beds and in places palaeokarst surfaces. These cyclothems were grouped by Ramsbottom (1977) into a series of major cycles or mesothems.

Non-marine influences are most pronounced in the higher parts of the Chief Limestone Group, particularly above the Fourth Limestone. Here, sequences of more typical Yoredale aspect occur, though generally without the thin coal seams found at the top of such cycles in adjoining areas such as Gilcrux (Young & Armstrong 1989).

The limestones of the present area resemble closely those described from the Dearham and Gilcrux area by Young and Armstrong (1989). These authors' description of the limestones is therefore adopted here.

7.3.1 Limestone

A detailed petrographical study of the area's limestone is beyond the scope of the present work. Because of its ease of application in the field and in the examination of hand specimens, Dunham's (1962) classification of carbonate rocks is adopted where appropriate for lithological description. The most detailed account of the petrography of west Cumbrian limestone is that by Stabbins (1969).

Wackestones were described by Dunham (1962) as limestone consisting largely of calcite mud with more than 10% of the rock composed of grains, commonly shell or other calcareous organic debris, supported by the mud matrix. Many of the limestones of this district are wackestones in which crinoid fragments occur in fine-grained medium to dark grey calcite mud matrix. Shell fragments are also found, but are less abundant.

Packstones of Dunham's classification are limestones with a considerable calcite mud component but in which the grains are sufficiently numerous to be in contact with one another. The fabric of the rock is then grain supported. Some of the limestones of the present district contain sufficient coarse clastic material to warrant the use of this term.

Mudstones in Dunham's nomenclature are limestones composed of lime mud in which less than 10% of the rock consists of grains. Included here are the fine-grained limestones described in previous accounts as porcellanous.

Edmonds (1922) described both pseudobreccias and 'spotted' limestones from west Cumbria. Eastwood (1930), Eastwood et al. (1931) and Eastwood et al. (1968) made frequent reference to the presence of 'spotted limestone' or 'spotted beds' within the Lower Carboniferous sequence, apparently using the term as synonymous with pseudobreccia. In a detailed study of the west Cumbria limestone succession. Stabbins (1969) confirmed that there is very little difference between the two. An alternation of pseudobreccias with 'standard' limestones was also noted by Stabbins (1969).

Pseudobreccia may be defined as a partially and irregularly recrystallised limestone characterised by a mottled or spotted appearance. The rock then resembles a breccia especially on weathered surfaces. Pseudobreccia is produced diagenetically by selective grain growth in which patchy and irregular shaped masses of calcite are embedded in lighter coloured less recrystallised calcareous mud. The boundaries between the patches, spots or 'clasts' are typically indistinct or gradational. The patches or spots may be up to 10 cm in diameter. Where they exhibit a relatively angular outline the term pseudobreccia was applied by Edmonds (1922). The term 'spotted limestone' was applied by Edmonds and other authors to the limestones in which the patches, up to 2.5 cm across, typically display a rounded outline. The origin of pseudobreccia has long been a problem although bioturbation of the newly deposited sediment followed by recrystallisation during diagenesis is thought to be an important factor.

Rubbly weathering limestones have been noted at a number of places in west Cumbria. These were taken by Stabbins (1969) to be pseudobreccias in an advanced state of recrystallisation in which the groundmass has been almost totally removed by pressure solution.

Most of the limestones are slightly bituminous and smell slightly 'oily' when hammered. They are commonly thickly bedded rocks with individual beds up to over 1 m. Thin beds of calcareous mudstone up to 0.1 m thick are locally common between thick limestone beds. Stylolitic surfaces are common. Most limestones are well jointed. Nodular limestones are conspicuous by their rubbly texture, especially in weathered faces.

Most of the limestones have experienced slight recrystallisation, although organic remains are generally still easily recognisable. Fossils are common and are usually most easily seen on weathered surfaces. Most common are crinoid fragments, brachiopods and large colonial corals. Bryozoa also occur and some limestones are rich in foraminifera.

7.3.2 Mudstone and siltstone

Thin beds of medium grey, commonly calcareous, mudstone up to 0.1 m thick are locally interbedded with some limestones though these are rarely exposed in the district. Walkden (personal communication in Mitchell et al., 1978, p.175) noted bentonitic characteristics in some of the Asbian shales of west Cumbria. These have been interpreted as the products of accumulated airborne volcanic dust which became weathered to soils during periods of emergence. No investigation of the clay mineralogy or geochemistry of any of the district's mudstones has been carried out during the present investigation. However, the basalts of the Cockermouth Lavas, of presumed Courceyan age in the north of the area, are evidence of early Carboniferous volcanic activity which continued nearby in later Carboniferous times. A source may therefore have existed for the supply of volcanic ash which could have produced bentonitic clays within parts of the Dinantian sequence.

Thicker mudstones are present between individual limestones, especially those above the Fourth Limestone, although in this district they are generally poorly exposed and normally form slack features between limestone terraces. Where seen, the mudstones vary in colour from medium to dark grey and are commonly calcareous. Some are silty and pass imperceptibly into siltstone.

7.3.3 Sandstone

Fine- to medium-grained sandstone occurs between several of the limestones. Most notable are those beneath the First Limestone, locally known as the Little Whirlstone, and the Orebank Sandstone beneath the Second Limestone. In the adjoining Dearham and Gilcrux area to the north Young and Armstrong (1989, p.11) noted that sandstones between the Second, Third and Fourth Limestones are generally much thinner than the limestones; only the Orebank Sandstone attains a thickness greater than the adjacent limestones.

The sandstones are typically fine- to medium-grained and are generally pale brown in colour. Cross-bedding is well marked in some exposures of the Orebank Sandstone. A siliceous cement may be present locally and rootlet traces have been noted in some exposures.

7.3.4 CHERT

Fine-grained silica in the form of chert occurs as irregular flattened nodules up to 15 cm across in the Fourth Limestone at Broughton Crags quarry [090 318].

7.4 **Details of stratigraphy**

The stratigraphical classification of the Chief Limestone Group has been outlined above (Figure 3 and Table 3). Descriptions which follow are based on observations made during the resurvey, those given by Eastwood (1930). Eastwood et al. (1931) and other authors, revised in the light of recent work. Faunal lists given here are quoted from existing publications, with minor revision where appropriate.

7.4.1 FIFTH TO SEVENTH LIMESTONE—GENERAL DESCRIPTION

The outcrop of the lowest three limestones and intervening clastic beds of the West Cumbrian Dinantian sequence is almost confined to the Lamplugh area, south of the Mockerkin Fault. North of this, Lower Carboniferous rocks are almost everywhere faulted against the Skiddaw Group and in only two places, one east of Deanscale and the other north east of Brigham, do beds beneath the Fourth Limestone reach outcrop. The combined thickness of the Fifth to Seventh Limestone in the present area is around 75 m.

Because of extensive drift cover, exposure of these beds is very poor in the district. In common with Eastwood et al. compilation of the Whitehaven Sheet, no attempt has been made to separate the lowest three limestones on either the 1:10 000 or 1:25 000 maps. Several exploratory boreholes for iron ore, drilled last century in the Lamplugh area, have penetrated these beds. The general account which follows is therefore based on the records of these together with observations made by Eastwood et al. (1931) for the formations elsewhere in the Whitehaven area.

Fifth to Seventh Limestone—Details

Because of heavy drift cover and insufficient unambiguous borehole and other sub-surface data, neither Dixon nor Eastwood made any attempt to distinguish separately these limestones on the six-inch geological sheets prepared during their survey of the area. However, certain individual outcrops and groups of outcrops were in some instances assigned tentatively to individual units for the purposes of description in the Whitehaven Memoir (Eastwood et al., 1931). This practice has been adopted during the present study.

The Seventh limestone is exposed in a disused quarry [0970 3065] at East House Farm. The limestone is light grey to brown in colour, thickly bedded (40 cm average) and shows planar bed boundaries. The outcrop is 150 cm high though Eastwood (1930) previously described 27 ft [8.2 m] of exposure. The limestone is fossiliferous: *Nematophyllum minus* M'Coy and brachipods were recorded by Eastwood (1930).

Limestone exposed in the banks of the River Derwent has been interpreted as representing the top of the Seventh Limestone (Eastwood 1930). The limestone is light grey in colour, coarse grained with bedding 10–30 cm thick. It is richly fossiliferous with crinoid columnals and bivalves. Eastwood (1930) noted *Nematophyllum minus, Lithostration martini* together with bryozoa. The line of quarries seen between Lamplugh Church and Scalesmoor is interpreted as having worked the Fifth Limestone (Eastwood 1931). The limestone is exposed in four quarries over a strike distance of 1 km. The quarries exhibit an upward transition from light grey to brown, fine-grained sparry packestone into a coarser-grained white to cream coloured packestone. The lower limestone is wavy bedded, with beds generally 10–30 cm in thickness. The limestone contains numerous crinoid columnals and shell material. In one quarry [0850 2171] a 1 m thick layer of patch reefs occurs towards the top of the lower limestone. The coral mounds are 30 cm thick and appear to be lenticular.

The overlying white limestone is richly fossiliferous with abundant crinoid debris and bivalves up to 10 cm. Beds are typically about 5 cm thick. A maximum thickness of 4 m for the two units is exposed. The limestones are cut by calcite-filled veins up to 5 mm thick and hematite staining is present in places.

The outcrop of Fifth to Seventh Limestone east of Deanscale is almost totally concealed beneath till and lacustrine deposits. On the lower, eastern slopes of Crag Hills, Eaglesfield, there are small exposures of limestone. As these are only a few metres beneath the inferred base of the Fourth Limestone, they must form part of the Fifth Limestone. A section [0994 2724] approximately 150 m south of Eaglesfield Crag Farm shows some 2 m of rather rubbly weathering pale grey limestone overlying up to 1 m of compact dark grey limestone.

A small outcrop [0996 2586] of sandstone overlying grey mudstone, 100 metres north of Bouch Quarry, is referred to the Fourth Shale on Six Inch Geological Sheet Cumberland 54 SE. No thicknesses are quoted, although the sandstone appears to be immediately overlain by the base of the Fourth Limestone. These beds are not exposed today.

7.4.2 FOURTH LIMESTONE—GENERAL DESCRIPTION

The Fourth Limestone is the thickest of the individual limestone formations of west Cumbria. Approximately 75 m of beds are assigned to the Fourth Limestone in the Great Broughton–Lamplugh area where it has been mapped as a discontinuous outcrop both north and south of the Mockerkin Fault. Defining the top and bottom of the formation is difficult in the generally poorly exposed ground of this district, and the boundaries depicted on the 1:10 000 and 1:25 000 scale geological maps should be regarded as conjectural. The best and most continuous exposures of Fourth Limestone are between Eaglesfield and Pardshaw. Several boreholes in the Lamplugh area have penetrated Fourth Limestone.

The term Fourth Limestone is a convenient name for a complex succession of beds which, although dominated by limestone, also includes several thin clastic intervals. Local names have been applied to the individual members of this sequence. For a detailed description of the Fourth Limestone, reference should be made to Eastwood (1930), Eastwood et al. (1931), Eastwood et al. (1968) and Stabbins (1969). The following summary of the formation has been compiled mainly from Eastwood et al. (1931):-

Cherty Limestones: dark grey, thinly bedded rubbly or compact limestones with chert nodules and silicified fossils. Fauna similar to Junceum Limestone. Eastwood et al. (1931, p.92) noted that it is impossible to distinguish between the upper part of the Junceum and the Cherty Limestones in isolated sections.

Junceum Limestones: dark grey, thinly bedded and rather rubbly in upper part becoming pale grey and more thickly bedded below. Chert nodules occur throughout and many of the fossils are silicified (beekitised). Some beds of cross-bedded crinoid debris locally. Bands of *Lithostrotion junceum* and, near the top a band containing *Lonsdaleia alstonensis*.

Erythrospongia Band and Saccammina Shale: thin and apparently impersistent parting of nodular limestone and limestone nodules in clay mudstone, the latter in places crowded with *Saccammina*. Two thin coal seams occur in the Great Broughton area. This bed may fill potholes up to 3 m deep in the underlying bed.

Saccammina Limestone: pale grey thinly bedded limestone in which *Saccammina* is usually abundant.

[1] **Russell's 'Seventh Shale'**: fine-grained calcareous or quartzitic sandstone with *Stigmaria* or sandy mottled mudstone or shale with abundant plant impressions.

Potholes Limestone: pale grey, thickly bedded limestone commonly with an uneven or potholed top. The *Orionastraea* Band near the top contains the corals *Orionastraea, Corwenia* and *Nemistium*.

[1] **Russell's 'Sixth Shale'**: a thin impersistent mudstone or locally a sandstone, in places filling potholes in underlying limestone.

Spotted Limestones: grey limestone pseudobreccias in which occur numerous spots or dark patches up to 0.15 m across. *Saccammina* locally occurs in the 'spots' but is absent from the groundmass. These beds commonly interdigitate with darker grey limestone like the underlying Rough Beds.

Rough Limestones: dark grey wavy-bedded limestone. Some contemporaneous erosion. *Girvanella* encrusts brachiopods at the base. Gastropods and bivalves more common than in most limestones above the Seventh. Trilobites are occasionally found.

Girvanella Band and Russell's 'Fifth Shale': thin calcite mudstone and mottled clay mudstone. The former yields *Spirorbis*-like annelids, ostacods, and locally small masses of *Girvanella*. The base is uneven but piping is shallow and local.

White Limestone: pale grey limestones commonly rubbly-weathering with several interbedded mottled mudstones. Most of the limestones are pseudobreccias. Some of the rubbly limestones may be *Spongiostroma*-like and true brecciated limestones are also present. The interbedded mudstones may fill channels in the limestone but potholes have not been noted. One or other of the mudstones in the middle of the unit was termed the 'Fourth Shale' by Russell.

Precise recognition of the individual members of the Fourth Limestone in the field is commonly difficult or impossible and it is not practicable to map these separately.

A very similar Fourth Limestone succession was reported from the Cockermouth area by Eastwood et al. (1968 fig. 14, 0 157) who also noted a striking thickening to approximately 130 m in the Gilcrux area. Stabbins (1969, p.302) noted a similar increase in thickness of the Fourth Limestone northwestwards from the Frizington-Rowrah area, a short distance south of the present district. This thickening clearly reflects contemporaneous movement along the growth faults which bound the edge of the Manx-Cumbria-Alston ridge and the Solway-Northumberland Basin.

The presence within the Fourth Limestone of units, albeit thin, of clastic sediment, reflects the incursion of non-marine influences from the north and north east. Within west Cumbria such incursions were comparatively weak, although when traced northeastwards towards Caldbeck the non-marine intervals thicken as the succession passes into the classic rhythmic 'Yoredale' sequence of the Pennines.

[1] The clastic beds within the Fourth Limestone were so named by Russell during the primary geological survey of west Cumbria.

Fourth Limestone—Details

On Crag Hills, south of Eaglesfield, the Fourth Limestone is locally well exposed forming low lines of white-weathering crags separated in places by slack features, no doubt marking the outcrop of weaker, possibly shaly, beds. These crags are especially conspicuous on the eastern side of the hill where pale grey, commonly pseudobrecciated limestones dipping westwards and referable to the White Limestone, are exposed, between [0983 2732 and 0946 2679]. According to Eastwood et al. (1931, p.92) beds up to the Rough Limestone crop out in these crags. The limestone on the top of the hill [0977 2713] and the dip slope to the west [e.g. 0969 2713] may belong to this division. The Girvanella Band or Russell's 'Fifth Shale' have not however been found here.

