BRITISH GEOLOGICAL SURVEY

TECHNICAL REPORT WA/89/70

Onshore Geology Series

The applied geological mapping of the Dearham and Gilcrux area, Cumbria

1:10 000 sheets NY03NE and 13NW: Part of 1:50 000 sheets 22 (Maryport) and 23 (Cockermouth)

B Young and M Armstrong

Cover illustration

Old pillar-and-stall workings in the Ten Quarters Seam exposed in Oughterside Opencast Site
Photo B Young

Geographical index

UK, England, Cumbria

Subject index

Land-use planning, thematic maps, Quaternary, Carboniferous, Permian, mineral resources, mining, engineering geology

This study was commissioned by the Department of the Environment, but the views expressed in it are not necessarily those of the Department

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

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PREFACE

This account describes the geology of the 1:10 000 scale sheets NY03NE and 13NW which lie within the 1:50 000 geological sheets 22 (Maryport) and 23 (Cockermouth). The resurvey was commissioned by the Department of the Environment with a provision for 50 per cent of the funding.

The area was first surveyed at the six-inch scale by T V Holmes, R Russell and J C Ward and published in 1890 and 1892 as Old Series One Inch Sheets 101NE and 101NW respectively. Some revision of Sheet 101NW was carried out by J G Goodchild and a new edition of this map was published in 1895. No explanatory memoirs were published for either sheet. A resurvey of the area was undertaken by T Eastwood between 1922-26 and 1928-32. New Series geological sheet 22 (Maryport) was published in 1930; sheet 23 (Cockermouth) was published as a Solid edition in 1959 and a Drift edition in 1960. A descriptive memoir for the Maryport sheet was published in 1930 and for Cockermouth in 1968. A revision survey at the 1:10,000 scale was carried out in 1986-87 by M Armstrong (NY03NE) and B Young (NY13NW) with D H Land and D V Frost as Programme Managers. Palaeontological work was carried out by P Brand and mineralogical determinations by I Basham and P H A Nancarrow.

We are grateful for much help and valuable information provided by British Coal, both the Opencast Executive and deep mines North-Western area, Bothel Limestone and Brick Co Ltd and numerous land owners.

F G Larminie
Director
British Geological Survey

July 1989

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Associated maps

Maps at 1:25 000 scale
Structure contours, Shallow coal workings, Mineralisation (in rear folder)

Thematic maps at 1:10 000 scale (available separately from the report)

Location of boreholes and shafts	NY 03 NE & 13 NW
Rockhead elevation	NY 03 NE & 13 NW
Drift thickness	NY 03 NE & 13 NW
Swallow holes	NY 13 NW

Geological maps at 1:10 000 scale (available separately from the report)
The maps are overprinted on Ordnance Survey topographical bases and produced for NY 03 NW & 13 NW.

SUMMARY

One of the key objectives of the Department of the Environment's Geological and Mineral Planning Research Programme is the collection and interpretation of geological information for land use planning purposes.

This aim coincides with the objectives of the Natural Environment Research Council, who through the British Geological Survey, encourage and support research into earth sciences.

The basic tool for such research is a geological map. In West Cumbria the first geological survey at a 6 inch scale was made in 1878 and revised between 1922 and 1932. The geological information relating to this area was therefore seriously out of date and a resurvey was commissioned with the funding shared between the Department of the Environment and the British Geological Survey.

The geology, mineral resources and geotechnical aspects of the Dearham and Gilcrux areas are reassessed using the resurveyed sheets NY 03 NE and NY 13 NW.

This part of West Cumbria comprises Lower and Upper Liddesdale Group, formerly known here as Carboniferous Limestone (Asbian and Brigantian), Hensingham Group, (Namurian) and Lower, Middle and Upper Coal Measures (Westphalian A, B and C). The area's main mineral product is coal which has been worked underground for several centuries. This has now ceased despite some reserves remaining. Opencast working is in operation and useful reserves remain for the future. Limestone has also been quarried extensively and is still worked in one quarry. Reserves exist for future working.

Quaternary sediments up to 30 m thick conceal much of the solid rocks. Till or boulder clay forms the most common superficial deposit and is of a fairly uniform composition. Glacial valleys cut into the boulder clay are filled with complex drift deposits including silts and laminated clays and often floored by sand and gravel.

Alluvial and River Terrace deposits are extensive only in the Ellen valley. Marine and estuarine alluvium occurs as a minor component of the alluvium in the Crosscanonby area.

Raised Beach Deposits, composed principally of sand and gravel, flank the modern beach deposits.

Made Ground, mostly in the form of colliery spoil and with smaller amounts of quarry spoil and domestic refuse, covers only a very small part of the area.

Extensive coal mining in the past now places restraints on planning and development of the area of the Coal Measures outcrop. Subsidence from deep mining is likely to be complete but that associated with collapse of old workings at shallow depths is difficult to predict. Ancient pillar and stall workings are often less than 30 m deep and some may be unrecorded. The positions of some old shafts are uncertain and many are likely to have been left untreated or inadequately treated after abandonment. The possible presence of unrecorded shallow workings should be taken into account before any development is contemplated in areas such as those near the outcrop of coal seams and appropriate site investigations carried out.

Some mudstone formations in the Lower Carboniferous may exhibit bentonitic characteristics. These may require that special consideration is given to the assessment of excavation and foundation conditions in any proposed development.

The till and sand and gravels generally provide good foundation conditions. Other superficial deposits such as made ground and alluvium are more variable and possess weaker engineering properties. Slopes in drift may fail if overloaded or over-steepened or if the drift deposits become locally weakened.

The area contains resources of coal which could be worked by opencast methods. There are also resources of limestone, building stones, fireclays, brick clays, shales and ganister in the area. Resources of sand and gravel are restricted to small areas and amounts present are likely to be limited.

Minor baryte vein mineralisation, locally accompanied by copper minerals, is widespread in the Dinantian and Namurian rocks. Small quantities of barytes have been mined in the past. The area merits further investigation for possible economic deposits of barytes and there are some grounds for considering the possible presence of barytes and base metal deposits at depth.

Widespread mining in the coalfield has disturbed the natural hydrogeological regime and potable groundwater is unlikely to be obtained in large quantities.

Domestic refuse is currently used to fill one old limestone quarry. The possibility of contaminated