Limestone with cherts belonging to either the Junceum or Cherty Limestones was formerly exposed in small quarries [0956 2758] west of the Eaglesfield to Deanscale road. These pits are today much obscurred though very small outcrops of medium grey, rather bituminous limestone with numberous shell fragments and some dark grey chert nodules are still visible.

Similar limestones, presumably at roughly the same stratigraphical horizon, crop crop out east of the road [0953 2725] approximately 300 metres further south. A prominent slack feature which parallels the strike immediately east of these outcrops may mark the outcrop of the Saccammina shale though no exposures were seen to confirm this.

According to Six Inch Geological County Sheet Cumberland 54 SE an old pit [0908 2627] south west of Deanscale exposed dark limestone assigned to the Rough Limestones. This pit is now filled and nothing is exposed there today.

In the valley west of Deanscale and north of the road to Dean, medium grey limestones (packestones), probably belonging to the Junceum or Cherty Limestones are exposed at several places. Low crags may be seen at [0893 2635]. At the Singing Well [0883 2632], a strong spring rises from a prominent bedding plane in thickly bedded medium grey limestone. An old, and now much overgrown quarry [0868 2628] south of Dean Wood, exposes about 2 m of medium grey wavy-bedded packestone in beds or posts up to 0.4 m thick. More than 3 m of limestone with cherts up to 7 cm across were noted here on Six Inch Geological Sheet Cumberland 54 SE.

Pseudobrecciated limestones, dipping west, are exposed in numerous small outcrops [e.g. 0873 2574, 0898 2564, 0923 2570. 0915 2594] in the otherwise drift-covered county south and south-west of Deanscale. The position of these within the Fourth Limestone sequence cannot be determined precisely, although beds up to and including the Spotted Limestones may be present. Numerous swallow holes into these limestones occur in the till-covered ground surrounding these outcrops.

Pale grey limestones, identified by E E L Dixon as White Limestone on Six Inch Geological Sheet Cumberland 54 SE, crop out on the north slope of Pardshaw Crags [1000 2580]. Several metres of the overlying Rough Limestone are exposed in the abandoned Bouch Quarry [0990 2575].

An old, shallow, and now much overgrown and partly flooded quarry [0953 2524], 150 m south east of Leegate exposed thinly bedded dark grey limestone with occasional nodules of chert, probably belonging to the Cherty Limestone.

7.4.3 Third Shale – General description and details

Eastwood et al. (1931, p.68) described briefly the beds which intervene between the top of the Fourth and base of the Third Limestone over much of the Whitehaven Sheet. The interval consists of dark shale overlain by sandstone, although in places only one lithology is present. The shale unit, which commonly contains plant fragments, is clearly non-marine whereas the presence of crinoid fragments locally at the top of the sandstone gives evidence of marine conditions.

The 'Third Shale' may be absent in the Hensingham area. Its presence and pattern of outcrop in the Great Broughton–Lamplugh district is in part conjectural; no exposure of beds definitely referable to this unit are visible in the district today though it was formerly exposed at Dean.

Over much of the Whitehaven area Eastwood et. al. (1931) report an average thickness of 2.1 m for the Third Shale. In the Lamplugh area, however, they record its thickness as 6.1 m consisting mostly of sandstone which fills potholes in the underlying limestone. It may be thicker at Dean where again it comprises mainly sandstone. Eastwood et al. (1931) noted exposures of this sandstone in Dean village although none is visible today.

7.4.4 Third Limestone – General description and details.

In common with the rest of west Cumbria the Third Limestone is very poorly exposed in the Great Broughton-Lamplugh area. Little detail can therefore be given for this unit. Eastwood et al (1931, p.68) observed that in the area of the Whitehaven sheet the unit typically consists of light to dark grey limestone containing crinoid debris but with few other identifiable fossils. Stabbins (1969, p.307) commented on the very few exposures though noted that packestone appears to be an important lithology. The Third Limestone varies from 3 to 8 m thick in the Whitehaven area (Eastwood et al., 1931) although this appears to thicken northwards towards Gilcrux where Young and Armstrong (1989, p.13) record up to 10 m.

The small exposures of limestone in Dean Village, between [0738 2520 and 0760 2520] mapped on Six Inch Geological County Sheet Cumberland 62 NW as Third Limestone are not visible today.

7.4.5 Orebank Sandstone Group – General Description

The beds between the Third and Second Limestones throughout west Cumbria take their name from a prominent sandstone unit exposed near Orebank House, Bigrigg near Egremont, southwest of the district. Although commonly dominated by sandstone this division includes beds of mudstone. A typical sequence for the Whitehaven Sheet area is that given by Eastwood et al. (1931, pp.68–69):

> "Thin, dark mudstone or shale; clay-ironstone and pyrites; plant fragments.
>
> Sandstone, white, light grey or coloured; micaceous or quartzitic; rootlets or (Tendley Hill) crinoids.
>
> Dark or striped shale; clay-ironstone and pyrites.
>
> Black laminated marine shale with abundant fossils in streaks ....."

Thicknesses are not given for individual units.

In a detailed study of borehole records Stabbins (1969, p.309) demonstrated a considerable thickness variation in the Orebank Sandstone Group throughout west Cumbria, noting also a marked regional variation in the sandstone–mudstone ratio. From a dominantly sandstone formation some 20 m thick near Egremont the proportion of mudstone increases progressively northwards, accompanied by an overall diminution in thickness to about 12 m at Lamplugh where locally as little as 20 per cent of the formation consists of sandstone. When traced northwards across the present district the Orebank Sandstone Group thickens progressively with sandstone becoming the predominant component. At Dean it is 13.4 m thick and at Tallentire, immediately to the north east of the area, the Orebank Sandstone Group attains a thickness of 35 m.

The Orebank Sandstone Group records an alternation of environments. The dark shales at the base, recorded by Eastwood et al. (1931) (see above) contain fossils indicative of a shallow marine environment. Sandstones, which make up much of the group, commonly exhibit cross-bedding and rootlet traces and are interpreted as the products of deltaic advance. The local presence of crinoid fragments within the sandstone, for example at Tendley Hill (Eastwood et al., 1931), indicates that marine influences were never far away. Stabbins (1969, p.314) has suggested that in the Broughton Craggs area there is evidence of an upward passage to low energy fluviatite and eventually a swamp environment. The development, at least locally, of an abundant flora in emergent or swamp conditions is indicated by the presence of a thin coal and underlying seatearth in the Broughton area. A rapid return to shallow marine conditions is recorded by the fossiliferous shale with brachiopod fragments and plant debris which overlies this coal.

Orebank Sandstone Details

The Orebank Sandstone is exposed in a quarry at Broughton Craggs [NY 0890 3172]. Eastwood (1930) described the section while the quarry was active, recording that 'some 30 ft [9.1 m] is exposed but the base is invisible owing to strike faulting. The upper beds of the group—with 4 ft [1.2 m] of white fireclay below a coal 3 ft 6 in [1.1 m] in thickness overlain by dark shales and the lowest beds of the Second Limestone'. The Orebank Sandstone is white to buff in colour, fine- to medium-grained and quartz rich with occasional thin lenticular muscovite-rich layers. The Orebank Sandstone is thickly bedded with beds 1–2 m in thickness in the lower part of the sequence. Some beds are massive whereas others show trough cross bedding with foresets up to 150 cm high. Individual beds become thinner upwards and are typically about 30 cm thick 1 m below the overlying mudstone unit.

A fauna was collected from the shales directly overlying the Orebank Sandstone. The combined fauna consists of:-

Hyalostelia?., Crurithyris? Echinoconchus? Isogramma sp., *Productus* sp., *Rugoschonetes* cf. *celticus, Schizophora?, Spirifer?, Donaldina* sp., *Hypergonia* sp., *Naticopsis* sp., *Neilsonai* sp., *Soleniscus* sp., *Straparollus?, Cardiomorpha* sp., *Cypricardella* cf. *concentrica, Edmonia* cf. *senilis, Leiopteria* sp., *Palaeolima* cf. *simplex, Palaeoneiolo* cf. *luciniformis, P.* cf. *mansoni, Parallelodon* cf. *semicostatus, Pernopecten* cf. *fragilis, Posidonia?, Pterinopectinella* sp. juv., *Sanguinolites* cf. *tricostatus, Streblochondira* sp., *Anthracoceras?,* conodont.

The fauna is consistent with late Viséan faunas of Scotland and of the Canobie area, although there are a few comparative faunas from Cumbria itself and in South Cumbria the Gleaston formation, which might be expected to contain a mud-facies similar to this, is not comparable on the basis of the published fauna (Mitchell in Rose and Dunham 1977, pp.35–36).

Pernopecten fragilis has so far only been recorded from the Blackhall Limestone in Scotland. Thus the range of the species has yet to be deduced, and *Neilsonia* is also well known from the same horizon, though the genus also occurs lower in the sequence in Scotland. Elements of this fauna have been found further south in West Cumbria in the mudstones underlying the Second Limestone.

South of the Derwent the Orebank Sandstone Group has been mapped as an almost continuous outcrop though much disrupted by faulting. Much of the outcrop is, however, drift-covered and exposures are few.

Sandstone was formerly worked in an old quarry in Quarryfield Planation [0940 2900] north of Eaglesfield. At the time of the last geological survey in the 1920s, more than 2.4 m of fine-grained white and buff 'freestone' were exposed here beneath about 1.5 m of till. The quarry is today very overgrown and partly filled with farm rubbish: no exposures can be seen. Blocks of rather slabby medium-grained pale fawn sandstone with numerous small (2–3 mm) ochreous spots are present in the spoil. The change from a westerly dip on the hillside to the west to the north-easterly dip recorded in the quarry almost certainly accounts for the wide outcrop width of the Orebank Sandstone hereabouts.

On the hillside about 200 m west of the quarry the Orebank Sandstone crops out beneath the Second Limestone. Though there are no exposures blocks of medium-grained pale fawn sandstone, some with abundant rootlets, are present in the soil, e.g. at [0919 2899].

South of Eaglesfield small outcrops [0906 2731 and 0898 2716] of Orebank Sandstone may be seen in the fields east of the lane to Dean. The rock here is a medium-grained and locally micaceous, pale fawn sandstone with numerous small ochreous patches similar to that seen in the spoil at Quarryfield Plantation (above).

7.4.6 Second Limestone—General description

This Limestone, the highest in the Dinantian succession, forms narrow and mostly drift-covered outcrops north of Broughton Craggs, around Eaglesfield, Dean and Pardshaw, and south of Mockerkin. In the south of the area, near Lamplugh, it is approximately 7 m thick but thickens slightly northwards to around 10 m in the Broughton Craggs area. Throughout west Cumbria Stabbins (1969, p.315) noted that it is predominantly a dark grey, somewhat argillaceous and wavy-bedded bioclastic packestone. Eastwood et al. (1931 p.69) commented that the colour was darker in the higher beds and that nodular limestone occurred at the top. Nodules and lenses of black chert recorded from the northern and eastern parts of the Cockermouth area described by Eastwood et al. (1968, p.159) have not been observed in the Great Broughton–Lamplugh district.

Second Limestone—Details

The Second Limestone forms a low line of rocky scars [From 0895 2932 to 0930 2870] on the steep east-facing hillside east of Tendley Hill Quarry. Small exposures here and in Eaglesfield village [0984 2825] show medium grey wavy-bedded packestones in beds up to about 0.5 m thick.

An outcrop of dark grey crinoidal limestone near the base of the Second Limestone was noted during the last geological survey in a field about 1 km south-west of Eaglesfield. Nothing is exposed here today.

7.4.7 First Shale and Little Whirlstone—General description

In common with normal practice in west Cumbria the clastic beds above the Second Limestone derive their name from the overlying limestone. The 'First Shale' of this area comprises a persistent sequence of grey to black shale immediately above the Second Limestone, passing upwards into shale with sandy wisps and plant fragments. This is overlain by a sandstone, the Little Whirlstone, which typically consists of a fine- to medium-grained sandstone with carbonaceous flecks and pyrite. It is generally rather coarser-grained than the Orebank Sandstone. Locally in the Great Broughton–Lamplugh district either shale or sandstone may comprise the whole of the sequence between the Second and First Limestones. Stabbins (1969, p.317) has shown that at Lamplugh the thickness of the First Shale is 3.4 m overlain by 0.9 m of Little Whirlstone. At Dean these thicknesses are increased to 4.9 m and 2.1 m respectively, whereas at Tallentire, immediately to the north-east of the present district the combined thickness is 6.1 m. Individual thicknesses for the shale and sandstone are not available here.

The First Shale and Little Whirlstone sequence appear to be products of a dominantly freshwater fluviatite to deltaic environment, similar to that in which the Orebank Sandstone Group was deposited. Stabbins cited evidence of marine influence locally at the top of the Little Whirlstone.

First Shale and Little Whirlstone—Details

The top part of the Little Whirlstone is well exposed in Tendley Hill Quarry [088 289] where it forms the floor of the workings. This unit here consists of a fine-grained pale fawn sandstone with numerous carbonaceous rootlets. It is siliceous and ganister like in the top 0.4 m. An excavation [0881 2907] in the floor of the northern part of the quarry showed 1.7 m of sandstone underlain by at least 0.4 m of dark grey, micaceous, coaly siltstone also with abundant rootlet traces. A further 5 m of thin siltstone are understood to be present above the Second Limestone.On the east-facing hillside east of Tendley Hill Quarry the Little Whirlstone and presumed underlying shale form well-marked scarp and slack features respectively between [0885 2927 and 0915 2862]. Blocks of pale fawn ganister with rootlets may be seen locally in the soil brash, although there are no exposures here.

7.4.8 First Limestone—General description

The First Limestone is the basal member of the west Cumbria Namurian sequence. As outlined above it is included here within the Chief Limestone Group.

Throughout much of the district the First Limestone, like much of the Lower Carboniferous sequence, is concealed by drift deposits. However the wide outcrop in the Brigham and Eaglesfield areas is locally comparatively drift free and good exposures may be seen in large abandoned quarries around Brigham and in the district's only active quarry at Tendley Hill. The large quarries in First Limestone at Broughton Crags are now almost completely backfilled with domestic refuse.

Over much of west Cumbria the First Limestone consists of medium to dark grey thickly bedded bioclastic packestones. Thin shaly partings along uneven or wavy bedding planes are common.

Eastwood et al. (1931, p.69) described the presence locally of wedge-bedding and the occurrence of patches of shell sand. Sandstone filled 'dykes' were also described though none of these features has been observed in the Great Broughton–Lamplugh district. The First Limestone is not markedly fossiliferous, although Eastwood et al. (1931) commented on the partial silicification of fossils locally. A bed up to 20 cm thick known as the *Chaetetes depressus* band occurs persistently about one metre above the base of the limestone, a feature noted elsewhere in northern England by Johnson (1958). Stabbins (1969, p.323) recorded the presence of six thin distinctive dark grey beds of skeletal packestone above a marked erosion surface, near the middle of the First Limestone, across a wide area of west Cumbria. The uppermost part of the limestone is more evenly bedded with well-marked thin (2–4 cm) interbeds of black shale, reminiscent of the 'Tumbler Beds' of the Alston Pennines.

Stabbins (1969) also commented on the persistence of individual beds within the limestone and concluded that this reflected a widespread uniformity of depositional conditions. The essential features of the First Limestone of Cumbria persist in its correlative, the Great Limestone of the Alston Pennines and southern part of the Northumberland Trough (Johnson, 1958; Johnson & Dunham, 1963; Fairbairn, 1978; Dunham 1990).