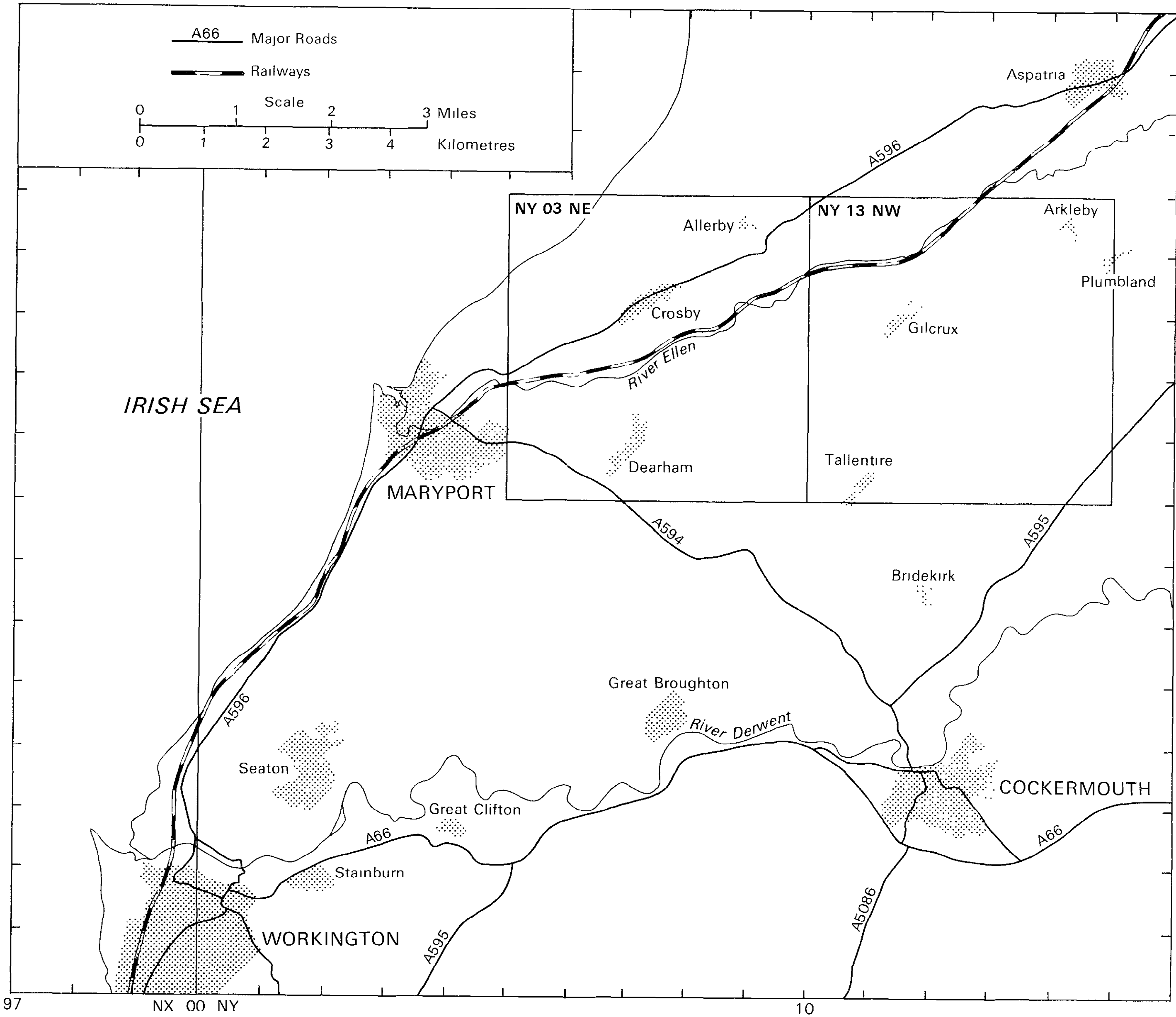


Figure 1 Location map

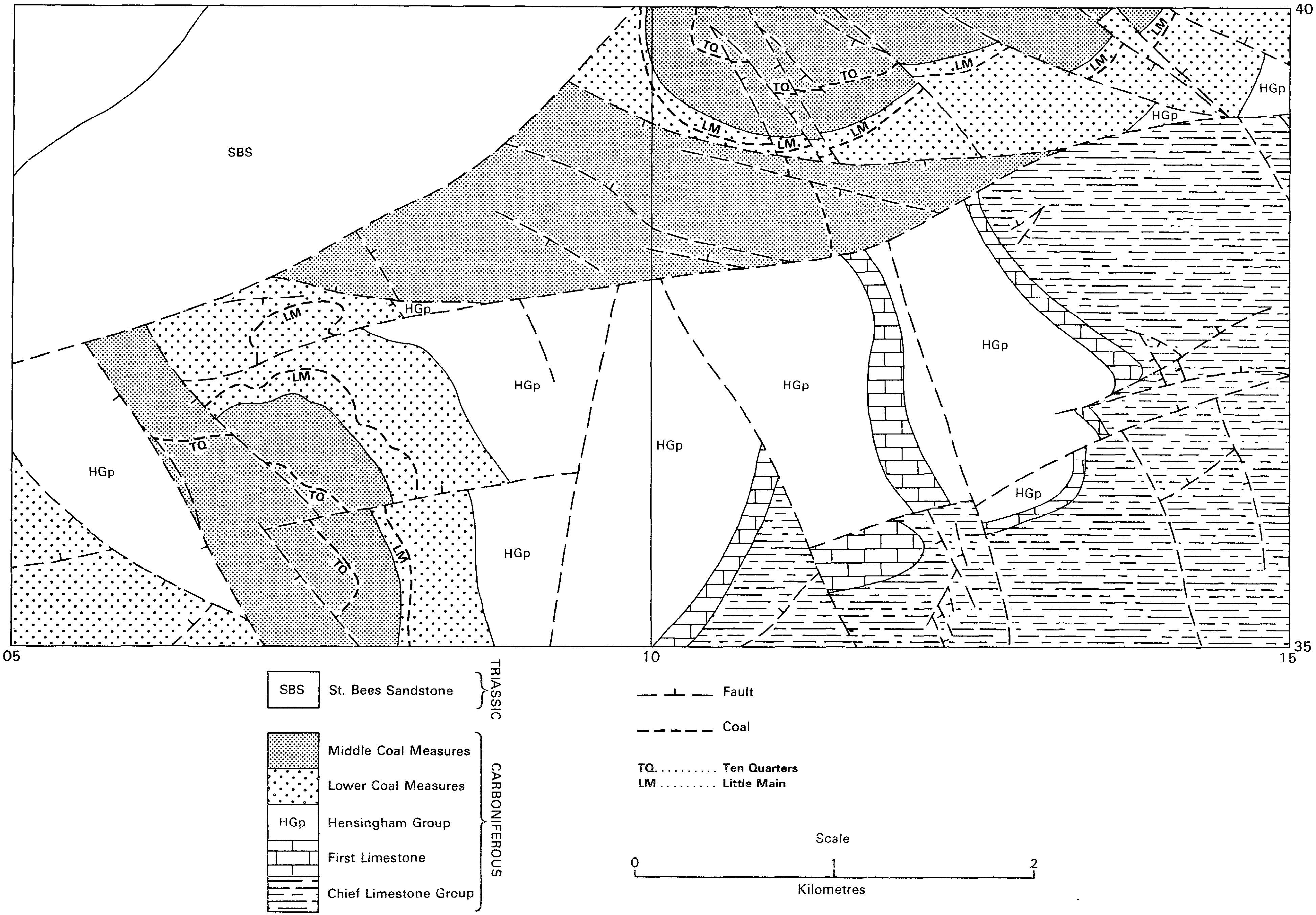


Figure 2 Simplified geological map

leachate escaping into streams at a lower level should be carefully monitored. Any redevelopment of the infilled quarry should ensure that load bearing walls do not span the quarry margins in order to eliminate differential settlement.

The Dinantian and Namurian limestone outcrops are marked by numerous swallow holes. Known swallow holes are indicated on the maps though many others may be present concealed beneath superficial deposits. Due consideration should be given to the presence of these and other solution cavities in the planning of any civil engineering projects on ground underlain by limestone formations.

INTRODUCTION

The district described in this report lies to the east of Maryport and to the north of Cockermouth in the county of Cumbria. It includes the villages of Dearham, Crosby, Allerby, Tallentire, Gilcrux and Parsonby (Figure 1). Between these small centres of population the district is predominantly rural with mixed pastoral and arable farming based on numerous scattered farms. Apart from agriculture the only significant sources of employment within the district today are opencast coal mining at Oughterside, north of Gilcrux and limestone quarrying at Moota, south of Parsonby. Underground mining of coal was formerly important in the west, based in and around the former pit villages of Dearham and Crosby. The district is served by the A596, A595 and A594 roads and is crossed by the Carlisle to Barrow in Furness railway line though the nearest stations are at Maryport and Aspatria one mile west and north east of the district respectively.

Inland from the Solway coast on the south side of Allonby Bay the western part of the district consists of undulating drift-covered country almost entirely below 100 m above sea level. East of a line between Gilcrux and Tallentire the ground rises more sharply to a broad ridge between Tallentire Hill (223 m), and the highest point, Moota Hill (251 m). The main drainage is to the west through the River Ellen which reaches the sea at Maryport: a small area on the south side of Tallentire and Moota Hills is drained by the tributaries of the River Derwent.

The main features of the district's geology are shown in Figure 2.

The western and northern parts of the district are part of the West Cumbrian coalfield (Westphalian). Namurian and Dinantian rocks reach the surface in the central and eastern parts of the district and although the structure is complicated by faulting, progressively older Dinantian rocks crop out in succession towards the south east. Namurian sediments are brought to the surface by faulting in a belt between Ellen Bank and Dearham. In the north west the Westphalian strata (Coal Measures) are overlain by the Triassic St Bees Sandstone. Much of the Coal Measures, Namurian and Triassic outcrops are concealed beneath glacial deposits. Alluvial deposits flank the River Ellen along much of its course. The Dinantian rocks are generally better exposed with only thin drift cover.

The regional geology has been summarised by Taylor *et al.* (1971) and Moseley (1978). Detailed descriptions of the district's geology have been given by Eastwood (1930) and Eastwood *et al.* (1968). Modern summaries of the Carboniferous stratigraphy are those by Taylor (1961) and Mitchell *et al.* (1978). In the present study the results of these earlier works, together with more recent information from boreholes and mining, have all been critically reviewed and re-correlated. All available mine plans have been examined and the ground has been resurveyed in detail.

Coal mining is a long-established industry in the district and dates back several centuries. For the oldest workings no plans exist. For many Nineteenth Century workings plans were either not made or have been lost. Many, though by no means all, of the surviving Nineteenth Century plans are unreliable to some extent. Plans of Twentieth Century workings in general provide an accurate record though inconsistencies are not uncommon between different plans of the same workings. The positions of many old shafts are therefore uncertain. Every effort has been made to locate and record all shafts as accurately as possible. Underground mining came to an end in the early 1950s with the closure of the district's last collieries at Birkby and Ellenbank. Since then several areas have been investigated as opencast prospects though to date extraction has taken place only at Oughterside, north of Gilcrux and at Blooming Heather south west of Dearham. Coal extraction at Oughterside ended in July 1988.

The district's most important extractive industry after coal mining is limestone quarrying. Numerous quarries mark the outcrop of the Dinantian limestones between Tallentire and Parsonby. Many were small and provided for

AGE	SYSTEM		STRATUM NAME	MAIN LITHOLOGIES	DEPOSITIONAL ENVIRONMENT	APPROX. THICKNESS (m)
Present day-0.01Ma	RECENT		Made ground	Colliery spoil, quarry spoil, material backfilled into opencast pits, domestic refuse		
			Calcareous tufa	Calcareous tufa	Lime-rich springs and streams	up to 0.3
			Blown sand	Sand	Windswept coastal lowland	? up to 5*
			Raised beach deposits	Sand and gravel	Marine beach formed at higher sea level	? up to 5*
			Peat	Peat	Boggy woodland	? up to 1*
			Marine and estuarine alluvium	Mainly clay and silty clay	Coastal marshes	? up to 5*
			Lacustrine alluvium	Silt	Freshwater lakes	? up to 3*
			Alluvial fan deposits	Clay, silt, sand and gravel	At junction of tributory streams with main valleys	? up to 4*
			Alluvium	Clay, silt, sand and gravel	Flood plains of rivers	? up to 5*
			River terrace deposits	Silt, sand and gravel	Flood plains of rivers	? up to 4*
0.01-2Ma	PLEISTOCENE		Glacial sand and gravel	Sand and gravel	Glacial meltwater	up to 3
			Boulder clay	Stony and locally sandy clay	Mainly sub-glacial	Locally in excess of 30
UNCONFORMITY-FOLDING, FAULTING, UPLIFT and EROSION						
195-280Ma	PERMO-TRIASSIC		St.Bees Sandstone	Reddish-brown laminated and cross-bedded sandstone	Alluvial plains of large braided rivers	up to 100
			St.Bees Shale	Red mudstones with a basal breccia (known only from boreholes)	Marine deposition on a coastal plain	up to 80
UNCONFORMITY-FOLDING, FAULTING, UPLIFT and EROSION						
280-315Ma	CARBONIFEROUS	UPPER	Coal Measures	Mudstones, siltstones, sandstones with coal seams	Fluvial and deltaic plain with periodic marine incursions	up to 330
315-330Ma			Hensingham Group	Mudstones, siltstones and sandstones with thick limestone (First Limestone) at base	Shallow marine basin overwhelmed by deltaic sedimentation	up to 165
330-345Ma		LOWER	Carboniferous Limestone	Limestones, sandstones, mudstones and some thin coals	Alternating periods of shallow marine basin (limestones) and deltaic incursions (sandstones, mudstones and coals)	up to 315

* Precise thicknesses of these deposits are unknown in the area. The figures quoted here are estimates only.

TABLE 1 GEOLOGICAL SUCCESSION IN THE DEARHAM AND GILCRUX AREA

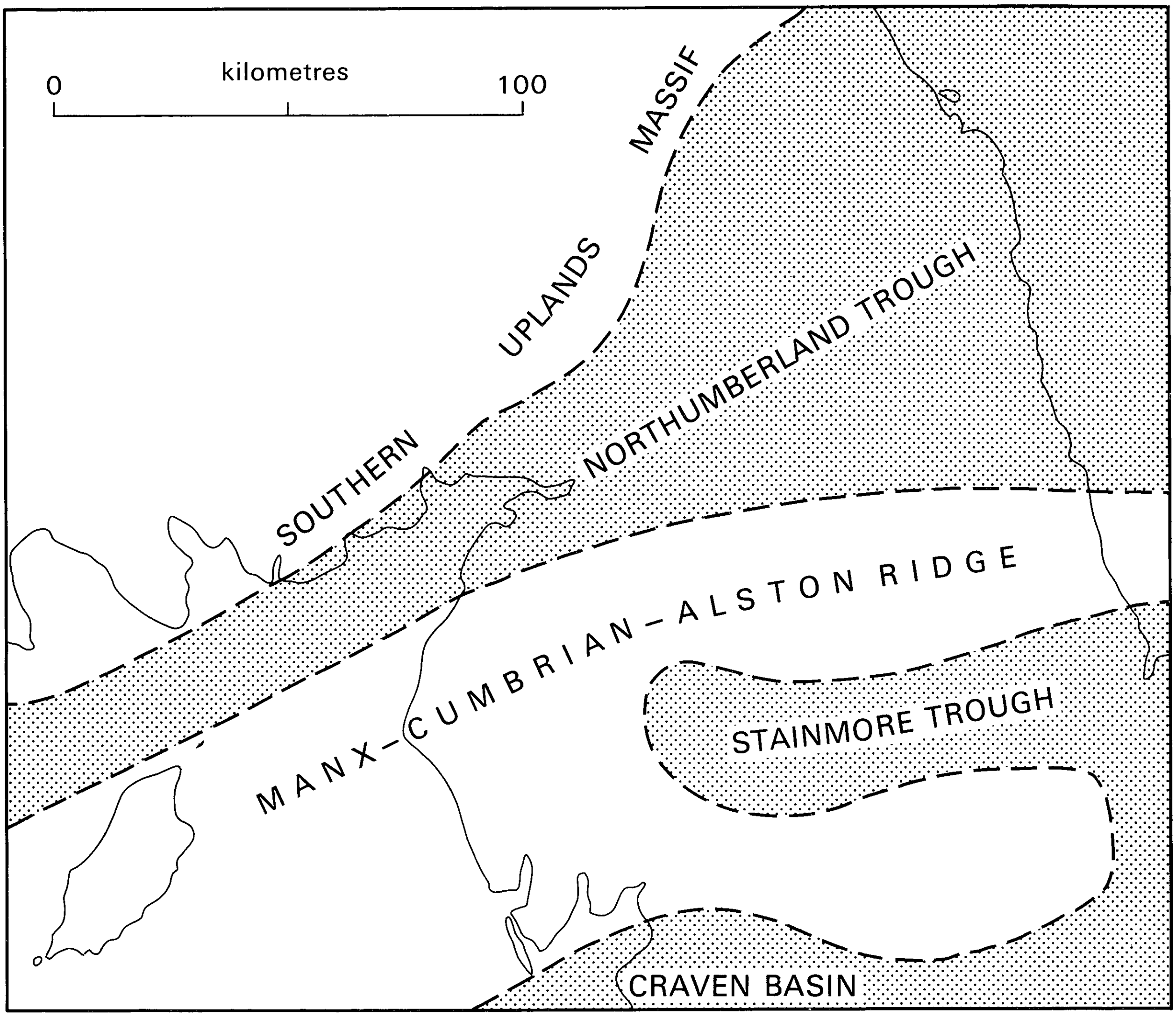


Figure 3 Simplified palaeogeography of the Lower Carboniferous

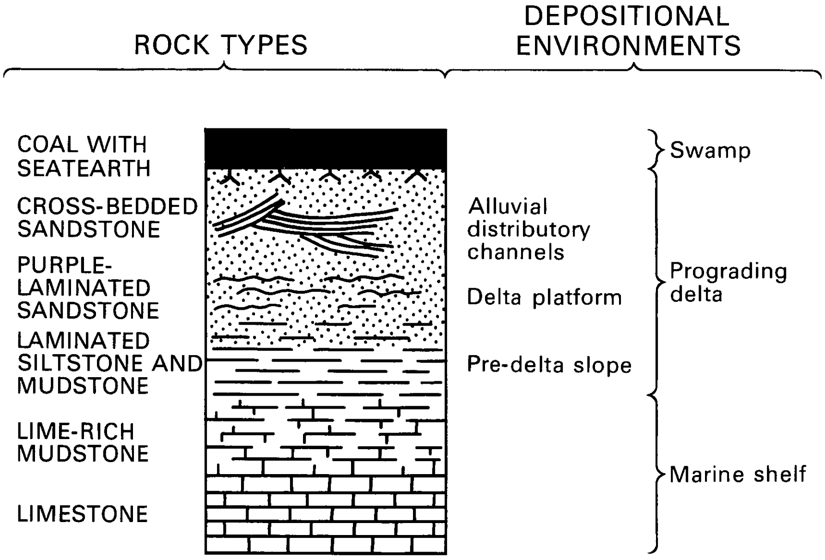


Figure 4 Idealized Yoredale cyclothem

local needs only though large quarries were worked at Wardhall and High Close to produce both burnt lime and limestone flux for the Workington Steel Works. Limestone is today quarried on a large scale at Moota Quarry for aggregate, roadstone and as a raw material for lime-silica bricks.

Some other minerals have been of minor interest in the past. These include sandstones from both the Carboniferous and Triassic formations which have been worked, mainly on a small scale, for local building stone. Small quantities of glacial sand and gravel have also been obtained locally. Trials have been made on baryte veins in the Namurian Hensingham Group west of Gilcrux.

Although coal mining was formerly extensive in the western and northern parts of the district no large scale urban development has taken place here. The relatively large 'pit' villages of Dearham and Crosby developed around and near to the collieries but large-scale industrial and urban developments were concentrated south east of the district along the coast south of Maryport. Today these villages serve mainly as dormitory settlements for a population largely employed outside of the district.

GEOLOGICAL HISTORY

The geological succession in the Dearham and Gilcrux area is summarised in Table 1. With the exception of the Triassic St Bees Sandstone in the north west all the solid rocks at outcrop are of Carboniferous age. No older rocks have been penetrated by boreholes but approximately 1 km SE of the district the Lower Carboniferous rocks unconformably overlie sediments of the Ordovician Skiddaw Group.

In Lower Carboniferous times the district was part of a shallow tropical sea on the northern flanks of the recently submerged Lake District Massif of Ordovician and Silurian sediments, volcanics and intrusives. An episode of volcanic activity early in the local Carboniferous sequence is indicated by the Cockermouth Lavas, which crop out approximately 0.5 km south east of the district and which are almost certainly present beneath the eastern part of the district.

Note: Throughout this report national grid references are given as 6 or 8 figure co-ordinates. All lie within the 100km square NY.

Throughout much of the Lower Carboniferous, limestones, many of which contain abundant shell, coral and foraminiferal remains, were deposited over the area. Beds of shale sandstone and locally thin coal reflect temporary incursions of non-marine conditions. Later in the Carboniferous this non-marine influence became dominant. In Namurian times shales and sandstones were deposited in fluviatile and deltaic environments and in Coal Measures or Westphalian times coal seams developed from equatorial swamp forests. Throughout much of the Carboniferous, subsidence kept pace with sedimentation though there is evidence that a greater amount of subsidence occurred to the north east over the area of the Solway and Carlisle Basin than over the margins of the Lake District Massif to the south.

Uplift, folding and faulting took place towards the close of the Carboniferous period and some sub-aerial erosion occurred before the deposition of the thick sequence of predominantly red sandstones of the Triassic St Bees Sandstone. This latter formation is believed to represent alluvial plain deposits laid down by a series of large braided streams. In addition some dune sands are thought to have formed and in places within the St Bees Sandstone red mudstones with intercalations of salt (halite) are interpreted as having formed on coastal flats which were subject to periodic evaporation.

Later deformation during the Tertiary times folded and faulted the St Bees Sandstone. There is no record of further geological events until the Quaternary. During this period a late-Devensian (between 26 000 and 10 000 BP) 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 streams and beach deposits both of which are still forming.