Throughout its outcrop in west Cumbria the First Limestone exhibits a progressive north-easterly thickening. In the present area Stabbins (1969) recorded thickness of 14.6 m at Lamplugh, 15.8 m at Dean and 17.9 m at Tallentire, immediately to the north-east of the district.

First Limestone—Details

Approximately 11 m of First Limestone, dipping gently east to south-east, is exposed in the rather overgrown faces of Ellerbeck quarry [0895 2973]. A manuscript note on Six Inch Geological Sheet Cumberland 54 NE records that *Productus giganteus*, *Dibunophyllum* sp, *Lonsdaleia floriformis* are common here.

The First Limestone outcrop north-west of Eaglesfield is scarred by numerous pits including the large working Tendley Hill Quarry [088 289]. This provides one of the finest and most complete sections of First Limestone in Cumbria. At the time of this survey, limestone extraction was underway from the vertical northern, western and southern faces. All but the lowest and highest beds were therefore inaccessible. Throughout the quarry the limestone is worked down to the Little Whirlstone which forms the floor of the pit. The top of the western face is very close to the base of the Hensingham Grit. The complete thickness (15.8 m) of the First Limestone is therefore visible in this face. The First Limestone at Tendley Hill is generally a medium grey thickly bedded packestone. Bedding planes are typically uneven or wavy. Stabbins (1969) recorded the *Chaetetes depressus* band here and also noted a very thin mudstone bed separating the base of the limestone from the top of the Little Whirlstone, although these were not seen during the present survey.

Vertical joints trending approximately 260 and 334 are prominent. Dolomite and calcite, accompanied by solid hydrocarbons, form veins in some of these joints, especially in the southern part of the quarry (see Section 11.4).

The First Limestone is also exposed in several old quarries west of Eaglesfield. The outcrop here and for about 1 km to the south-west is marked by numerous sink holes, many of which penetrate through several metres of overlying Hensingham Grit (see Section 12.11).

A number of small pits worked First Limestone immediately north-west of Dean though these are mostly overgrown and obscured today.

8. CARBONIFEROUS ROCKS: HENSINGHAM GROUP

8.1 Introduction and Classification

The Hensingham Group is the term applied to the whole of the Namurian succession above the top of the First Limestone (Figure 4). The position of the top of the Hensingham Group is frequently difficult to determine, due either to the absence or difficulty in identifying the Subcrenatum marine band.

Three fossiliferous horizons have been recorded from the lower part of the Hensingham Group in the Ullock boreholes. The lowest band occurs at a variable distance above the First Limestone and contains a combined fauna of: *Kochiproductus?, Pleuropugnoides* sp., *Productus* cf. *productus, Schellwienella* cf. *rotundata, Serrtocrista?*, spiriferid, *Donaldina* sp., *Euphemites?, Edmondia sulcata, Sanguinolites* cf. *striatus*.

The middle band contains a combined fauna consisting of: *Serpuloides carbonarius, Buxtonia?, Eomarginifera* cf. *lobata, Lingula mytilloides, Orbiculoidea* cf. *nitida, Pleuropugnoides* sp., *Productus* sp., *Promarginifera* sp., *Spirifer* sp., *Spiriferellina* cf. *octoplicata*, gastropod indet, *Edmonida?, Promytilus?, Schizodus?*

The uppermost band includes a thin limestone and contains: Sponge spicules, *Caninia* sp., *Fenestella* sp., *Avonia youngiana, Composita* sp., *Lingula* sp. *Orbiculoidea* sp., productoid, *Schizophoria* sp., *Bellerophon* sp., *Edmondia?, Palaeoneilo luciniformis, Reticycloceras sulcatum*.

The faunas are not diagnostic. The uppermost band may be Arnsbegian (E_2) in age, but equally could be lower in the sequence. Every band could not be identified in each of the Dean boreholes and only one band could be recognised in the Gatra No. 4 borehole.

The *Gastrioceras cumbriense* marine band has been identified in Ullock No. 2 [0651 2419] and No. 4 boreholes [0572 2422]. These beds thus belong to the Yeadonian Stage. The lowest horizon in this part of the sequence occurs in Borehole 4, at c.71 m, and lies some 4 m below the *Gastrioceras cumbriense* Marine Band. The fauna present is: *Lingula mytilloides, Productus* sp., high spired gastropod, *Posidonia?*, pectinid. Beds containing a marine fauna at c.98 m in 2 and c.66 m in Borehole 4 represent the *Gastrioceras cumbriense* Marine Band. The combined fauna is: *Serpuloides carbonarius*, chonetoid, *Lingula mytilloides, Donaldina sp., Dunbarella* sp., *Posidoniella?*, orthocone, *Anthracoceras* or *Dimorphoceras* sp., *Gastrioceras* cf. *crenulatum, G. cumbriense* and platformed conodonts.

8.2 Details of stratigraphy

The Hensingham Group is exposed in quarries at Brigham and Broughton Craggs and also in a number of outcrops in the Dovenby area.

At the abandoned Brigham Quarries [083 302], a white to buff coloured, fine- to medium-grained sandstone is exposed in quarry faces up to 10 m high. Bedding thickness shows an upward transition from thick- to medium-bedded. Planar cross-bedding gives the thinner beds a 'flaggy' appearance. Eastwood (1931) assigns the sandstones seen in Brigham quarry to the Hensingham Grit, describing coarse, micaceous units from the quarry.

Hensingham Group rocks are exposed in the backwall of Broughton Craggs quarry [091 319]. Here white to buff, fine- to medium-grained sandstone shows a change in bedding thickness from beds 1 m in thickness at the base to thinly bedded, 'flaggy' units at the top of the 6 m exposure. The sandstone, which contains feldspar in places, shows planar cross-bedding. Eastwood (1931) describes an unspecified thickness of dark shales intervening between the first Limestone and the Hensingham Group.

A buff-coloured, fine- to medium-grained sandstone is exposed in a number of small outcrops in the Dovenby area. Rootlets are present locally. A thin carbonate-rich mudstone to siltstone is exposed in Dovenby Beck [0915 3310]. Eastwood (1931) recorded the occurrence of crinoids and productoids in a 'sandy limestone' which was overlain by a ... "white fine grained siliceous sandstone, seen for 10 ft [3 m], which in its harder portions resembles the ganister of Dearham".

South of Brigham, the Hensingham Grit forms rounded drift-free hills to the west of the road to Eaglesfield. Abundant soil brash and clearance stones incorporated into drystone walls consists of medium-grained pale fawn sandstone. Some blocks contain white mica and some contain scattered patches of kaolinite, apparently replacing original feldspar. Blocks of siliceous ganister-like sandstone containing rootlet traces are locally abundant. Small (1–2 mm) ochreous spots are common in places and a few blocks built into the wall at [0840 2980] display patches of pale purple colouration reminiscent of the reddening which affects parts of the Coal Measures.

The Hensingham Grit was once worked in two small quarries south of the Greysouthern to Eaglesfield road. In the northernmost of these [0836 2830] approximately 1.5 m of medium-grained fawn sandstone with abundant rootlet

Figure 4 Generalised vertical section of the Hensingham Group.

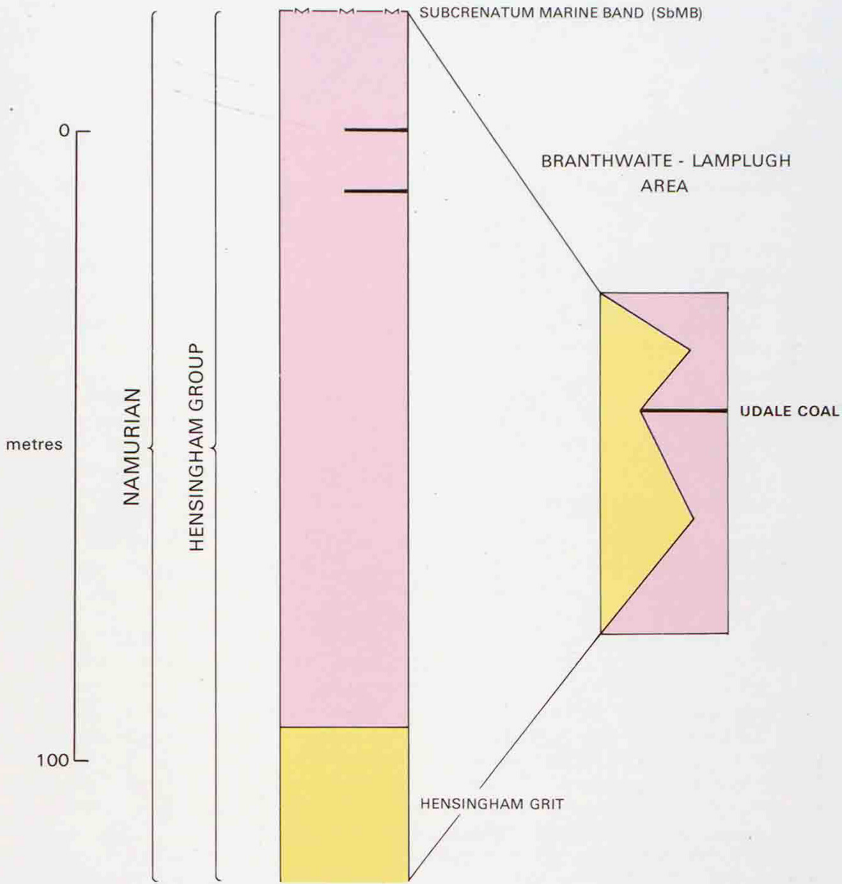
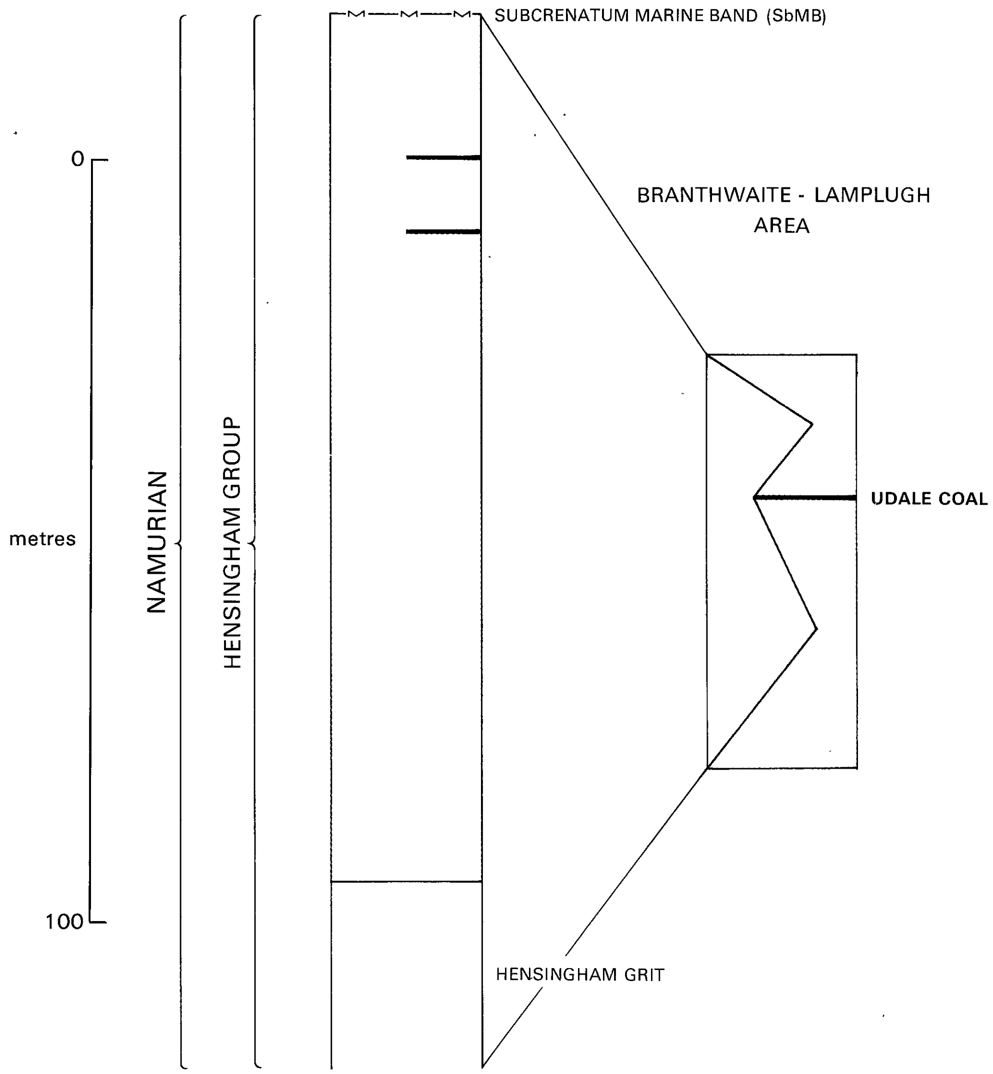


Figure 4 Generalised vertical section of the Hensingham Group.



traces is exposed. An isolated pillar near the entrance of the southern pit [0850 2816] exposes 0.9 m of medium-grained, massive, pale fawn sandstone overlying up to 2.0 m of medium-grained rather slabby, perhaps cross-bedded sandstone with scattered kaolinite, probably replacing feldspar.

West and south-west of Eaglesfield the Hensingham Grit has a wide drift-free or almost drift-free outcrop. A striking feature of this area is the large number of swallow holes which penetrate the grit, presumably into the underlying First Limestone. Some of these appear to penetrate the complete thickness of the Hensingham Grit, here estimated to be about 25 m (see Section 12.11).

Flaggy sandstones, siltstones and mudstones high in the Hensingham Group crop out in the unnamed stream west and south-west of Rigg House between [0500 2340 and 0514 2286].

9. CARBONIFEROUS ROCKS: COAL MEASURES

9.1 Introduction and Classification

The generalised section of the Coal Measures shown in Figure 5 of the district is based on the description of these rocks by Eastwood (1930) and on the revision by Taylor (1961). The sequence preserved within Great Broughton-Lamplugh district extends up to 20 m above the Cumbriense Marine Band, i.e. above the base of the Upper Coal Measures. The Coal Measures preserved in the district therefore include representations of Westphalian A, B and C stages.

9.2 Seam Nomenclature

The seam nomenclature adopted in the present study is that used by Young and Armstrong (1989) and corresponds to the seam names currently used by the British Coal Opencast Executive in West Cumbria. Problems arise, however, in correlating present day seam nomenclature with that formerly used in the coalfield. An individual seam may have been worked under different names in different areas and, more confusingly, the same name may have been used for different seams in different collieries. Problems arising from seam nomenclature may prove particularly difficult in dealing with mine plan information. A correlation of seam names encountered during the present study is given in Table 5.

9.3 Conditions of deposition

The West Cumbrian coalfield forms part of the large Pennine Basin, which extended from the Wales–Brabant massif in the south northwards, to approximately the position of the present day Southern Uplands. Faunal evidence shows that the coalfields of Northern England were originally part of a continuous depositional area (Calver 1969), and were separated by Variscan deformation and subsequent erosion.

The Pennine Basin was separated from the Scottish Basin by landmasses coincident with the present day Southern Uplands and Cheviot Hills. The Thornhill and Sanquhar coalfields may represent connections between the two basins (Guion & Fielding 1988).