LOWER CARBONIFEROUS - DINANTIAN

Classification

The Dinantian sequence of west Cumbria is dominated by limestone. Individual limestone formations have long been recognised and known in descending order as the Second Limestone, Third Limestone etc. Their naming in this order dates from the early days of west Cumbrian iron ore mining when successively lower limestones were encountered in shaft sinking and mine development. Strata between the limestones comprise mudstones and sandstones: one of the

<table>
<tr><th colspan="2">CHRONOSTRATIGRAPHY</th><th colspan="4">LITHOSTRATIGRAPHY</th></tr>
<tr><th></th><th>Mitchell et al 1978</th><th></th><th>Eastwood et al 1968</th><th>George et al 1976</th><th>This Report</th></tr>
<tr><td>NAMURIAN</td><td></td><td>FIRST LIMESTONE</td><td rowspan="9">UPPER CHIEF LIMESTONE GROUP</td><td></td><td></td></tr>
<tr><td rowspan="11">DINANTIAN</td><td rowspan="6">BRIGANTIAN (Zone D_2 of Garwood 1913)</td><td></td><td rowspan="11">CHIEF LIMESTONE GROUP</td><td rowspan="8">UPPER LIDDESDALE GROUP</td></tr>
<tr><td>SECOND LIMESTONE</td></tr>
<tr><td></td></tr>
<tr><td>THIRD LIMESTONE</td></tr>
<tr><td></td></tr>
<tr><td rowspan="2">FOURTH LIMESTONE</td></tr>
<tr><td rowspan="5">ASBIAN (Zone D_1 of Garwood 1913)</td></tr>
<tr><td></td></tr>
<tr><td>FIFTH LIMESTONE</td><td rowspan="3">LOWER CHIEF LIMESTONE GROUP</td><td rowspan="3">LOWER LIDDESDALE GROUP</td></tr>
<tr><td></td></tr>
<tr><td>SIXTH LIMESTONE</td></tr>
</table>

Figure 5 Classification of Lower Carboniferous

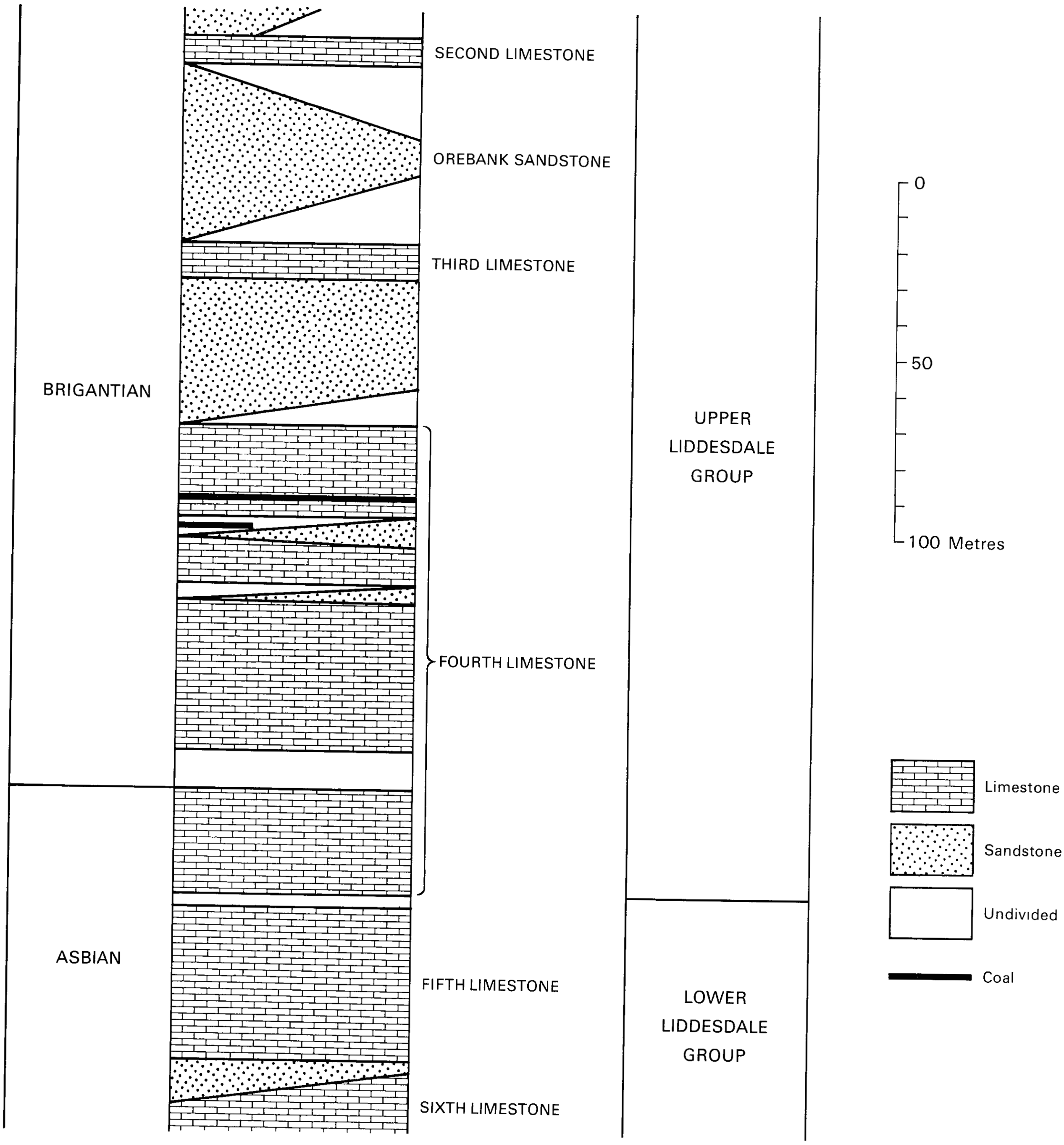


Figure 6 Generalized vertical section of Lower Carboniferous

sandstones, between the Second and Third Limestone is known as the Orebank Sandstone. Seven limestone formations are recognised in Cumbria. The uppermost, the First Limestone, is of Namurian age and is described on p 17. In the present district the lowest beds at outcrop belong to the top few metres of the Sixth Limestone: the Seventh Limestone does not crop out.

The chronostratigraphical and lithostratigraphical classification of the Dinantian rocks is summarised in Figure 5 and details of the sequence present in the district is shown in Figure 6. For correlations with the Lower Carboniferous of other parts of Britain see George *et al.* (1976). In this report the Geological Survey classification (eg Day 1970) of the Dinantian rocks of the Border counties into the Liddesdale groups is adopted to enable comparisons to be made with other areas. Detailed descriptions of the sequence in the district are given in Appendix 1.

Conditions of deposition and sedimentology.

The basement surface on which the Lower Carboniferous deposits of northern England were deposited was characterised by structurally contrasted areas (Figure 3). During Carboniferous times the area lay within the tropical belt. Areas of relatively rapid submergence formed 'troughs' or 'basins' between 'blocks' or 'massifs' which subsided much more slowly. Markedly different stratigraphical sequences, both in thickness and lithological composition, were deposited in each of these areas. The boundaries between 'troughs' and 'basins' were comparatively narrow hinge zones along contemporary fault lines. In northern England a broad 'trough', the Northumberland Trough, extended from the area of the present Solway across the whole of Northumberland and into the area now occupied by the North Sea. An area of relatively buoyant rocks formed a 'block' area, the Manx-Cumbrian-Alston Ridge, extending from the Isle of Man across the Lake District and into the present northern Pennines, with further 'troughs' to the south in the Stainmore and Craven areas. Lower Carboniferous sedimentation started earlier in the 'troughs' than on the 'blocks', though these too were submerged by Asbian times. A land mass lay to the north of the Northumberland Trough, in a position now occupied by the Southern Uplands. From this, abundant, though intermittent, supplies of terrigenous sediment were transported southwards throughout the Lower Carboniferous.

The present district occupies a position on the northern margin of the Manx-Cumbrian-Alston Ridge. At the base of the local Lower Carboniferous sequence the Cockermouth Lavas are evidence of volcanic activity represented by several flows of olivine basalt.

The Lower Carboniferous sediments of northern England record an interplay of marine and deltaic influences. A cyclical repetition of lithologies: limestone, mudstone, sandstone and locally coal, may be explained by alternating periods of relatively slow and rapid subsidence. During the former period delta lobes advanced across the area from the north depositing mud and sand. Occasionally deltas were built up to above sea level so allowing the formation of swamp forests now represented by coal seams. More rapid subsidence allowed warm clearer water from the south to overwhelm the deltas and led to the deposition of marine limestones. The sequence of rocks deposited during each such cycle of events is termed a cyclothem. The ideal Yoredale cyclothem is shown in Figure 4.

In this district the Lower Liddesdale Group and lowest part of the Upper Liddesdale Group consist predominantly of limestone indicating that non marine influences were comparatively weak at this time. Rhythmic sedimentation within an essentially limestone environment is recorded in the observed upward sequence of calcareous shale, dark grey limestone and light grey or white limestone within the Asbian. Ramsbottom (1973) ascribed this cyclicity to worldwide (eustatic) changes of sea level. In his model, marine transgressions were marked by marine bioclastic limestones; regressions by algal, dolomitic and fine-grained limestones, shales and sandstones. In some areas emergence is indicated by non-sequences, minor unconformities and local breccia beds. Ramsbottom (1977, p 282) grouped these rhythmic units or cyclothems into a series of major cycles or mesothems (each of which may be recognized by a distincitve fossil assemblage).

Deltaic advances were more pronounced in the Upper Liddesdale Group with limestones becoming relatively subordinate. Elements of the classicial Yoredale cyclothems of the Pennines (eg Dunham 1950, Johnson 1960, Ramsbottom 1973) may be recognized.

Limestone

Because of its ease of application in the field and in examination of hand specimens Dunham's (1962) classification of carbonate rocks is adopted in this report.

Wackestones were described by Dunham (1962) as limestones 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. The limestones of this district are almost all wackestones in which crinoid fragments occur in a 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. None of the limestones of the present district contain sufficient coarse clastic material to warrent the use of this term except perhaps very locally where very small concentrations of coral or shell debris occur.

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.

Many beds of nodular limestone are present in the district. The nodules are almost certainly primary features of the sediment and thus such rocks are probably best considered as grainstones in Dunham's classification.

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 though 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.

Where free of superficial deposits most of the limestones give rise to distinctive landscape features. The Fourth and Fifth limestones in particular typically form terraced hillsides with low limestone crags alternating with grass covered slack features marking the outcrop of the thin interbedded mudstones, siltstones and sandstones. Swallow holes are common both on drift-free outcrops and in areas where limestone is present beneath drift or a thin cover of solid rocks. The thin soils of the limestone outcrops support a characteristic limestone grassland flora.

Mudstone and siltstone

Thin beds of medium grey, commonly calcareous mudstone, up to 0.1m thick are locally interbedded with some limestones. Bentonitic characteristics have been noted in some of the Asbian shales of West Cumbria (Walkden, personal communication in Mitchell *et al.* 1978, p175). These have been interpreted as the products of accumulated air-borne 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 Arundian age, beneath the Seventh Limestone indicate volcanic activity which could have continued nearby in Asbian times. Bentonitic clays may therefore be present in some of the mudstones interbedded with the limestones.

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

Sandstone

Fine to medium-grained sandstone occurs between most of the limestones. In the Asbian and lowest Brigantian, sandstones are subordinate in thickness to limestones. In the upper part of the Brigantian they are thicker, with the sandstones between the Second, Third and Fourth Limestones locally comprising the bulk of the sequence. Most of the sandstones are fine to medium-grained very pale brown rocks, though coarse-grained sandstones are present in places. Some are characterised by a hard siliceous cement and may be regarded as ganister. Traces of cross-bedding may be seen in some exposures.

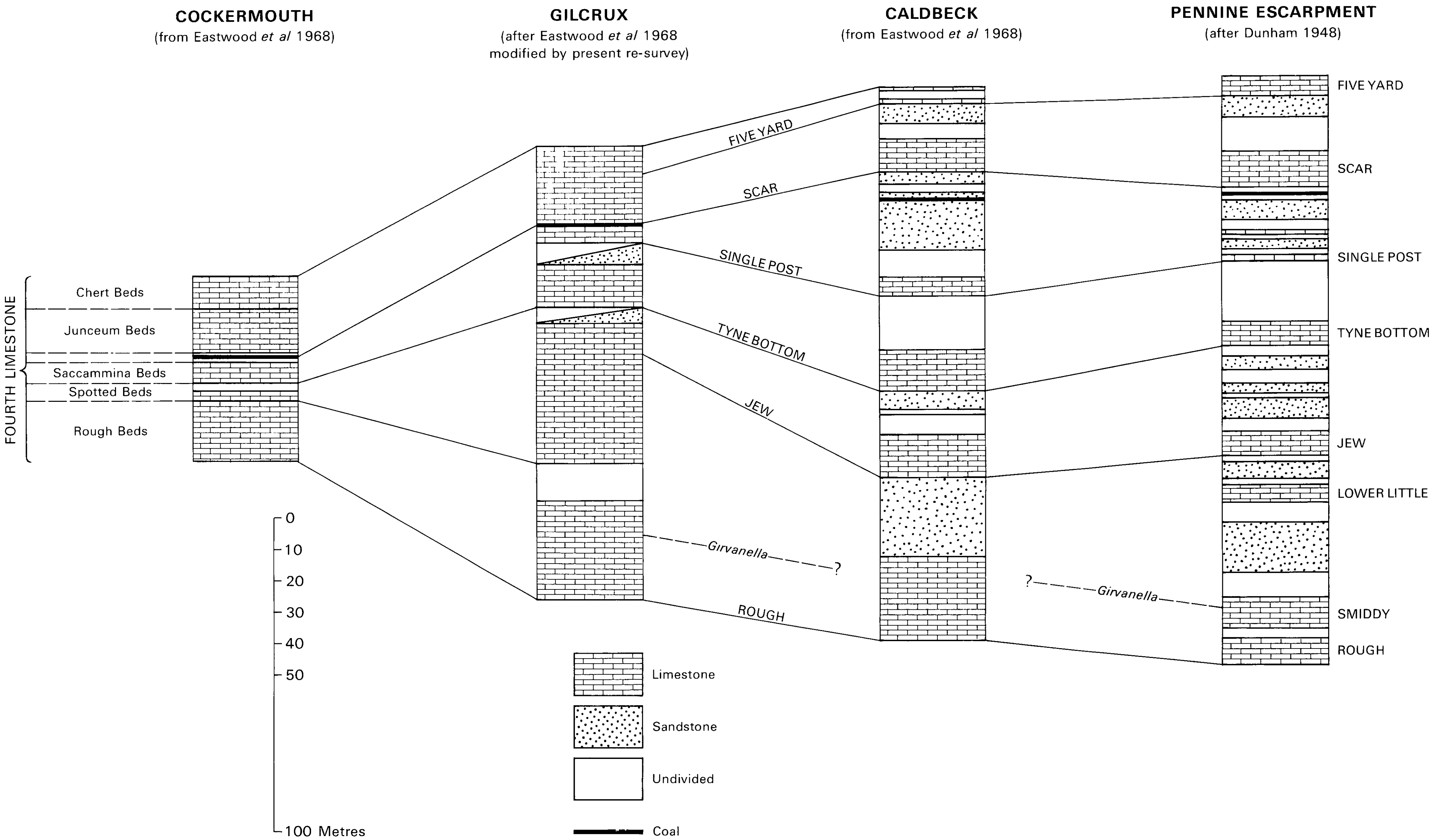


Figure 7 Correlation of Fourth Limestone of the district with the Cockermouth, Caldbeck and northern Pennine successions

Chert

Fine grained silica in the form of chert occurs as irregular and flattened ovoid nodules up to 0.15 m across in the lowest few metres of the Fourth Limestone on the south side of Moota Hill [1488 3561 and 1477 3573].

Coal

Thin coals up to 0.2 m thick were noted within the Fourth Limestone by Eastwood *et al.* (1968). These are no longer exposed and none were seen during the resurvey.

Stratigraphy

The stratigraphical classification adopted here for the Lower Carboniferous has been outlined above (see Figures 5 to 7). Descriptions which follow and in Appendix 1 are based both on observations made during the resurvey and those given by Eastwood *et al.* 1968 some of which have been revised in the light of more recent work. Faunal lists given here have been obtained from existing publications with minor revisions.

Lower Liddesdale Group

Sixth Limestone and overlying beds In its western and northern outcrops on the Cockermouth Sheet this division varies in thickness from 24 to 37 m (Eastwood *et al* 1968, p 155). Only the upper 20 m crop out in the area described in this report. Limestone, assigned to the Sixth Limestone, is exposed in a quarry at Parsonby [1453 3826] though much of the mapped outcrop is here concealed beneath boulder clay. Mapping indicates the presence of Sixth Limestone beneath boulder clay in the extreme south of the area, south of Moota Hill [around 143 351].

In the single exposure of this limestone in this area the rock is a compact dark grey rock. Elsewhere in the Cockermouth area Eastwood *et al.* (1968) record white limestone in the upper part with some beds of shale and in places a thin coal seam. The limestone is overlain, in this area, by thin shales and sandstones (see Appendix 1).

Fifth Limestone and overlying beds This limestone is estimated to be some 40 m thick. The Fifth Limestone forms wide outcrops in the extreme east and south east of the district. Although much covered by boulder clay sections are exposed in abandoned quarries at High Close [1461 3809] and near Parsonby Brow [1433 3833, 1464 3745 and 1416 3809].

Within the district much of the Fifth Limestone consists of thickly-bedded massive grey limestone though beds of nodular limestone also occur, especially near the top, where they alternate with more massive beds.

Beds overlying the Fifth Limestone, estimated to be up to 14 m thick, comprise mainly mudstone.

Upper Liddesdale Group

Fourth Limestone and overlying beds Following the practice of previous workers, notably Eastwood *et al.* (1968) the term Fourth Limestone has been retained for the 130 m or so of strata, composed predominantly of limestone, which overlie the Fifth Limestone and mudstone. A generalised succession for the Fourth Limestone of the district is given in Figure 6. From this it is clear that limestone is the main lithology though interbedded units of sandstone and mudstone are important and thin coals have been noted locally in the upper part of the sequence. Both thickly bedded massive limestones and markedly nodular limestones are common. Up to 40 m of sandstone, with a few metres of shale at the base locally, overlie the Fourth Limestone. Medium to coarse-grained gritty sandstones are present north of Wardhall Common [140 373]: fine grained siliceous ganister is present near Millstone Moor [135 360].

The Fourth Limestone succession of the present district is intermediate between the west Cumbria sequence which is composed almost exclusively of limestone and the Caldbeck and Pennine areas where characteristic rhythmic "Yoredale" cyclothems are well developed. A correlation with these other areas is given in Figure 7. More details of the Fourth Limestone sequence and its correlation with other districts are discussed in Appendix 1. The Fourth Limestone forms a wide outcrop in the east and south of the district. Natural exposures are common and there are numerous abandoned quarries in both the limestone members and locally in the interbedded sandstones. Quarrying continues today in the Fourth Limestone at Moota Quarry [146 363].

Third Limestone and overlying beds The Third Limestone is up to 10 m thick. It forms narrow outcrops in the east and south of the area but is generally poorly exposed. It is typically a dark grey limestone with abundant scattered crinoid debris. In most places it may be classified as a wackestone though in a few samples the crinoid fragments are sufficiently abundant to merit the term packstone.