The Coal Measures sequences of the Pennine basin have been interpreted as being deposited in a mainly deltaic environment. A review of recent work on the sedimentary environments recorded in the British coalfields is given in Guion and Fielding (1988). The Coal Measures are thought to have been laid down on a broad, flat coastal deltaic plain which extended from present day northern Europe to North America. The sequences preserved in the British coalfields represent a complex assemblage of depositional environments. Sediment transport took place

Table 4 Chronostratigraphical and lithostratigraphical classification of the Coal Measures

CHRONOSTRATIGRAPHY		LITHOSTRATIGRAPHY	
UPPER CARBONIFEROUS = SILESIAN	Westphalian C	Upper coal measures	COAL MEASURES
		Cambriense (St Helens) Marine Band	
	Aegirinum Marine Band	Middle Coal Measures	
	Westphalian B		
	Vanderbeckei (Solway) Marine Band		
	Westphalian A	Lower Coal Measures	
	Subcrenatum Marine Band		

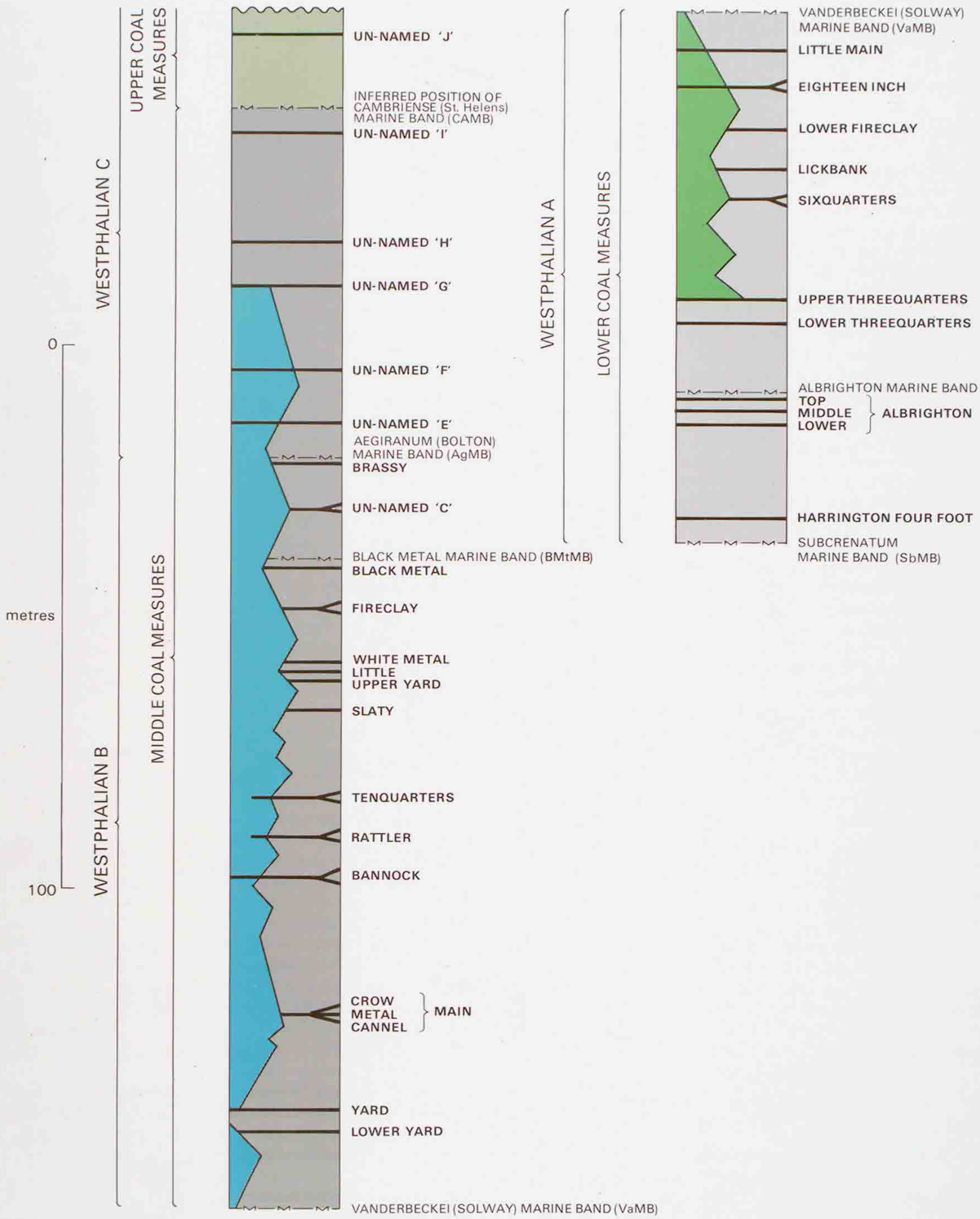


Figure 5 Generalised vertical section of the Coal Measures

Table 5 Correlation of local seam names with seam nomenclature used in this report.

MOORSIDE COLLIERY	DEAN MOOR COLLIERY	ASBY COLLIERY	BGS SEAM NOMENCLATURE
Rough	Dean Moor Upper Coal		Slaty
Anthony Wiley		Bannock Bed	Ten Quarters
Eighteen Inch	Galloway Band	Rattler	Rattler
Yard	Dean Moor Lower Coal	Yard Band	Bannock

in a system of channels, which varied both in size and sinuosity. Deposition took place in interdistributary bays and lakes by means of minor distributary channels, crevase splays and overbank deposition.

The coals present within the sequence represent accumulations of organic rich material which have undergone compaction and diagenesis (coalification).

Within deltas peat development occurs dominantly within swamp environments, though some cannel coals may represent the accumulation within lakes of transported organic material. A detailed discussion of coal formation is beyond the scope of this report. A comprehensive review of coal depositional environments is given by McCabe (1984).

9.4 Reddening

The upper part of the Coal Measures sequence is characterised by the intermittent presence of strong red colouration. These reddened strata were formerly classed as the Whitehaven Sandstone 'Series' which was regarded as a separate formation with an unconformable base (Eastwood 1930). Eastwood compared the Whitehaven Sandstone 'Series' with the Halesowen Formation, a formation of the Barren Measures Group of the English Midlands. However it has subsequently been shown that the reddening in Cumbria is a secondary effect superimposed on the normal grey measures, by oxidation in pre-Permian times. No primary transition from Coal Measures-type depositional environments to 'red bed' depositional environments has been identified in the West Cumbrian coalfield.

9.5 Lower Coal Measures: Details of stratigraphy

The **Subcrenatum Marine Band** has been proved in a number of boreholes in the Ullock area. In Ullock No. 2 Bore [0607 2378] the Subcrenatum Marine band occurs 6 m below the Harrington Four Foot seam. The fauna collected from this marine band in this and other boreholes in the district includes: *Serpuloides carbonarius, Lingula mytilloides, Orbiculoidea?,* crinoid columnals. No outcrops of the marine bands are known in the district.

The **Harrington Four Foot** may occur as a split seam. A sandstone unit, 3 m thick, occurs between the two leaves in Ullock No. 2 Bore [0607 2378]. The seam commonly has a sandstone roof and appears to be washed out by a thick sandstone unit at Moorside. The seam has a maximum thickness of 94 cm as a single seam. As a simple split seam it has been recorded with a lower leaf of up to 35 cm and an upper leaf of around 13 cm separated by a variable thickness of measures. Between 6 and 26 m of measures intervene between the Harrington Four Foot and the lowest of the Albrighton Seams.

The deeply incised unnamed stream [0643 2211] 550 m north of Kidburngill exposes fine-grained pale buff, flaggy, cross-bedded sandstone interpreted as part of the sequence between the Harrington Four Foot Seam and the Albrighton Coal Group. A pale grey and fawn seatearth mudstone exposed at the western end of the stream section [0635 2213] is probably beneath one of the seams of the Albrighton Coal Group.

Clay ironstones were mined from several adits driven south-west from the bank of the River Marron, south-east of Branthwaite. Eastwood et al. (1931, p.190), suggests that this ironstone occurred at the horizon of the 'Mussel Bed' above the Yard seam. The structural and stratigraphical interpretation of the present survey indicates that a level a little above the Harrington Four Foot seam is more likely. Dark grey shale and clay ironstone nodules and slabs, commonly with abundant specimens of *Carbonicola* are present on the small spoil heaps from adits between [0595 2470 and 0613 2455]. Old shaft heaps with identical spoil east of Totter Gill between [0646 2394 and 0675 2380] suggest that the same ironstone was worked on the upthrow side of a NNW–SSE trending fault.

Up to 4 seams compose the **Albrighton Coal Group**. These are termed the **Bottom, Middle, Top Albrighton** and the **Albrighton Rider**. Marine bands have been proved in Greysouthern No. 2 and No. 3 boreholes [0672 2812, 0720 2813]. A fauna collected from the roof of the lowest of the 4 seams constituting the Albrighton Coal Group in Greysouthern No. 2 possibly represents the Siddick Marine Band. The fauna consists of foraminifera and *Planolites opthalmoides*. A correlation has been made between mussel bands occurring at c.141 m in Greysouthern No. 2 and at c.46 m in Greysouthern No. 3 boreholes.

The faunas present in the two boreholes are: Greysouthern No. 2—fauna in mudstone above seatclay *Carbonicola subconstricta/torus group, C. torus?, Naiadites* sp., *Geisina arcuata,* with at the base of the bed foraminifera *Lingula* sp.

The non-marine fauna from Greysouthern No. 3 is comparable with that described as the 'Daubhill Fauna' by Calva (in Taylor, 1961, pp.7, 20). This correlation suggests that the marine horizon is the Templemans Marine Band; the Albrighton Marine Band appears to be absent here. The 'Daubhill fauna' is also seen in the Dean and Ullock boreholes where the fauna consists of: *Carbonicola* sp. (aff. *fallax?*), *C.* cf. *torus,* aff. *communis, C. martini, C.* aff. *pseudorobusta, C.* cf. *rhomboidalis, Curvirimula* sp., *Naiadites* sp., *Geisina arcuata, Planolites moutanus, Anthraconaia?, Anthracosphaerium bottoni?*

The seam split is best developed in the Broomy Hill area [0595 2600], where the Bottom Albrighton and Albrighton Rider may be separated by up to 12.5 m. Maximum thicknesses for the individual leaves are: Bottom Albrighton 37 cm, Middle Albrighton 62 cm, Top Albrighton 23 cm and Albrighton Rider 18 cm. In the south of the district at Moorside only a single thin seam is present. This seam has a maximum thickness of 29 cm and is both overlain and underlain by thick sandstone units.

The overgrown sides of the abandoned railway cutting between 300 and 550 m south of Kidburngill expose beds between the Albrighton Coal Group and the Upper Threequarters Seam: the Lower Threequarters Seam has not been recognised in this area. At the northern end of this group of exposures, medium-grained sandstone in beds up to 0.5 m may be seen [0645 2120]. Much of this sandstone is brownish grey though locally some purplish brown colour banding is also present. Small (2–3 mm) pellets of earthy goethite occur in places. Further south [0645 2108] approximately 2 m of grey silty mudstone are exposed beneath and immediately to the north of the old footbridge [0646 2097]. This is typically fine-grained, pale fawn and rather flaggy but appears to become more thickly bedded downwards. A thickness of at least 3 m of thin sandstone appears to be present.

The **Lower and Upper Three Quarters Seams** are separated by 1.5–2.5 m in the Moorside area. This interval increases to 9.5 m in the Broughton Moor area where sandstone occupies much of the interval. A similar northwards increase in the seam interval was recorded by Barnes et al. (1988, p.12) in the Workington and Maryport area.

The Lower Three Quarters exhibits its thickest development in the Moorside area, where it is up to 91 cm in thickness. Elsewhere the Lower Three Quarters shows an overall northward thickening from an average thickness of 20 cm in the Dean area to around 50 cm north of the River Derwent.

A seatearth mudstone, exposed in the stream [0641 2083] 250 m north-west of Linefoot Bridge may be the seatearth beneath the Upper Threequarters Seam though no coal is exposed here. Grey and fawn silty mudstones above this seam are poorly exposed between here and South Mosses [0420 2092]. On Six Inch Geological Sheet Cumberland 62 SW Dixon notes quartzitic sandstone in the stream near Mossgill [0629 2087] though this was not seen during the resurvey.

The Upper Three Quarters and Six Quarters seams are separated by up to 25 m of beds. The thicker intervals are dominated by sandstone as for example at Buckhill Colliery, Great Broughton. In the Hennah Hall area a thin median seam, 5–10 cm thick, is present within the thick sandstones.

The **Six Quarters Seam** occurs both as a single seam, up to 1.5 m thick and as a split seam, with up to 3 leaves. At the Blooming Heather opencast site, near Broughton Moor, the Six Quarters was worked as a split seam with a shale interval of 6–7 m. In the Mayfield area the shale parting is 20–50 cm thick, with, in addition, a thin mudstone parting locally splitting the lower leaf.

As in the adjacent Workington and Maryport area (Barnes et al., 1988, p.12) the beds above the Six Quarters seam are commonly sandstone. This sandstone, termed the Six Quarters Rock, locally erodes or washes out the Six Quarters seam. Exposure of hard white, rather siliceous, generally medium-grained sandstone, referred to the Six Quarters Rocks, may be seen in the west bank of the River Marron [0591 2536] immediately north of the site of Branthwaite Colliery. The Six Quarters Rock was formerly worked as ganister at this colliery. The sandstone exposed in the bed of the Marron [0595 2485] at the weir in Branthwaite is likely to be the Six Quarters Rock. The Six Quarters Rock, which averages 4 m in thickness over most of the area, is up to 23 m thick at Moorside.

The **Lickbank Seam** is a single seam which ranges in thickness from 5–79 cm, with an average thickness of 40 cm. The seam is underlain by either a seatearth or mudstone which passes down into the Six Quarters Rock.

The sandstone, formerly worked in the quarry [0577 2484] immediately west of Branthwaite may belong to the sequence above the Lickbank Seam. The quarry is now filled, mainly with earth spoil, and nothing is exposed today.

A sandstone which crops out at several places in the fields east of Rigg House [0520 2341] south of Branthwaite lies, according to the present survey, in the beds above the Lickbank Seam. The best exposure of this sandstone is a small crag [0553 2350], perhaps in part an old quarry face, north of Whitebanks Wood. The rock is a fine to medium-grained, thickly bedded quartzitic sandstone which is locally hard, perhaps due to a silica cement. A few plant fragments were observed on bedding planes. Eastwood et al. (1931, p 188) remarked on the rather friable, possibly decalcified, nature of the rock in this exposure. They further comment in some detail on the fauna collected from it, noting that although the rock is generally unfossiliferous, parts, especially the rather coarser-grained beds, contain casts of marine shells. Most common were bivalves though rare brachiopods have also been found. Identifiable shells are few though the following were recorded by Eastwood et al. (1931): *Productus* cf. *carbonarius* de Kon, *Productus* spp., *Schellwienella* sp., *Aviculopecten* cf. *carboniferus* (Stevens), *Aviculopecten* sp., *Limatulina alternata* (M'Coy), cf. *Limatulina flemingini* (McCoy) [Young] *Protoschizodus* sp. or *Schizodus* sp. [casts], cf. *Sedgwickia attenuata* M'Coy, *Euphenus?, Loxonema* sp. Plant remains include *Stigmaria ficoides* Sternb., *Calamites* sp. and other indeterminate remains.

The shell fauna is clearly marine; the plant remains are likely to be drifted fragments. This sandstone therefore poses considerable questions of correlation. Eastwood et al. (1931, p.188) drew attention to its affinities with parts of the Hensingham Group, in particular a sandstone with marine fossils at Barfs Quarry, Distington, about 5 km west of the present district, although he also commented on the lithological similarity to other apparently non-fossiliferous Coal Measures sandstones, perhaps at the same horizon, elsewhere in the Branthwaite area. The precise stratigraphic position of this unusual marine sandstone was not resolved by Eastwood et al. (1931) although on Six Inch Geological Sheet Cumberland 57 NW it was included within the Middle Coal Measures. The recent resurvey has not been able to resolve this problem further. The sandstone is tentatively placed above the Lickbank Seam within the Lower Coal Measures.

The **Eighteen Inch Seam** occurs as a split seam in the Broughton Moor area. The leaves are separated by up to 130 cm of mudstone. The upper leaf has a maximum thickness of 48 cm; the lower leaf is up to 40 cm thick locally as at Alice Pit [0798 3343] where it includes a thin seatearth parting, 5–10 cm thick. Further south the Eighteen Inch occurs as a single seam, which averages 30 cm but which locally attains 84 cm in thickness.

Even where a coal is absent the level of the Eighteen Inch seam is marked in a number of boreholes by either a mussel band or a thin mudstone unit in an otherwise sandstone-dominated sequence. The mussel band seen in the Ullock boreholes contains a fauna which includes: *Carbonicola* aff, *venusta, Naiadites flexuosus?, N.* aff. *quadratus* and *Geisina arcuata*.

The interval between the Eighteen Inch and the Little Main seam varies between 3.5 m to 8.7 m over the district. A seatearth overlying mudstone is commonly present beneath the Little Main. The thicker intervals are marked by the presence of a sandstone up to 5 m thick. At Moorside the Little Main is underlain by a thick sandstone of unknown thickness. In some areas e.g. 200 m west of North Mosses [0616 2114] no seams are present between the Little Main and the Six Quarters seams. Elsewhere the Lickbank seam may be preserved.

The **Little Main seam** shows a northwards thickening from an average of 30–40 cm in the south to 50–60 cm in the Broughton Moor area. The Little Main commonly overlies a seatearth. A musselband has been reported from the roof mudstones of the seam (Barnes et al., 1988, p.12). The musselband fauna includes *Anthraconaia* cf. *williamsoni, Anthracosia* cf. *regularis, Carbonicola* cf. *bipennis, C.* cf. *oslancis, C. venusta*, ostracods and fish.

The interval between the Little Main and Half Yard seams varies in thickness from 5–18 m. The average thickness is 6–8 m at Moorside. An average interval thickness of 10–13 m is present in the Little Clifton area. Strata between the Little Main and Half Yard may be either entirely mudstone or sandstone, only rarely are both lithologies present at the same locality.

The **Half Yard** occurs both as a split and as a single seam. The seam split is best developed in the northern part of the area where the two leaves may be separated by up to 2 m. The interval is dominated by mudstone in the Broughton Moor area, whereas sandstone is present in the interval further south. The lower leaf is consistently thicker than the upper. The former is usually between 33 and 63 cm thick; the latter ranges in thickness from 23–43 cm.

9.6 Middle Coal Measures: Details of stratigraphy

The interval between the Half Yard and the Lower Yard increases northwards from 9 m at Moorside to 13 m in the Little Clifton area and to a maximum of 19 m at the former Blooming Heather Opencast Site. The interval is dominated by mudstone. A seatearth is locally present beneath the Lower Yard.

Faunas characteristic of the **Vanderbeckei (Solway) Marine Band** have been recorded in Ullock No. 2 and No. 3 boreholes. The fauna includes *Anthraconia* sp., *Anthracosia* cf. *aquilina, A.* cf. *ovum, A. phrygiana, Anthracosphaerium, Naiadites carinatus* and *N. quadratus.* The base of the cycle in Ullock No. 2 Bore contained *Lingula mytilloides*.

In the banks of Gill Beck [0642 2163] immediately north of Kidburngill interbedded fine-grained fawn sandstones and siltstones immediately above the inferred position of the Solway Marine Band are exposed though the Marine Band itself is not seen.

The **Lower Yard Seam** is locally present between the Half Yard and Yard seams. The seam shows a northwards thinning, from 50–60 cm thick at Moorside to an average thickness of 15 cm in the Lostrigg and Blooming Heather areas.

The interval between the Lower Yard and Yard maintains a relatively constant thickness of between 4 m and 6 m over the entire district. A seatearth is commonly developed beneath the Yard seam and the Lower Yard is typically directly overlain by mudstone. A sandstone may be present between the seams, although mudstone dominates the interval over much of the area.

The interval between the Half Yard and Yard seams shows an apparent thinning when a Lower Yard seam is not developed in the interval. The interval, which is dominated by mudstone, ranges from 10–15 m in thickness. No pattern of thickness variation could be established.

The **Yard Seam** is a single seam throughout the district. The seam, which may be banded, has an average thickness of 40–60 cm, although a seam thickness of 175 cm was recorded at Moorside. In the Broughton Moor area the seam is 75–85 cm thick. In places the mudstones which overlie the Yard seam contain *Anthraconaia* sp., *Anthracosia beaniana, A. carissima, A.* cf. *concinna, A.* cf. *phrygiana, A.* cf. *regularis* and *Naiadites quadratus*?

The interval between the Yard and Main Band seams shows a northwards increase from 10–22 m in the Moorside area to 18–25 m in the Broughton Moor area. The interval is composed mainly of mudstone in the south with thin sandstone bodies, up to 5 m thick locally. An un-named median seam is present in the north of the district, within an interbedded sequence of sandstones and mudstones which pass upwards into a seatearth directly beneath the Main Band.

The **Main Band** was the principal economic seam worked in the district. The seam splits northwards into three leaves which have been named the **Cannel, Metal** and **Crow** seams respectively.

In the south of the district the Main Band is generally a single seam which ranges in thickness from 109–356 cm with an average of about 2 m. It may be banded and in places a split is developed. Where the seam is split the upper leaf is thicker, up to 213 cm, with the lower leaf 49–50 cm thick. A sandstone, 1 m thick, is developed between the two leaves in Ullock No. 3 bore [0679 2311].

Traced northwards the split becomes more prominent. A single seam may still be present, either as a single coal up to 84 cm thick or a banded seam with 5–10 cm thick mudstone and seatearth layers between 30 cm coals. The banded coals are up to 223 cm thick. Where the seam is split the upper leaf is generally thinner than the lower. The upper leaf varied from 35–289 cm. The lower seam may represent a combined Cannel and Metal seam up to 2 m thick. A 10 cm mudstone parting is developed in the lower seam in places. The interval between the two leaves, which typically comprises mudstone or seatearth, is consistently around 80 cm.

The tripartite split is ubiquitous in the Broughton Moor area. Here the Cannel is the thickest individual seam with an average thickness of 150 cm. The seams may have thin mudstone partings of 3–15 cm. The interval thickness between the Metal and Cannel ranges from 15–60 cm. A seatearth may be present below the Metal, with mudstone occupying the rest of the interval. The Metal seam ranges in thickness from 84–121 cm. Within this a single mudstone parting of approximately 15 cm is commonly present.

A mudstone-dominated interval, averaging 1.5 m in thickness, is present between the Metal and Crow seams. Ironstone bands may occur within this interval.

The Crow seam is the thinnest of the three main splits of the Main Band and varies from 55–79 cm. A mudstone band up to 13 cm thick may be present within the seam.

In common with the area to the west (Barnes et al., 1988, p.13) the Main Band is commonly overlain by a persistent sandstone known as the **Main Band Rock**. This unit probably occupies a major channel or group of channels and commonly exhibits an erosive base on the Main Band Seam. The underground workings of Clifton, Melgramfitz and Asby collieries encountered washouts in the seam.

The Main Band Rock was formerly worked for building stone in a quarry [0550 2782] at Furnace House, south of Little Clifton. According to Eastwood et al. (1931, p.194) some 6 m of Main Band Rock were exposed here. The pit is today heavily overgrown and partly filled with farm rubbish. However the remaining exposures in the upper parts of the faces show fine- to medium-grained, rather slabby, pale fawn sandstone, locally with rather ochreous staining. Some of the stone from this quarry, used in the walls of the farm buildings at Furnace House, exhibit a little rather patchy purple staining.

The Main Band has been extensively worked beneath the area south of Little Clifton. Old shafts are numerous and there is much evidence of surface subsidence into shallow workings in the seam.

The **Bannock seam** is a single seam with an average thickness of 50–100 cm, although it is up to 2 m thick at Moorside. The seam may have a seatearth or mudstone floor which passes down into the sandstones above the Main Band.

The interval between the Bannock and Rattler seams is up to 13 m in thickness, with an average of 4–6 m. The interval is dominated by mudstone, with 1–2 m thick sandstone beds present in places. To the north of the River Derwent the Bannock seam is frequently absent. Up to 40 m of mudstone may be present between the Rattler and Crow seams. A 15 m sandstone occurs locally in this interval.

The east bank of Lostrigg Beck [0511 2847] 350 m west of Punderland exposes approximately 3.5 m of thinly bedded pale fawnish grey fine-grained sandstone in the interval between the Bannock and Rattler seams.

Several exposures of the beds between these seams may be seen in the banks of the River Marron at

Bridgefoot. Almost 4 m of fine-grained cross-bedded sandstone with scattered tabular clay-ironstone nodules is exposed in the north bank of the river immediately east of Bridgefoot Bridge [0568 2922]. At least 3 m of similar cross-bedded sandstone, although without clay-ironstones, is exposed beneath Cat Bank [0560 2930] on the west bank. Grey to buff siltstones, with interbedded lenticular sandstones crop out in the west bank 140 m further downstream. Old diggings in the bank immediately above these exposures mark the outcrop of the overlying Rattler Seam.

The **Rattler** seam occurs dominantly as a single seam, although a split occurs in in the northern part of the district. The seam invariably has a mudstone floor. The Rattler has a maximum thickness of 122 cm as a single seam, with an average thickness of 40–60 cm. The interval between the two leaves of the split seam is 76–317 cm, 76 cm of seatearth being recorded in Henry Pit [0558 3427]. At Moorside the Rattler is washed out in places by a sandstone up to 25 m thick, though this sandstone does not cut down as far as the Bannock.

The Rattler to Ten Quarters interval is dominated by mudstone. Thin sandstones, 2–3 m in thickness, may be present within the interval. At Moorside the interval is sandstone dominated, with 12 m sandstone units forming the floor to the Ten Quarters seam. The interseam interval varies from 3–15 m across the district; no consistent pattern of thickness change can be distinguished.

The upper 4–5 m of the measures above the Rattler Seam are exposed in the steep western bank of Lostrigg Beck [0504 2870] approximately 500 m west of Little Clifton. The following section was visible in 1990:

COAL (TEN QUARTERS)	1.00 m
Unexposed	1.00 m
Sandstone, fine-grained, thinly bedded, pale fawn	0.50 m
Sandstone, fine- to medium-grained, thickly bedded, pale fawn. Relatively well-laminated parting 0.15 m thick about 0.3 m from base	1.50 m
Mudstone, silty, crudely laminated, pale grey to fawn. Numerous evenly spaced beds of clay-ironstone nodules up to 10 cm across	3.0 m seen

The lowest two units of this sequence are also exposed near the top of the east bank [0520 2867] 100 m downstream. An unexposed vertical interval, estimated to be between 4 and 5 m, separates these exposures from the top of the Rattler Seam, which is exposed at the normal water level of the stream. There is much coal and shale debris here suggesting some crop workings in the Rattler.

The upper part of Harry Gill, between [0524 2990 and 0549 2997], exposes beds between the Rattler and Ten Quarters seams. Fine-grained, slabby, cross-bedded sandstones predominate with at least 3 m exposed in one section [0534 2989] in the south bank near the head of the gill. About 80 m further upstream, approximately 2 m of pale grey to buff, blocky-weathering siltstone is exposed close to the inferred base of the Ten Quarters seam.

In Cat Bank [0561 2936], the steep west bank of the River Marron, north of Bridgefoot, a small crop working in the Rattler was noted during the resurvey. A few centimetres of coal were exposed, although the full thickness of the seam could not be established. The section visible in 1989 was as follows:

Sandstone rubble	1.00 m
Sandstone, fine-grained, pale fawn, abundant wavy coal partings up to 10 cm thick	0.75 m
Sandstone, fine-grained, pale fawn to brown, very similar to above but with few coal partings	0.50 m
COAL (RATTLER)	0.10 m seen

On the west bank of the Marron the Rattler was worked underground at shallow depth from the Fortuna Drift [0568 2944] driven north-west into the outcrop of the seam. Surviving plans show the workings to have been of small extent.

The **Ten Quarters Seam** is commonly a single seam. The seam may be banded with 2-5 cm thick mudstone partings separating coal layers up to 60 cm in thickness. The seam has an average thickness of 150 cm, increasing in thickness to 250 cm in the Moorside area. A split Ten Quarters seam is developed in places. The upper leaf ranges in thickness from 13–174 cm, being generally thicker than the lower leaf which is 20–149 cm thick. The mudstone interval between the two leaves is 15–90 cm.

The interval between the Ten Quarters and Slaty seams is dominated by mudstone, though sandstones up to 20 m thick may be present, forming both the roof of the Ten Quarters and the floor of the Slaty. In the Broughton Moor area a 44 m thick sandstone was recorded beneath the Slaty. This sandstone body washes out both the Ten Quarters and Rattler seams.

The Ten Quarters Seam is well exposed in the steep and generally inaccessible west bank of Lostrigg Beck [0504 2870] approximately 500 m west of Little Clifton. The seam is here about 1 m thick and is overlain by up to 1.5 m of **Ten Quarters Rock** which here comprises rather flaggy, pale buff sandstone. The Ten Quarters Rock is also exposed 250 m downstream in the east bank [0534 2882].

Eastwood et al. (1931, p 180) record outcrop workings in the Ten Quarters [0560 2936] north of Bridgefoot. The Ten Quarters Rock, here a fine-grained pale fawn sandstone, was formerly worked for building stone in small and now overgrown quarries [0557 2933] on the west side of the lane.

Branthwaite Edge is capped by a thick unit of reddened sandstone mapped during the previous survey as 'Whitehaven Sandstone'. The present survey suggests that this sandstone lies above the Ten Quarters Seam. However exactly similar reddened sandstone which was also previously classified as Whitehaven Sandstone, and interpreted here as lying above the Black Metal coal, caps the high ground west of Moorside Colliery. We suggest that the sandstones at Branthwaite Edge and above Moorside Colliery are part of the same unit, the base of which appears to occupy a channel cut down eastwards from above the Black Metal seam down to a little above the Ten Quarters. The orientation of the channel is unknown. The sandstone has been worked from several pits on Branthwaite Edge [e.g. 0620 2305, 0644 2287 and 0606 2292], all now mostly degraded and overgrown. The rather larger abandoned Branthwaite Edge Quarry [0595 2290] exposes a total thickness of about 5 m medium- to coarse-, and locally very coarse-grained massive reddened sandstone. A few shale pellets are present in places. The coarser-grained portions of this rock contain minute crystals of specular hematite coating the quartz grains, a feature previously noted by Young (*in* Jones et al., 1990, p.119) at the Keekle Extension Opencast Coal Site, near Whitehaven [NX 997 177] (see also Section 11.2).

Similar medium- to coarse-grained thickly bedded reddened sandstone, in beds up to 2 m thick, was worked in a quarry above Moorside Colliery [0529 2172], although no specular hematite has been observed here.

The **Slaty seam** occurs both as a single seam and a split seam with up to three leaves. As a single seam the Slaty appears to show a northward thinning decreasing from an average thickness of 1.5 m in the south of the district to a thickness range of 15–30 cm in the north.