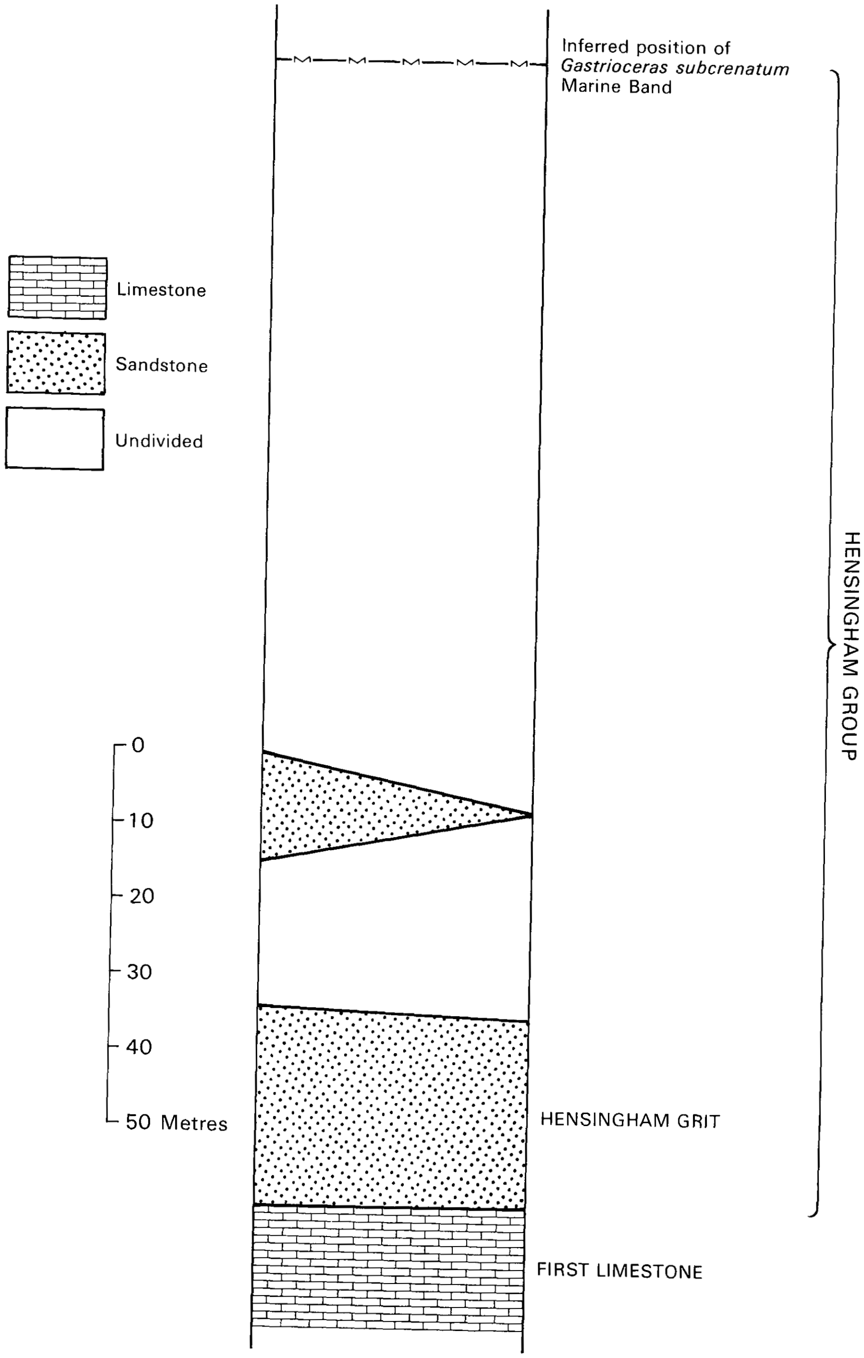


Figure 8 Generalized vertical section of Namurian

Up to 50 m of beds overlie the Third Limestone. These were collectively referred to the Orebank Sandstone by Eastwood *et al.* (1968, p 159). Although little detail is known about their composition in the present district it is clear that shales locally comprise an important part of this sequence. In this report the term Orebank Sandstone is preferred only for the well-marked sandstone which overlies the limestone.

Second Limestone and overlying beds This Limestone, which is up to 8 m thick, forms very narrow boulder clay-covered outcrops in several of the fault blocks south of the Gilcrux Fault. It comprises mainly grey limestone with scattered crinoid debris. Exposures are few except in the south of the district.

UPPER CARBONIFEROUS - NAMURIAN

Classification

The Namurian sequence of the district is shown in Figure 8. Detailed descriptions of the sequence present within the district are given in Appendix 2. The lowest formation is the First Limestone which was included with the Chief Limestone Group in previous classifications (eg Eastwood *et al.* 1968 and Barnes *et al.* 1985). The strata above the First Limestone up to the inferred position of the *Gastrioceras subcrenatum* Marine Band are known as the Hensingham Group with a thick sandstone unit, the Hensingham Grit, at the base.

Conditions of deposition and sedimentology

The broad regional structural framework of 'troughs' and 'blocks' established in Dinantian times persisted into the Namurian. The alternation of marine limestone deposition with increasingly important influxes of deltaic sediment established in the latter part of the Dinantian continued into the Namurian. The basal formation of the Namurian, the First Limestone, marks the last significant period of marine limestone formation. Above this, in the Hensingham Group, clastic sediments are dominant as deltaic influences assumed increasing importance. Occasional periods of marine influence are represented by thin beds of limestone or mudstone which yield a characteristic fauna. The establishement, albeit relatively briefly, of such marine conditions affected a very wide area. The marine beds so deposited are therefore of great value for regional correlation. The Namurian strata represent a transition from the predominantly marine conditions of the Dinantian to the almost exclusively freshwater deltaic environments of the Westphalian.

The basal member of the Hensingham Group known as the Hensingham Grit has been interpreted as a near-coast deposit (Ramsbottom 1978, p 179).

The Hensingham Group is very poorly exposed not only in the district but throughout its outcrop in west Cumbria and relatively few boreholes have penetrated it. It is thus the least well known part of the Carboniferous sequence. However the limited amount of data available suggest that the group is subject to considerable variations in thickness. Smith (1921) records at least 488 m of beds assigned to the Hensingham Group in the Bank End and Blue Dial boreholes [0512 3845 and 0724 4067]. In neither borehole was the base of the Group proved. At Crosby the Hensingham Group has thinned to approximatley 158 m and at Aspatria, immediately north of the district a similar thickness is recorded. Eastwood (1939) attributes this thinning to the development of an east-north-east trending anticlinal ridge soon after the deposition of the First Limestone. Eastwood *et al.* (1968, p 81) suggest that there is clear evidence for the progressive thickening of the Hensingham Group northwards into a southwesterly extension of the Northumberland Trough as advocated by Trotter and Hollingworth (1927).

Limestone

The details of limestone lithologies in the Dinantian apply equally here. The First Limestone is generally a medium grey thickly-bedded wackestone with scattered crinoid and shell debris.

Sandstone

The best exposed and hence the most well known sandstone in the sequence is the Hensingham Grit. This is typically a coarse- to very coarse-grained thickly bedded massive sandstone in which kaolinised feldspar grains are common. Pellets of earthy hematite or hematite-rich shale up to 2cm across are present locally. Fine-grained, rather flaggy, sandstones occur higher in the Namurian sequence.

Mudstone

Dark grey mudstones, locally with brachiopods crop out near Gilcrux. Clay ironstone nodules are present in some of the mudstones. Silty

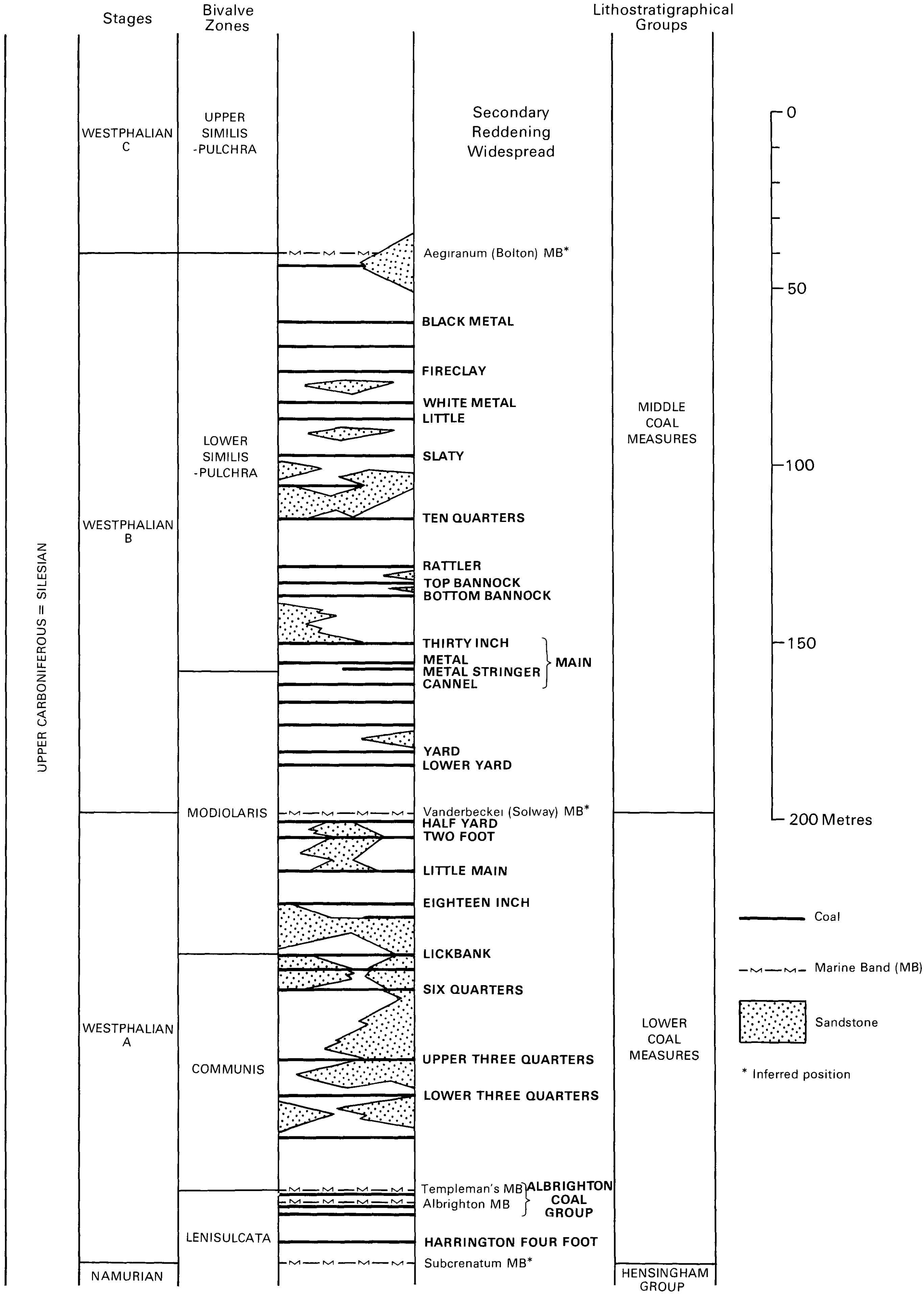


Figure 9 Generalized vertical section of Westphalian

mudstones with plant fragments have also been recorded.

Stratigraphy

The First Limestone of Cumbria is the equivalent of the Great Limestone of Northumberland and the northern Pennines and the Main Limestone of the Yorkshire Pennines. It belongs in the Pendleian Stage (E_1) of the Namurian. Because so little detail is known about the Hensingham Group sequence it is difficult to suggest reliable correlations with other areas. However the limited evidence available from elsewhere in Cumbria indicates that the Group belongs to the Pendleian and Arnsbergian Stages. The position of the stage boundaries within the succession of the present district is unknown: and no attempt has been made to suggest their presence on figure 8. In places in Cumbria much higher beds, belonging to the Yeadonian Stage yield *Gastrioceras cumbriense*. A considerable non-sequence, in which four Namurian stages are absent is thus indicated (Ramsbottom 1978, p 179). It is not known whether higher beds of Yeadonian age are present in this district.

Details of individual formations including descriptions of exposures are given in Appendix 2 (p 45).

First Limestone

The First Limestone which is up to 15 m thick typically consists of a medium grey, thickly bedded limestone. Thin shaly partings along uneven or wavy bedding planes are common. The wide outcrops of First Limestone in the faulted ground south of the Gilcrux Fault are considerably obscured by a cover of boulder clay. Natural exposures may be seen on Tallentire Hill [120 358], Top Wood [133 362] and Wardhall Common [137 371] and in several abandoned quarries.

Hensingham Group

The term Hensingham Group is applied to the whole of the Namurian succession above the top of the First Limestone.

In this district the basal member of the Hensingham Group is the Hensingham Grit. This has a maximum thickness of 25 m and forms wide outcrops south of Gilcrux. Where seen in the Top Wood [133 367] and Gilcrux [117 376] areas the Hensingham Grit is typically a coarse-grained gritty, rather feldspathic sandstone. Elsewhere its outcrops are concealed beneath boulder clay.

The 125 m of beds which are estimated to comprise the remainder of the Hensingham Group are very poorly known both in this district and elsewhere in Cumbria. Although they occupy wide outcrops south and south west of Gilcrux they may be seen only in a very few widely scattered exposures, the best of which are in Rose Gill [0910 3740] and Leathers Gill [1250 3800].

UPPER CARBONIFEROUS-WESTPHALIAN (COAL MEASURES)

Classification

A generalised section of the Coal Measures (Figure 9) is based on the description of these rocks by Eastwood (1930) and on the revision by Taylor (1961). Details of the sequences within the district are given in Appendix 3. The base of the Coal Measures is drawn at the presumed position of the base of the Subcrenatum Marine Band, the preserved sequence within the Dearham-Gilcrux area extending some distance above the inferred position of the Aegiranum Marine Band.

Conditions of deposition and sedimentology

Fluvial and deltaic sedimentation established in the district during the Namurian (p 15) became dominant during the deposition of the Coal Measures. Although the sea was largely excluded, there were periodic, short-lived but widespread marine incursions, probably associated with eustatic fluctuations of sea-level. The Coal Measures sequence is cyclic, and can be regarded as being constructed from many individual cycles, each approximating to an ideal form in which fossiliferous mudstone is overlain by unfossiliferous mudstones and sandstones, succeeded by a seatearth with a coal seam at the top (Figure 10). Cycles are in reality commonly incomplete and may vary laterally. They may die out or conversely a single cycle may split, giving rise to additional cycles. The Coal Measures sediments are dominantly argillaceous, with the bulk of the strata consisting of mudstones, silty mudstones or very fine-grained sandstones. The coarser grained sandstones are in places pebbly and commonly represent fluvial channel-fills. The bases of sandstones may therefore rest on the eroded surfaces of subjacent strata, and this may account for the absence of otherwise persistent coal seams in certain areas.

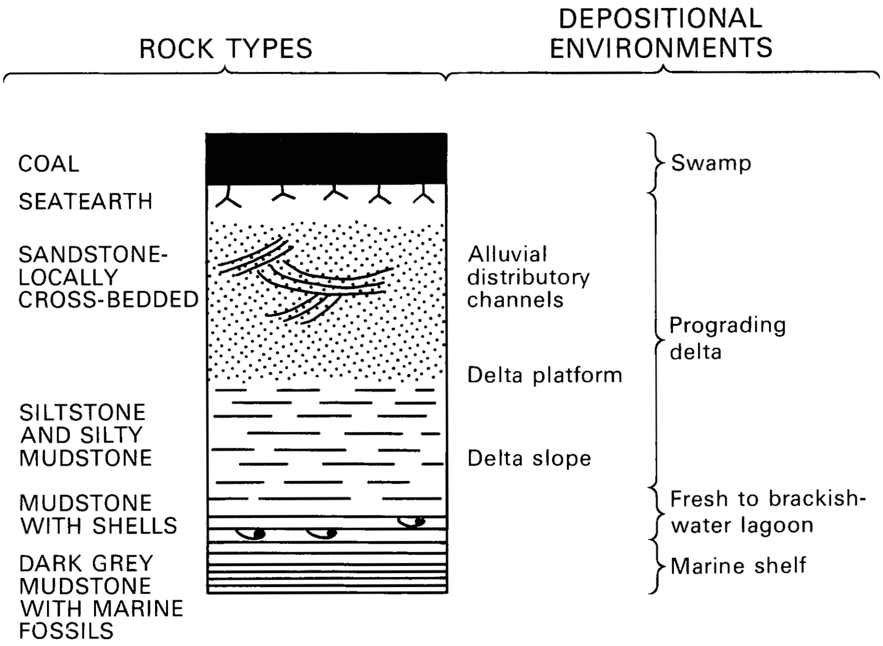


Figure 10 Idealized Coal Measures cyclothem

Reddening

The higher part of the Coal Measures sequence is characterised in the area, as elsewhere in Britain, by the presence of red colouration. Such red strata were formerly categorised as the Whitehaven Sandstone 'Series', and were regarded as a formation distinct from, and unconformable upon the 'Productive Coal Measures' (Eastwood 1930). It was subsequently shown (Taylor 1961) that the reddening was a secondary effect superimposed on the normal grey measures and related to intense oxidation below a pre-Permian land surface at a time when the climate was arid and the watertable markedly depressed. It is not known to what extent this reddening or oxidation affects the engineering properties of these rocks, if at all.

Stratigraphy

The following account (also see Appendix 3 p 47) is based on the descriptions by Eastwood (1930) and Taylor (1961), with subsequent revision of borehole correlations, examination of mine plans and assessment of available information from opencast exploration. With one stated exception faunal lists are based on Taylor (1961) and have not been revised.

Stratigraphical summary (see Appendix 3 for details)

Lower Coal Measures

This division, about 130 m thick, lies between the inferred position of the *Subcrenatum* Marine Band (at the base) and the inferred position of the *Vanderbeckei* Marine Band. The strata are mainly mudstone with thick, but commonly impersistent, sandstone beds.

There are some ten named, and economically important, coal seams ranging from 0.23 m to 0.82 m in thickness (see Figure 9). The Lickbank and Three Quarters seams have been economically the most important and reserves of these two seams may remain in the area.

The Lower Coal Measures are exposed sporadically along the valley of the River Ellen between the Dearham and Mother Pit Faults, and also in the lower part of Row Beck north of Dearham.

Middle Coal Measures

This division attains a thickness of about 225 m in the Dearham and Gilcrux area, but is incomplete: Triassic strata rest unconformably on the eroded top. The upper 65 m of the Middle Coal