Boreholes from the Moorside Colliery [0547 2165] and also the Outfields Colliery [0822 3399] further north record a split seam. At Moorside Colliery the upper leaf of the bipartite split is 60 cm thick; the lower leaf ranges from 45–92 cm. The mudstone interval ranges from 16–30 cm. At Outfields Colliery the upper and lower leaves are 18 cm and 49 cm thick respectively separated by a mudstone interval 25 cm thick. The tripartite split developed at Moorside Colliery has an upper leaf of 26 cm, a middle leaf of 51 cm and a lower leaf of 35 cm. The upper leaves are separated by 5 cm of mudstone and the lower leaves by 25 cm of seatearth.

The Slaty to **White Metal** interval is dominated by mudstone. The interval thickens northwards from an average of 6–10 m at Moorside to 10–14 m at Blooming Heather. In places the Slaty seam may be absent, with up to 30 m of mudstone with 3–7 m sandstone units present between the Ten Quarters and White Metal seams.

The almost vertical west bank of the River Marron, immediately under the A66 roadbridge and for up to 70 m downstream, exposes approximately 6 m of grey, rather blocky silty mudstones with lenticular beds of buff fine-grained, cross-bedded sandstone.

Eastwood et al. (1931, p.180) note an outcrop [0599 2959] on the east bank of the Marron near the old saw mill in which shaly and muddy sandstones above the Slaty Seam pass upwards into sandy mudstones with abundant plant fossils. This section was not seen during the present survey.

The **Upper Yard Seam (or Little)** may be present between the White Metal and Slaty seams. In the Broughton Moor area the Upper Yard Seam ranges in thickness from 13–54 cm. The Upper Yard is separated from the White Metal by up to 373 cm of mudstone and seatearth.

The **White Metal** is developed both as a single and a split seam. The split occurs mainly in the north of the district. In the Broughton Moor area the upper leaf of the split ranges from 33–53 cm in thickness with the lower leaf ranging from 40–94 cm. The leaves may be spearated by up to 457 cm of mudstone. Where a single seam is developed in the Broughton Moor area the seam thickness increases to up to 153 cm. Further south, where two seams are developed at the position of the White Metal, it is difficult to identify whether the lower seam represents a split White Metal seam or the Upper Yard Seam.

Where the White Metal is developed as a single-banded seam it ranges in thickness from 15–231 cm, with the thickest development in the Moorside area.

The interval between the White Metal and Fireclay seams is up to 14.7 m in the Moorside-Outgang area, thinning northwards to approximately 4 m in the Broughton Moor area. Mudstone is dominant in the interval in the Moorside-Outgang area with sandstone and seatearth present in the interval at Broughton Moor. Where the White Metal is absent up to 20 m of mudstone may occur in the Slaty-Fireclay interval.

The **Fireclay Seam** is a single seam everywhere except in the area of the Low Close Opencast Site, where it was worked as a split seam. The single seam may be banded and varies in thickness from 40–60 cm. The split seam has an average upper and lower leaf thickness of 60 cm and 20 cm respectively with up to 87 cm of mudstone present in the interval.

The Fireclay to **Black Metal** seam interval is also dominated by mudstone though with some sandstone units. The interval varies in thickness from 7–16 m with an average of 8–10 m. The thinnest interval occurs in the Moorside area. An ironstone band, 61 cm in thickness, is recorded from the interval in Moorside Colliery No. 3 Borehole [0548 2166].

The **Aegiranum (Bolton) Marine Band**, also called the Brassy Marine Band by Trotter (1953), has not been identified within the present district.

The marine band was reported from both the Main Drift of the Solway Colliery and the St Helens No. 11 Bore by Taylor (1961). The faunas described from these two localities were respectively: *Ammonema* sp., *Lingula mytilloides, Platyconcha?,* gastropods indet [small], *Dunbarella* sp., *Posidonia sulcata, Metacoceras* cf.*perelegans, Anthracoceras sp.* [juv], *Hindeodella* sp., platformed conodonts, fish debris and crinoid columnal, *Lingula mytilloides,* small gastropods including *Platyconcha?* and *Strobeus*?, pectinid (indeterminate), *Pernopecten carboniferus, Posidonia sulcata, Schizodus?,* coiled nautiloid, probably *Metacoceras cornutum,* orthocone nautiloid probably *Pseudorthoceras* sp., *Anthracoceras* cf. *hindi, Politoceras [Homoceratoides]* sp. conodonts [abundant] including *Hindeodella* sp., *Idiognathodus* sp., *Lonchodus?, Ozarkodina* sp., *Streptognathodus* sp.; fish debris including *Megalichthys sp.,* Palaeoniscid scales and perhaps fragments of *Listracanthus* spines.

The **Unnamed 'G',** which is a single banded seam up to 50 cm in thickness, is separated by up to 7.5 m of mudstone from the **Unnamed 'H'**. This single seam is 30 cm thick. A further 7.8 m of mudstone separates the **Unnamed 'I'**, a 43 cm thick seam, from the **Unnamed 'H'**. Mudstone strata, 8.7–10.3 m in thickness, occur between the **Unnamed 'I'** and **Unnamed 'J'**.

9.7 Upper Coal Measures: Details of stratigraphy

The St Helens Marine Band has previously been described from strata between the Unnamed 'I' and Unnamed 'J', although the marine band was not identified in either of the boreholes which penetrated this interval in the present district. The marine band has been recognised in two boreholes in the St Helens Colliery [0066 3224 and 0011 3151] where it is a black mudstone bed with *Lingula*. The St Helens Marine Band is tentatively correlated with the Cambriense Marine Band which marks the base of the Upper Coal Measures.

The **Unnamed 'J'** is recorded both as a 92 cm thick, banded, single seam and a split seam 116 cm in thickness. The split seam has a lower leaf 27 cm thick and an upper leaf 76 cm in thickness. They are separated by 16 cm of mudstone.

10. STRUCTURE

The oldest deformational events recorded in the district are those affecting the Skiddaw Group. The structure exhibited by the Skiddaw Group in the district is described in Section 3.

The structure of the Carboniferous strata is dominated by sinuous, NW–SE striking normal faults. These downthrow both to the north-east and south-west (Figure 6). Cross faults trending east-west to ENE–WSW are also developed. These downthrow both to the north and south.

Swarms of minor faults are recorded on mine plans and opencast completion plans, and are well exposed in some quarries e.g. Broughton Craggs. These trend north-south to NW–SE, paralleling the major faults. Dip-slip slickencryst lineations were observed on fault surfaces in the Orebank Sandstone at Broughton Craggs quarry. A strike-slip lineation is seen on a north-south trending fault surface within the Fourth Limestone, also at Broughton Craggs quarry [090 318]. Barnes et al. (1986) interpreted an *en echelon* set of NW–SE faults as the result of sinistral strike-slip on an underlying north-south trending structure.

Cross faults both truncate and terminate against NW–SE trending faults suggesting a coeval development of the faults as displacement was transferred through the network.

Detailed measurements from mine plans and field observations reveal that faults generally dip between 60° and 80°. Adjacent to many faults are zones of deformation, tens of metres wide, within which bedding is disrupted and steeply inclined. Conjugate joints and veins, now filled with calcite, are developed within the limestone units, for example on the banks of the River Derwent, west of Papcastle [0964 3142].

All the dip-slip faults identified have normal displacements. Throws are locally in excess of 350 m, e.g. the Mockerin Fault, which throws Middle Coal Measures against the Skiddaw Group.

Bedding dips throughout the area are generally shallow ranging from 5–20° to the west or north-west. No evidence of folding was identified, though a very open north-south to NE–SW trending fold has been described from the Great Clifton area (Barnes et al., 1986).

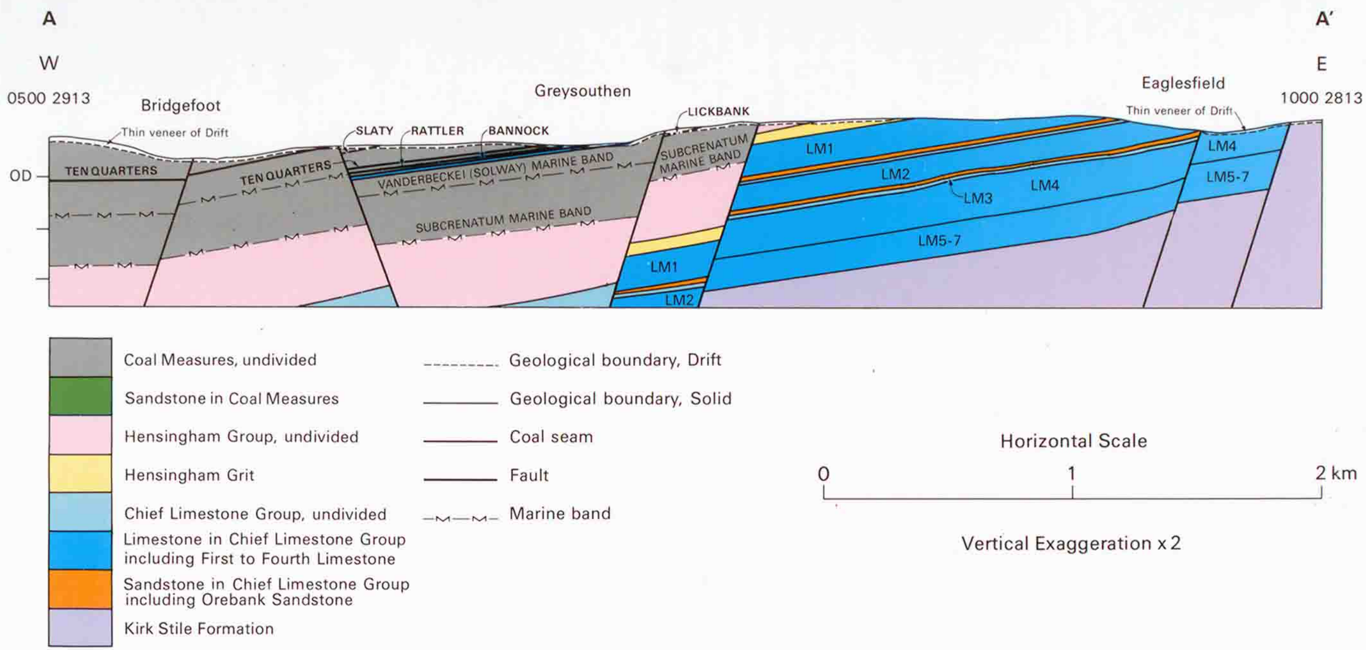


Figure 6 Horizontal section

11. EPIGENETIC MINERALISATION

11.1 **Introduction**

Although the Great Broughton–Lamplugh area includes the northernmost known deposits of the west Cumbrian hematite iron ore field, occurrences of epigenetic mineralisation are few. Most of the district lies between the richly mineralised, and formerly economically important, iron ore field of the Frizington–Egremont area (Smith 1924), and the well mineralised but as yet substantially unexplored Lower Carboniferous outcrop of the Gilcrux-Caldbeck area (Young & Armstrong, 1989; Cooper et al., 1991).

Epigenetic mineralisation in the district is almost confined to the Lower Carboniferous Limestone with only traces of related mineralisation in the Skiddaw Group and the Coal Measures.

11.2 **Hematite mineralisation**

The west Cumbrian hematite iron ore field extends along the Lower Carboniferous outcrop south-westwards from near Lamplugh to Calderbridge, south of Egremont (Kendall, 1873–75, Smith, 1924, Schellman, 1947). Within this comparatively small orefield many very large bodies of high-grade hematite have been worked, particularly during the latter part of the Nineteenth and first part of the Twentieth Century. The west Cumbrian field is known to have produced well in excess of 100 million tonnes of ore containing on average between 50 and 60 per cent metallic iron. Small-scale mining continues today at Egremont.

Within the Dinantian, and locally higher beds, hematite occurs as irregular metasomatic replacements, mainly of limestone, closely associated with faults especially those which trend roughly NW–SE. Vein-like ore bodies occur along some of the faults, but replacement of wall rocks appears always to have been of major importance in ore formation and compartively few, if any, true fissure veins are present in the Carboniferous. These, however, comprise an important expression of this mineralisation in the Skiddaw Group rocks immediately to the south-east of the district.

An important feature of these deposits, and one which serves to link those in the Carboniferous with those in the Lower Palaezoic rocks, is their almost monomineralic composition. Hematite, in various forms, is the overwhelmingly dominant mineral. West Cumberland is well known for the mammillated variety of hematite known as 'kidney ore'. Whereas this and the related crystalline fibrous form known as 'pencil ore' are locally important, the major part of most of the deposits consists of massive, compact, purplish grey hematite. Well-crystallised 'specularite' is common in small amounts and soft earthy forms of the mineral also occur.

Gaugue minerals are present in very subordinate amounts. These include dolomite, quartz, calcite, baryte, fluorite, manganese oxides, rare siderite and locally small amounts of pyrite, marcasite, chalcopyrite and galena. The mineralogy of these deposits has been reviewed by Smith (1924), Young (1987) and Goldring & Greenwood (1990).

The origin of the west Cumbrian hematite bodies has long been the subject of discussion and controversy. However the most modern synopses of the problem are those by Rose & Dunham (1977) and Dunham (1984). In proposing models for the origin of the deposits these authors attach great importance to the long-observed relationship of the host rocks to the unconformable cover of permeable Permo-Triassic beds. Where such rocks rest directly on Carboniferous Limestone orebodies are common; where thick shale of Namurian, Westphalian or early Permian age intervene orebodies are typically absent. The essential role played by these Permo-Triassic beds was as a conduit along which iron-rich fluids gained access to the Carboniferous and older host rocks. Deep subsidence of Permo-Triassic rocks into the Irish Sea Basin is envisaged as heating saline fluids which leached several elements, including iron, from ferrunginous source rocks, perhaps including the St Bees Sandstone. These fluids were driven up-dip by convective and tectonic pressures into the west Cumbrian and Lake District areas. Where they could gain access to limestones, via fault channels or through permeable beds, these reactive fluids brought about extensive metasomatic replacement to produce the large irregular orebodies typical of the orefield. It has been suggested (Young *in* Jones et al., 1990, p.118) that coarse-grained sandstones high in the Coal Measures may locally have provided additional conduits from iron-bearing fluids.

Fluid inclusion studies on gangue minerals suggest mineralising temperatures of around 100°C (Shepherd 1973). Rose and Dunham (1977) propose a Cretaceous to Tertiary age for the mineralisation.

In the Great Broughton–Lamplugh area hematite ore was produced between about 1880 and 1930 from a group of pits collectively known as the Coronation Mine near the Lamplugh Tip Inn, west-south-west of Lamplugh. The ore occurred here as a series of irregular and vein-like bodies associated with several faults in the Fourth Limestone. Bodies up to 30 m in vertical thickness and around 90 m in breadth were worked here. Details of the mines, parts of which were then working, have been described by Smith (1924).

Much of the ore consisted of massive compact hematite with some soft 'smit' ore. The best ore contained about 55 per cent metallic iron with 5–8 per cent silica and 0.004–0.008 per cent phosphorus. Samples of this ore, accompanied by pale buff dolomite, calcite and a little quartz may be found in the dump from the Coronation pit immediately west of the Lamplugh Tip Inn [0756 2014] and a similar assemblage was noted in the dumps from Whinna Pit [0732 2049], now largely landscaped and concealed beneath a modern house.

In 1924 Coronation Mine was producing about 1000 tons of ore per week. Smith (1924) records outputs of 950 tons from Murton Pit [0761 2006] in 1880, 380 tons from Whinna Pit in 1883 and 17 060 tons from Coronation and Murton in 1913. The ore was taken from the mine by aerial ropeway to a loading bay [0648 2097] on the old railway south of the former Lamplugh Station. A small pile of dolomitised limestone with hematite may be seen today at this site.

Numerous boreholes have been sunk in search of hematite in the Crossgates area. Most were unsuccessful, although Smith records hard compact hematite and soft smit in the Fourth Limestone in one hole.

Smith (1924, p.147) records that hematite was raised many years ago from a shallow shaft about 250 m west-south-west of Lamplugh Church. The ore was found at the faulted contact of the limestone (probably the Fifth) and Skiddaw Group mudstone. The shaft is understood to have penetrated Skiddaw Group rocks and this appears to have passed through the fault. BGS records indicate two shafts at this site [0862 2070 and 0857 2073] though no records of the depths or details of the beds penetrated have been found. According to Smith (1924) a boring approximately 150 m north-north-west of the shaft proved a total thickness of about 2 m of ore and 'spar' near the surface in the Fifth Limestone. Another borehole 90 m north-west of this found only gossany limestone with hematite filling joints, also in the Fifth Limestone. Neither the date of working or the quality and quantity of ore mined is known, though the latter is likely to have been small. The extent of the workings is unknown but is unlikely to have been large. Little remains today to mark the site of these workings.

Hematite is said by Smith (1924, p.148) to have been obtained from a shallow shaft, the site of which was then long obliterated near Havercroft Cottage [0775 2202]. The horizon from which the ore was obtained, the precise position of the shaft, the extent of the workings, the amount of ore raised and the date of working are all unknown.

Trials have been made for hematite on the north side of Crag Hills, west of Eaglesfield Crag. A small shaft is said to have been sunk into the Fourth Limestone. No records of the sinking have been found but it is likely to have been very shallow. A small depression in the field [0975 2747] may mark the site of the shaft. Small, overgrown spoil heaps adjacent to this show much compact grey limestone, similar to that in nearby outcrops, commonly veined by coarse white calcite and with bright red earthy hematite coating joints and forming patchy replacements. A few fragments of solid red earthy hematite are also present. Red earthy hematite may be seen coating joints on the limestone exposed a few metres east of the site of the shaft. Exploration boreholes were sunk in the Fourth Limestone in the fields up to 250 m north of the trial shafts. Detailed records have apparently not been preserved, although a manuscript note by E E L Dixon made at the time of the last survey (1921–24) indicated 0.18 and 0.5 m of ore at depths of about 13 m in two boreholes. The date of these trials is unknown.

An adit [0908 2021] driven eastwards in mudstones of the Loweswater Formation on the west side of High Hows may have been a trial for hematite. No records of the trial have been found and there is no evidence that any mineralisation was encountered. Mapping reveals no potential ore-bearing structures nearby. The date is unknown but it is likely to have been driven during the operation of the Kelton Fell and Knockmurton Mines, immediately to the south, late last century.

In the coarse-grained, reddened Coal Measures sandstone exposed in the abandoned Branthwaite Edge Quarries [0595 2290], minute crystals of specular hematite locally encrust coarse sand grains in the most porous parts of the rock. The presence of very similar concentrations of interstitial specular hematite, in coarse-grained Coal Measures sandstone at the Keekle Extension Opencast Coal Site [NX 997 177] near Whitehaven, has been tentatively interpreted as evidence for these beds having acted as conduits through which flowed some of the fluids responsible for the west Cumbrian hematite mineralisation (Young *in* Jones et al., 1990, p.119).

11.3 Base metal mineralisation

Firman (1978, p.237) refers to a trial working for copper near Papcastle. According to J A D Dickson (personal communication *in* Cooper et al., 1991) the trial consisted of an adit formerly visible near the entrance to Broughton Crags Quarry [091 317]. The adit, which was still visible in the 1950s, was driven along a NW–SE trending fault adjacent to which the limestone, assumed to be the Fourth, was strongly dolomitised. Chalcopyrite is understood to have been the ore mineral, although nothing is known of its abundance or of any associated minerals. This quarry has long been abandoned and used as a rubbish dump. Nothing can today be seen of the adit or of any mineralisation *in situ* although traces of chalcopyrite in limestone were found in 1987 on the overgrown quarry dump about 200 m north of the presumed position of the adit. Dickson recalls that chalcoyrite was formerly visible in limestone and dolomite a short distance to the south-east in the banks of the River Derwent, along what was presumed to be the same fault. During the present survey no mineralisation was seen in the river bank, which here appears to be entirely within drift deposits.

A few small crystals of chalcopyrite, pyrite, marcasite and brown sphalerite have been collected from a dolomite vein in the First Limestone of Tendley Hill Quarry [088 288]. Dolomite veins are numerous in this quarry but sulphides are rare.

11.4 Hydrocarbon mineralisation

The first Limestone at Tendley Hill Quarry [088 288] is cut by numerous veins of dolomite up to 10 cm wide. Calcite is present in many of these, and locally forms veins unaccompanied by dolomite. The veins, which are most numerous in the southern face of the quarry, fill joints which mostly trend between 240 and 270, although some trend about 340. The limestone adjacent to the dolomite-filled joints is not dolomitised.

Typically the veins consist of coarsely crystalline pale fawn to cream dolomite, locally with well-developed curved rhombic crystals in central vugs. White calcite, some pyrite and marcasite, and rare chalcopyrite and sphalerite locally overgrows the dolomite. Black to dark brown bitumen commonly coats dolomite and calcite crystals in the centre of the veins and locally forms patches up to 1 cm across. Much of the bitumen is soft and pliable with a rather dull greasy appearance. Some is relatively hard and brittle with a black glossy appearance. More rarely discrete rounded globules of black bitumen up to 3 mm across encrust dolomite crystals.

Similar hydrocarbons have recently been reported from the Third Limestone of the Gilcrux area and from the First Limestone at Park Head Quarry, Caldbeck (Young & Armstrong 1989, p.52). Limited geochemical investigation, by M E Stuart and B P Vickers of BGS, of samples from all of these occurrences indicate the presence of generally similar hydrocarbon compounds which appear to be partially thermally matured material originating in a marine carbonate environment.

Small quantities of such hydrocarbons are well known from low temperature mineral veins in many parts of Britain, and may well have been derived from organic-rich wall-or source-rocks. Abundant hydrocarbon mineralisation, apparently very similar in style to that at Tendley Hall, has been described from the Great Limestone, the local correlative of the First Limestone, from the Matten area of Northumberland by Creaney et al. (1980).

12. QUATERNARY

12.1 Introduction

A great hiatus in geological time separates the latest Carboniferous rocks from the next group of deposits in the district, those of Quaternary age. Over the whole of northern Britain the Quaternary witnessed a period of great glacial activity with extensive erosional and depositional features contributing much to the present day landscape. The effects of glacial erosion are most marked in upland areas; depositional features predominate in lowland areas. The present district, lying immediately adjacent to the mountains of the Lake District, is dominated by glacial deposits and landforms developed on the margins of this upland area.

Quaternary, or drift, deposits include sediments of glacial and post-glacial origin (Figure 7). Glacial deposits here consist mainly of boulder clay or till together with smaller areas of glacial sand and gravel. Of the area's post-glacial deposits the most widespread is alluvium, belts of which flank much of River Derwent, parts of the Marron and locally some minor streams. River terrace deposits have also been mapped locally in both valleys. Very small alluvial fans have also been identified and small former post-glacial lakes, now filled with lacustrine alluvium or peat, have also been recognised.

Drift deposits mantle much of the district. Post-glacial erosion by the modern drainage has removed superficial deposits in a few places in the valleys of the River Marron and Lostrigg Beck and locally in the main Derwent Valley. Drift-free outcrops of solid rock occur on the high ground south of Branthwaite Edge and along the eastern part of the area, particularly in the Eaglesfield and Lamplugh areas.

12.2 Classification

Previous descriptions of the Quaternary sequence of west Cumbria by Eastwood et al. (1931) drew attention to three glacial episodes separated by interglacial periods. More recent work has cast doubt on this interpretation and it is likely that the sequence described by these authors records oscillations in the movements and advances of the ice sheets rather than separate glacial episodes. Modern interpretations of the glacial history of Cumbria have been reviewed by Pennington (1978).

In any heavily glaciated area many of the glacial erosion features and most of the deposits seen today are likely to be the products of the most recent glacial episode. Within the Lake District Mitchell et al. (1973) have provided evidence, based on radiocarbon dating, for the main glaciation having occurred within the Devensian glacial stage (approximately 25 000–10 000 BP). Trotter and Hollingworth (1932) described a boulder clay from north Cumbria which Pennington (1978, p.209) suggested may date from the previous glacial stage, the Wolstonian. The 'Early Boulder Clay' described by Eastwood et al. (1931) from the Derwent Valley, Kelton Fell and the Egremont area may also, in part, belong here. More recently Boardman (1991) has cited evidence for deposits of a pre-Devensian glacial episode in parts of the Lake District.

It is probable, though no evidence can be cited, that some of the erosional features of west Cumbria may at least in part, be the result of pre-Devensian glacial episodes. Any earlier deposits are likely to have been removed by subsequent glaciation or to have been incorporated into these later deposits.

In their review of the Quaternary deposits of Britain, Evans and Arthurton (1973) placed the entire glacial sequence of Cumbria, with the exception of the older boulder clay mentioned above, within the Late Devensian.

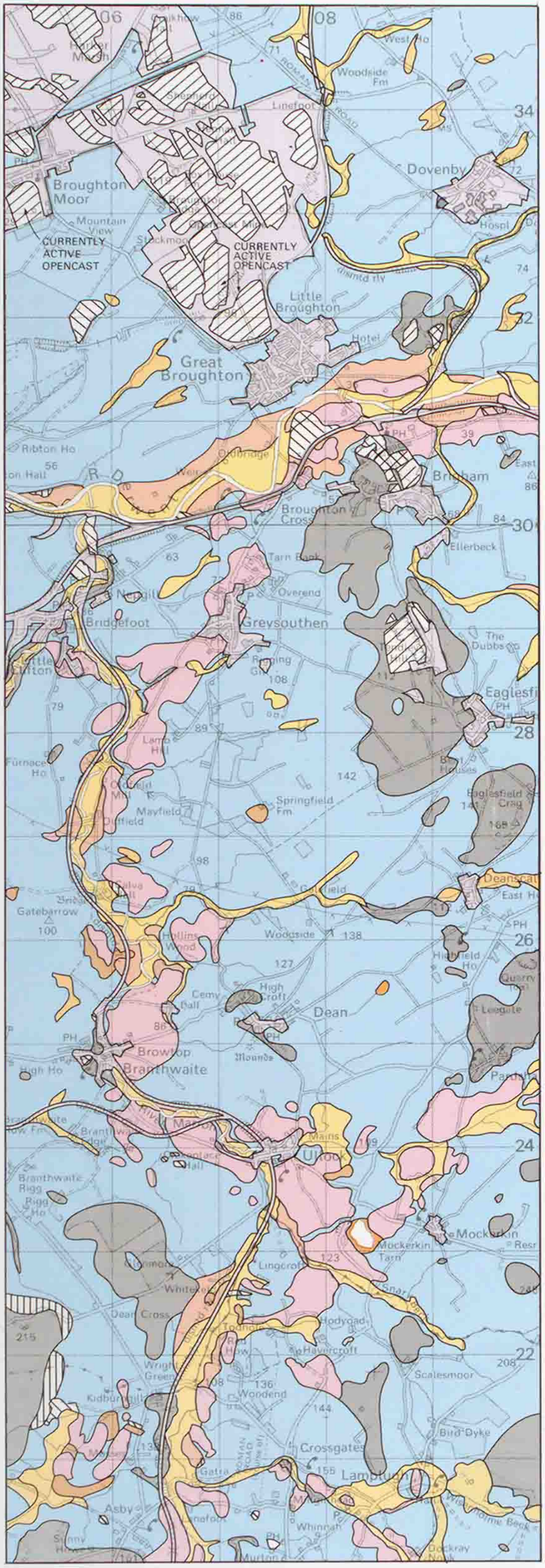
Pennington (1978) has described in detail lake sediments deposited in late-glacial times in the Lake District. Sediments belonging to this period may be present in Mockerkin Tarn but this has not been investigated during the present survey.

Post-glacial deposits within the area belong to the Flandrian stage (from 10 000 BP—present day). These include alluvium, river terrace deposits, small areas of lacustrine alluvium, alluvial fan deposits and peat.

12.3 Conditions of deposition

It is now generally accepted that the main features of the landscape, including well-developed drainage systems, were well established by the beginning of the Quaternary and that these features exerted considerable influence on the glacial history.

During the Quaternary a progressive and dramatic cooling of Britain's climate led to the establishment of thick ice-sheets over much of the country. Glacial deposits, both in Britain and Europe, record evidence of several periods of glacial advance separated by intervals of retreat, during which the climate ameliorated, on occasions becoming warmer than that of the present day. At the glacial maxima it is likely that ice covered even the highest peaks of the Lake District. The great thickness of ice which developed over the Lake district mountains moved radially into the surrounding lowlands. In west Cumbria this westerly flow of Lake District ice was deflected by southerly flowing ice from the Southern Uplands of Scotland. The immense ero-



KEY

Landslip

Peat

Alluvium: a variable sequence of clay, silt, sand and gravel. May include peat locally

River terrace deposits: similar to alluvium. Distinguished by occurrence as elevated terraces

Lacustrine deposits: mostly clay, silt and some gravel. May include peat locally

Glaciofluvial deposits: sand and gravel

Morainic deposits: heterogeneous glacial debris characterised by markedly hummocky surface

Till (boulder clay) and glacial drift, undifferentiated: mainly stony and sandy clay

Solid rock, undifferentiated

Worked-out opencast coal seam area or quarry in solid rock

Made ground (Solid and drift boundaries below made ground based on old records)

Worked-out ground and made ground

Landscaped ground, eg areas around opencast sites

(See also Fig 11, Made and Disturbed Ground)

This figure is a simplified portrayal of 1:25 000 scale map 2 which should be consulted for detailed information

Scale

0 1 2 3

kilometres

Figure 7 Drift geology map

sive power of such moving ice sheets stripped the pre-glacial landscape of superficial deposits and broken or weathered rock, often producing extensive smooth surfaces of relatively unweathered rock. The modifying effects of glacial erosion on the landscape are important in the central Lake District where features characteristic of heavily glaciated uplands abound. These include hanging valleys, corries, arêtes and straightened 'U' shaped valleys, commonly with overdeepened basins now occupied by lakes.

In lowland country, such as the present district, present day landscape features owe more to deposition than erosion. Here much of the rockhead surface has been mantled by till. This comprises a variable mixture of materials deposited beneath the ice sheet (lodgement till) and in places at its margins during phases of melting. Boulders of distinctive rock types (erratics) within the till give evidence of the direction of derivation. Smoothing of sub-glacial till deposits by moving ice gave rise to characteristic elongate till ridges known as drumlins, the form and orientation of which indicate the direction of ice movement.

During the final stages of the last glacial episode, glacial meltwater was important both in eroding melt water channels and in depositing water-borne glacial debris. During the retreat stages of the last glaciation large volumes of meltwater were, in places, impounded by ice, producing large glacial lakes. Two such lakes developed in the present district. Lake Cockermouth covered a wide area of the Derwent valley and Vale of Lorton: Lake Pardshaw occupied the valley between Ullock and Pardshaw, including the present Mockerkin Tarn. Eastwood et al. (1931) have described these lakes and some of the late-glacial deposits formed in and adjacent to them.

Deposits of sand and gravel formed by meltwater streams either adjacent to, or beneath, a waning ice sheet include features known as kames and eskers. Melting of large masses of ice which locally became trapped within the outwash gravels sheet produced hollows known as kettle holes. In their detailed review of the glacial and post glacial history of the Whithaven district Eastwood et al. (1931) assign many of the sand and gravel deposits of the present area to kame and esker deposits.

Progressive climatic improvement in post-glacial times led to the establishment of the drainage system seen today. Deposits including river terraces, alluvial fans and alluvium were laid down adjacent to many of the streams, and shallow ponds, and lakes on the till surface became filled with lacustrine alluvium.

12.4 Till

Till or boulder clay mantles much of the district. Over large parts of the western and northern parts of the district its surface exhibits well-developed low, elliptical or elongated drumlin ridges, typically with a NE–SW alignment. Whereas in places these reflect the trend of ridges in the underlying rockhead surface they are mainly a reflection of the dominant flow direction of the ice sheet which deposited the till. In common with the adjacent Dearham and Gilcrux area the till of the present district appears to be a lodgement till, that is one deposited beneath an icesheet.

There are few good natural exposures of till. Where streams have cut through the till layer into solid rock, e.g. in the River Marron and Lostrigg Beck, the till surfaces have become heavily vegetated. Large sections are occasionally exposed in opencast coal workings around Broughton Moor. Most of the sections through till in old quarries are heavily overgrown and obscured.

Despite the poor exposure it is clear that much of the till consists of clay, sandy clay or clayey sand in which occur a large number of cobbles or boulders, in places up to 1.5 m across or even larger in places. These erratics comprise mainly rocks derived from the Carboniferous outcrop though with a large proportion of Lake district rocks. Prominent amongst these are various Borrowdale Volcanic Group lithologies and a rather smaller proportion of Ennerdale Granophyre. Greywacke sandstones and cleaved mudstones from the Skiddaw Group are also found though in smaller numbers. In its unweathered state, in deep excavations or borehole cores, the matrix of much of the till is grey or brownish grey. When weathered it is typically brown in colour. No erratics of undoubted southern Scottish origin have been identified in the district. This suggests that the Scottish or Irish Sea Ice of Eastwood et al. (1931) was deflected to the west of the district by the main flow of ice away from the Lake District mountains. However in their detailed review of the glacial history of the Whitehaven area Eastwood et al (1931) indicate that at times the boundary of the 'Irish Sea ice' and the Lake district ice ran roughly north-south across the district.

Many, if not all, of the areas mapped as drift-free were probably originally till-covered as evidenced by the common occurrences of erratic boulders in the soil of these areas. Post-glacial erosion has, in these places, removed much of the comparatively thin drift cover to expose the underlying solid deposits.

12.5 Glaciofluvial deposits

Within the Great Broughton–Lamplugh area these comprise the deposits previously mapped as glacial sand and gravel. These form a belt of discontinuous outcrops along parts of the Derwent valley which extends southwards along the Marron. Comparatively wide spreads are also present to the north and north-west of Mockerkin. The outcrop of these deposits is typically marked by hummocky ground, commonly with steep slopes. Where the gravels are very well drained the soil is characteristically dry, and vegetation quickly dries and wilts in prolonged dry weather. Gravelly soils are conspicuous in ploughed land and in steep river banks. Difficulty is commonly encountered in delimiting the extent of sand and gravel outcrops and in places the three-dimensional nature of the deposits is far from clear.

The fluvioglacial deposits of the district typically consist of fine- to coarse-grained, moderately- to well-sorted gravel with some coarse sand locally. They are the products of glacial outwash laid down by meltwater streams at the margins of, and in places beneath, the melting ice sheets.

Eastwood et al. (1931) relate many of the sand and gravel deposits of the district to stages in the deglaciation of the Lake District and adjacent lowlands. In their detailed review of glacial and post-glacial features they identify the spreads of gravel around Greysouthern, at the junction of the present day rivers Derwent and Marron, as part of an outwash-delta deposited in a former glacial lake, Lake Cockermouth, which occupied the upper Derwent valley. The gravel deposits between Branthwaite and Calva Hall are considered to be further outwash deltas into an arm of Lake Cockermouth. Large spreads of gravel around Ullock and Mockerkin Tarn are interpreted by Eastwood et al., as esker-deltas on the margin of the former glacial lake Pardshaw. Steep east-facing slopes on gravel deposits west of Mockerin Tarn were regarded by these authors as ice-contact slopes.

Sand and gravel ridges, north of Todhole and south of Mockerin Tarn, were identified during the last survey by E E L Dixon as eskers. Spreads of sand and gravel north of Asby were described by Eastwood et al. (1931, p.253) as kames related to a series of marginal channels.

Several large and comparatively deep closed basins or kettle holes may be seen in the fields between Branthwaite Hall [063 252] and the River Marron.

Natural exposures of fluvioglacial deposits are rare, although small sections may be seen in several small, and now mainly degraded, pits from which small amounts of gravel were extracted in the past.

Old gravel workings north of Townhead Farm, Greysouthen [0715 2955] and north of Curl Beck [0627 2777] are today overgrown. Coarse subrounded gravel, composed mainly of Borrowdale Volcanic Group rocks with smaller quantities of Carboniferous sandstones, were dug from new barn foundations at Townhead [0704 2939] and similar gravel was also seen in temporary exposures at a building site in Greysouthen village [0716 2892].

On the east side of Calva Hill [0632 2653] coarse gravel composed of Borrowdale Volcanic and Skiddaw Group rocks and pink Ennerdale Granophyre was noted beneath the hedge line. Long-abandoned and degraded gravel pits [0596 2588] may be seen at the southern end of Broomy Hill. Here, and on the upper slopes of the hill, there are small exposures of coarse gravel composed mainly of Skiddaw Group rock types and vein quartz.

A small pit near Woodend, [0686 2148] worked intermittently for local farm use, exposes up to 2.0 m of crudely bedded alternately coarse and very coarse gravel composed of a large variety of Lake district rock types. Slight convolutions in the bedding may be the result of slumping or perhaps cryoturbation.

In the steep west bank of the Marron, [0566 2992] north of the A66 road bridge, up to 2.0 m of rather poorly sorted gravel are exposed about 4–5 m above river level. Thick vegetation and surface wash render interpretation difficult but this ground appears to be a bed or lens within till.

12.6 **Alluvium**

Alluvium forms a continuous wide belt of flat ground flanking the River Derwent. Similar, though narrower, belts occur adjacent to much of the River Marron and Lostrigg Beck and some of the minor streams.

Sections through alluvium may be seen at a number of places in river banks where recent erosion is active, though sections showing more than 1.0 m of these deposits are rare. These reveal a variety of deposits including brown silts and clays and locally gravels. Silts up to about 1.0 m thick commonly overlie gravels.

At surface much of the alluvium of the River Marron consists of brown silt. Alluvial gravel may be seen locally at depths of between 1.0 and 0.4 m, e.g. in the east bank of the Marron at Amy's Hole [0566 2698]. The gravel here is locally cemented into a pan by iron and manganese oxides. Gravelly alluvium occurs at the surface in a number of places, e.g. about 150 m downstream of Amy's Hole.

The alluvial deposits may locally include beds of peat or peaty clay and silt. The spoil from ditches in the alluvium of the Marron north of Lanefoot Bridge [0655 2085] shows peat amongst gravelly loam. A ditch [0557 2141 to 0566 2147] adjacent to the site of Moorside Colliery shows up to 1.0 m of grey and brown silty loam overlying peat. Up to 0.5 m of peat occur here though the total thickness is unknown and the nature of the underlying deposit has not been established. Some peat was noted in the sandy and gravelly spoil from a flooded excavation in the Marron alluvium 150 m west-north-west of Ullock Bridge [0727 2400] and at least 0.75 m of peat were recorded beneath 0.5 m of brown alluvial silt in a ditch [0689 2258] 200 m south-west of Whitekeld also in the Marron valley.

Apart from parts of the Derwent valley where boreholes prove the full thickness of the alluvium no reliable estimates can be made for the thickness of the deposit. In the Branthwaite area solid rock is exposed at water level in the River Marron (between [0600 2542] and [0594 2486]). The alluvium here clearly does not exceed 1.5 m in thickness.

12.7 River terrace deposits

River terrace deposits have been mapped at a number of places along the valleys of the rivers Derwent and Marron. They typically form bench-like features up to about 3 m above the level of the adjacent alluvium. Exposures of river terrace deposits are very rare though they appear to consist of silts and gravels very similar to the alluvium.

12.8 Lacustrine deposits

Isolated areas of alluvial deposits filling enclosed basins, formerly occupied by small lakes, have been mapped at several places. Exposures of these sediments are very rare and confined to temporary sections in ditches. They appear to consist mainly of brown silts and although no reliable thicknesses can be given they are unlikely to exceed 1–2 m in this district.

12.9 Alluvial fan deposits

Alluvial fan deposits have been mapped at several places where tributary streams join the main valley. They are distinguished on their surface morphology. These deposits are generally of very small extent (mostly less than 200 m^2) though deposits of this type, covering more than 4 ha have been mapped at Moorside Parks [0520 2075] and at Moorside Colliery [0540 2135]. No good sections have been seen through any of these deposits. No precise thicknesses can be given for fan deposits within the district though they are unlikely to exceed 3–4 m.

12.10 Peat

Small areas of peat have been mapped filling shallow enclosed basins in the till surface and locally in the alluvium. In most instances these deposits may represent the final stage in filling of small lakes and may thus overlie lacustrine silts. Peat occupies a small part of the shallow basin [0615 2677] north of Calva Hill in the Marron Valley, but its relationship to the adjacent lacustrine deposits is not clear. A ditch section near the edge of the rather more extensive peat which surrounds part of Broomy Hill [0574 2610] south of Calva Hall shows up to 0.3 m of dark brown peat overlying 0.5 m of grey, micaceous silty sand, interpreted as lacustrine deposits.

The most extensive areas of peat are in the low ground between Asby and Moorside Colliery. A ditch [0597 2143] cut through one of these peat areas 450 m west-south-west of Kidburngill Bridge showed at least 0.7 m of peat beneath 0.3 m of brown silty loam.

No reliable figures are available for the thickness of any of these peat deposits though they are unlikely to exceed 1.5 m.

The local presence of peat beds within alluvial deposits has already been mentioned.

No dates have been obtained from any of the peat deposits of the district.

12.11 Karst Features

Geomorphological features characteristic of country consisting predominantly of bedrock with a high degree of solubility in natural groundwater are known collectively by the term 'karst'. In common with most areas of Lower Carboniferous Limestone in Britain the limestone outcrops in the eastern part of this district exhibit a number of typical karst features. These were almost certainly initiated during interglacial periods in the Quaternary when availability and movement of groundwater was at a maximum.

Perhaps the most conspicuous of these karst features are the numerous swallow holes or dolines, the distribution of which is shown on Map 5. Swallow holes are developed on the outcrops of most of the districts limestones but are present, or at least are recognisable, only in certain areas.

Whereas most swallow holes occur on outcrops of bare limestone, or on limestone with only a comparatively thin cover of superficial deposits, they may locally penetrate for a considerable distance upwards into overlying strata. A remarkable group of often large swallow holes may be seen on the outcrop of the Hensingham Grit west and south-west of Eaglesfield.

Most of the swallow holes are roughly conical in form. They are generally up to 40 m in diameter at their widest point and are usually less than 5 m deep: many are much shallower. The sides and bases are commonly smooth and covered with superficial materials. In a few instances bare limestone, or where the swallow hole penetrates beds above limestones, other solid rocks are exposed on their sides and bases. Examples include the hole [0874 2753] through the Hensingham Group into First Limestone about 1 km south-west of Eaglesfield and in an almost vertically sided hole [0947 2711] in Fourth Limestone adjacent to the Eaglesfield to Deanscales road. The base of most holes is dry, although in a few cases the floors may be wet, especially after prolonged rain. Two wide, though very shallow, swallow holes in the First Limestone west of Eaglesfield [0875 2819] are boggy or contain a shallow depth of water except in particularly dry weather. A small amount of relatively impervious till may be present in the floor of these.

Almost nothing is known about the district's underground drainage. Some solution-widening of joints and bedding planes in limestone is apparent in many quarries, although the cavities created rarely exceed 0.2 m across. Cave-like cavities up to 1.5 m wide and 1.0 m high with rounded waterworn surfaces in the outcrop [0718 2004] of the Third Limestone south of Smithy Beck, Murton and in the Fourth Limestone at Rakegill Beck [0787 2066], Lamplugh have however been noted. No evidence of any extensive cave system has been discovered in any of the numerous quarries in the limestone outcrop. It is therefore probable that no major cave system is present and that underground drainage is effected by numerous channels along and between joints and bedding planes. Many of the swallow holes of this area, particularly those on the bare limestone outcrop, like those of the adjoining Dearham and Gilcrux area (Young & Armstrong 1989, p.30), appear to resemble the 'solution dolines' of Cramer (1941). These are developed by pronounced surface solution of bedrock at or around some favourable point such as a joint intersection.

In the Dearham and Gilcrux area Young & Armstrong (1989) concluded that none of the swallow holes resulted from collapse into solution voids. However on the outcrop of Hensingham Grit west and south-west of Eaglesfield, collapse of beds overlying limestone clearly is important in the development of swallow holes. Here, within an area of about 40 ha, approximately 40 swallow holes penetrate the grit into the underlying First Limestone. Whereas a number of these clearly penetrate only a very small thickness of grit, the majority must penetrate through several metres with a considerable number penetrating virtually the full thickness of the Hensingham Grit, (here approximately 25 m). The adjacent First Limestone outcrop contains comparatively few swallow holes, and those which have been identified occur close to the base of the Hensingham Grit. Swallow hole development is still active in this area; local farmers report the occasional sudden collapse of the surface to produce new swallow holes. Some of the holes around [088 280] are reputed to have formed within the last ten or twenty years.

It is difficult to account for this high concentration of swallow holes penetrating the Hensingham Grit, especially when the bare limestone outcrop is apparently so little affected. We suggest that a high groundwater flow through the comparatively permeable Hensingham Grit, in interglacial, or postglacial times, caused pronounced solution of the limestone surface, particularly adjacent to joints and joint intersections in the way advocated by Cramer (1941) for 'solution doline' development. The resulting solution beneath the sandstone cover may well have produced larger cavities than seen elsewhere on the bare limestone outcrop. It is possible that such solution is still occurring, though perhaps intermittently, when groundwater levels rise sufficiently. Collapse into the resultant voids could well explain this concentration of solution features.

Most of the swallow holes are apparently unconnected with the modern drainage system and commonly occur on hill slopes well away from valleys. Comparatively few instances are known of stream channels feeding into swallow holes. The finest example of an active stream sinking into a swallow hole, here in Fourth Limestone, is that [0903 2640] 300 m west of Home Farm, Deanscales. This is an example of an 'alluvium sink doline' of Cramer's (1941) classification. The stream rises again 200 m west-south-west at the Singing Well [0883 2633].

Where free of superficial deposits several limestone formations form bare craggy outcrops, typically with little or no soil cover. Good examples of such limestone scars occur to the east of Tendley Hill on the outcrops of the First and Second Limestone and on the Fourth Limestone outcrop of Crag Hills, Eaglesfield, south of Deanscales. Solution sculpturing of the type described by Bogli (1960) is present on some of the limestone outcrops. In some quarries small crusts of flowstone up to a few centimetres thick have been deposited on joint surfaces.

A small area of poorly-developed and overgrown limestone pavement with characteristic 'clints' and 'grykes' is present on the outcrop of Fourth Limestone west-south-west of Scalesmoor [0850 2174].

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