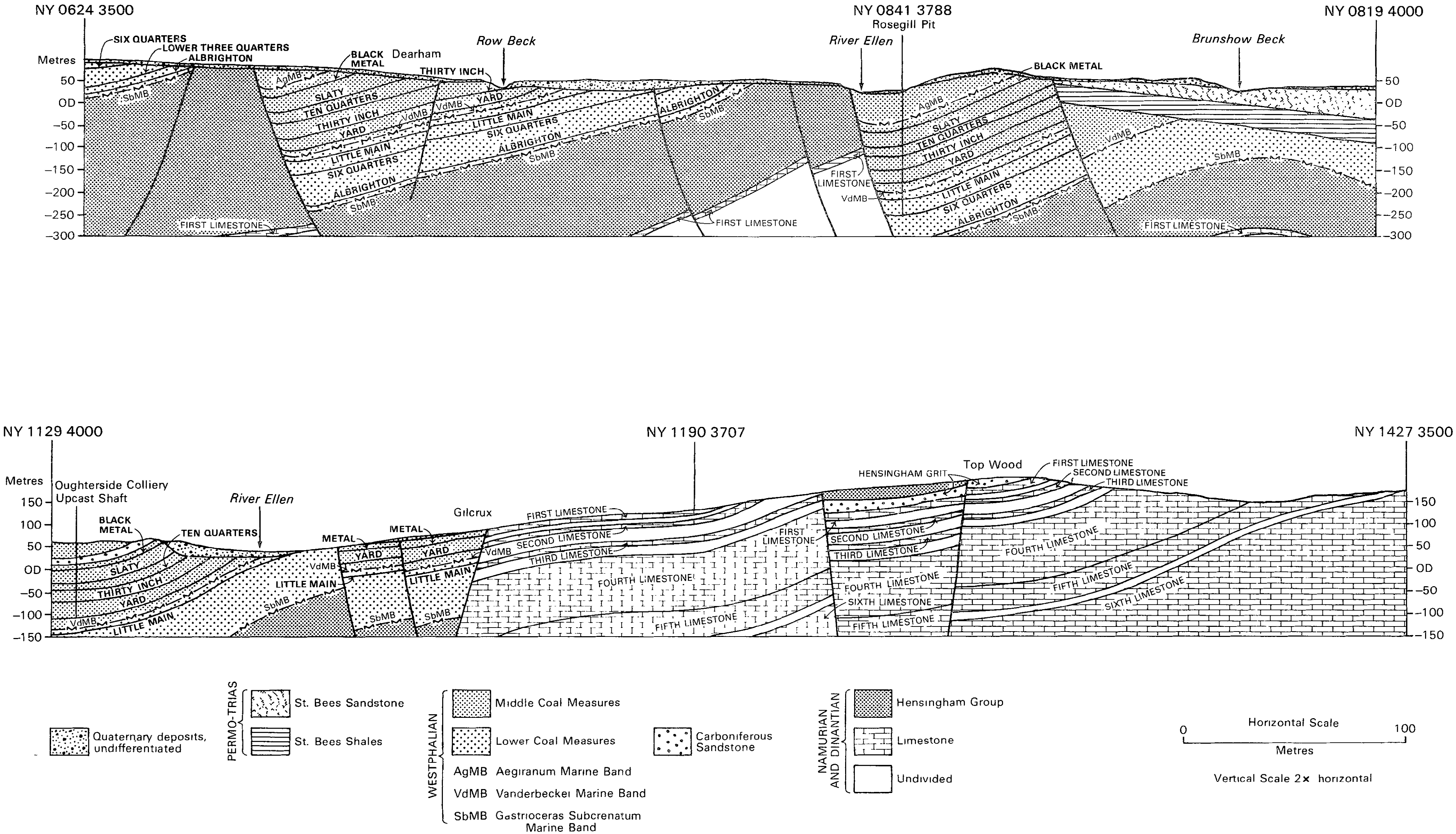


Figure 11 Horizontal sections

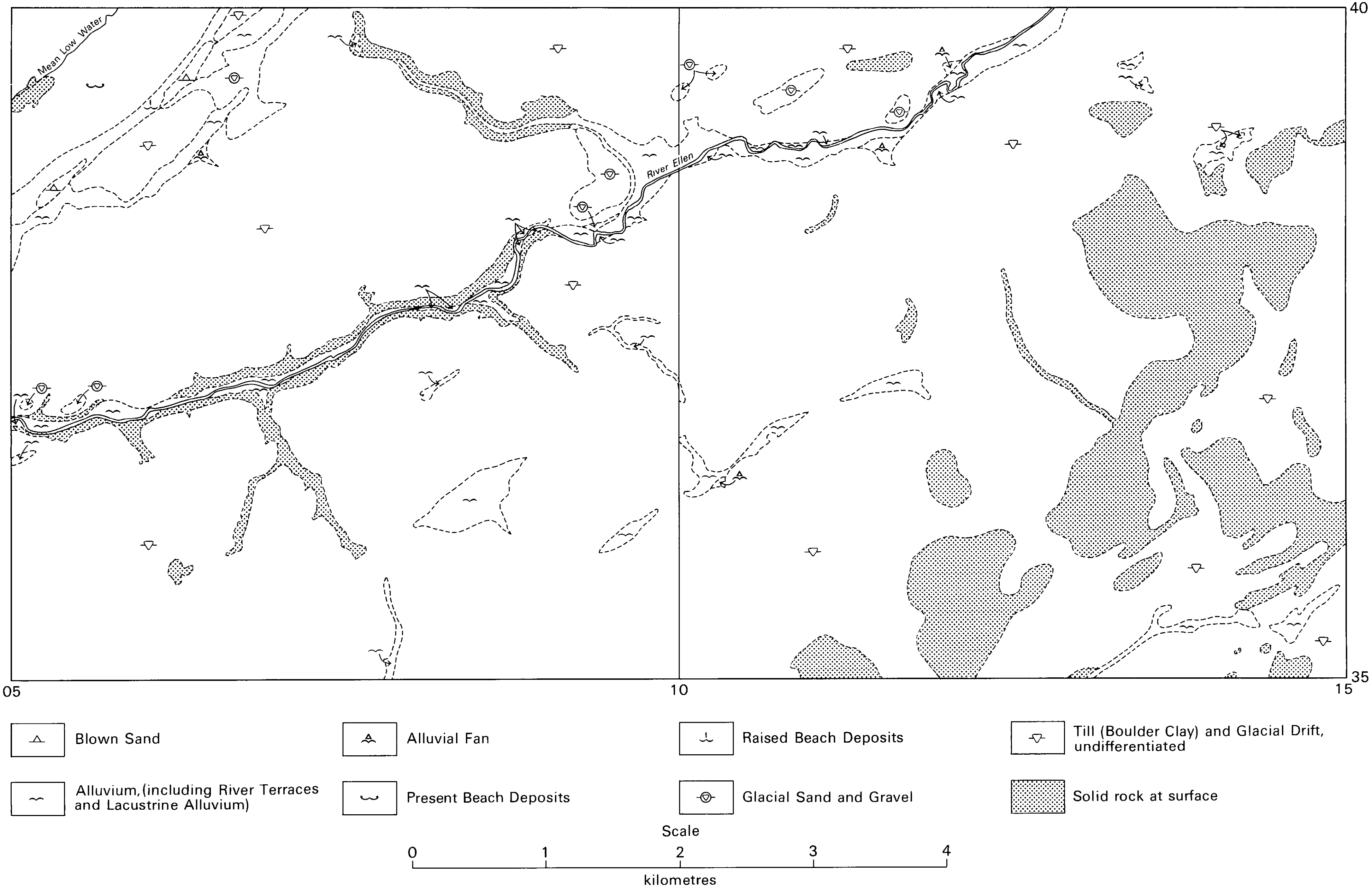


Figure 12 Quaternary deposits

Measures is secondarily reddened below the unconformity and is of little economic value.

The strata are mainly mudstones with interbedded sandstones which are generally impersistent. Near Dearham there are exposures along the Row Beck and also in its tributary Garley Gill. In the valley of the River Ellen strata of the Middle Coal Measures are exposed in a north bank tributary between the Mother Pit and Rosegill faults. Upstream from the Rosegill Fault reddened strata high in the division are visible in riverside exposures.

Some ten named seams have been worked in the past the most important of which has been the Main Band. This coal has a tripartite structure containing three leaves called in ascending order the Cannel, the Metal Band and the Crow seams with variable thicknesses of intervening measures. Each leaf may exceed 1m in thickness and the aggregate thickness of the Cannel and Metal Band at Dearham is about 2.70 m. Recently it has been worked in the Oughterside Opencast Site [NY 110 400].

The Ten Quarters Seam has also been widely worked within the district and is of excellent quality.

PERMO-TRIASSIC

Classification

Permo-Triassic rocks are confined to the area north-west of the Maryport Fault and comprise the St Bees Shales and the St Bees Sandstone. The basal mudstone formation, the St Bees Shales, which is only known from boreholes, rests unconformably upon the Coal Measures. In south and west Cumbria the St Bees Shales are considered to be of Permian age. The higher beds, however, may be of Triassic age (Arthurton *et al.*, 1978). The younger St Bees Sandstone, which is wholly of Triassic age, occupies the entire surface outcrop of the Permo-Triassic rocks north of the Maryport Fault.

Conditions of deposition and sedimentology

Towards the close of the Carboniferous period extensive deformation took place which was accompanied and followed by uplift and erosion. Permian and Triassic strata, predominantly red in colour, were laid down in intermontane basins which coalesced eventually to bury the Carboniferous land surface. The St Bees Shales represent sediments laid down in a coastal plain environment marginal to an area of marine sedimentation now the site of the Irish Sea. The overlying St Bees Sandstone marks an influx of coarser sediment laid down on alluvial plains traversed by large braided rivers.

Stratigraphy

The major stratigraphical subdivisions are summarised below. More detailed descriptions of the sequence in the district are given in Appendix 4.

St Bees Shales

This formation is not exposed but is known from boreholes to comprise some 80 m of red mudstones with a thin breccia at the base.

St Bees Sandstone

This formation consists mainly of fine-grained reddish brown, laminated and locally cross-bedded sandstone. The total thickness of the St Bees Sandstone in the area is about 100 m. Outcrops of thickly-bedded and cross-bedded sandstone occur on the coast north of Bankend [050 392] and in disused quarries [0760 3990] north east of Crosscanonby.

STRUCTURE

The Carboniferous rocks of the area are cut by two principal sets of faults, one trending north-westwards and the other with trends varying between east-west and east-north-eastwards. The principal faults shown on the geological map are proved from coal-mining evidence to be accompanied by an even greater number of minor faults parallel to the principal trends. Members of both sets of faults truncate fold structures, although it is possible that faults and folds developed simultaneously. The north-west trending faults throw down both to the south-west and to the north-east whereas the complimentary set approximately at right angles throw down mostly, but not exclusively, to the north.

The neighbourhood of Maryport marks a transition between an area to the south in which faults of north-west trend are dominant (Barnes *et al.*, 1986), and the Dearham-Gilcrux area in which faults of east-north-east trend assume a greater importance. Contemporaneous faulting on east-north-east lines, with accompanying deformation in the marginal zone may have affected the deposition of Lower Carboniferous sediments. Subsequent re-activation of such faults in late or post Carboniferous times may have given rise to the existing fault pattern.

There is no direct evidence of contemporaneous faulting of Carboniferous age. However Eastwood (1930) concluded that an anticline (or dome) in the area of the Crosby Borehole west of Allerby was initiated following the deposition of the Namurian First Limestone, thus accounting for the known variations in the thickness of the Hensingham Group between the Crosby area and the Hayborough-Bankend area where the strata are much thicker.

All faults in the Dearham-Gilcrux area are known to displace various horizons within the Carbonifeorus sequence and therefore the latest fault movements are no earlier than the late Carboniferous. The juxtaposition of the secondarily reddened Coal Measures strata against the Hensingham Group along the Gilcrux Fault where it crosses Rose Gill, and also along the Mother Pit Fault south of Rose Gill Mill, may be of significance in this connection. As the reddening does not appear to cross these faults it may be concluded that final fault movements postdate the reddening and are therefore probably of Permian or later age. Final movement along the east-north-east trending Maryport Fault which brings Coal Measures against St Bees Sandstone is clearly no earlier than mid-Triassic, although early or pre-Triassic initiation of movement may have taken place.

All faults in the area are normal, hading in the direction of downthrow (Figure 11). The dip of the fault-planes is generally about 60 degrees to 80 degrees although shallower inclinations are known. Faults are generally multiple, a major fracture being accompanied by a zone of subsidiary faults, in places extending several metres on either side. The dip of the strata commonly steepens near a fault, in places becoming near vertical, as along the Dearham Fault.

In the ground south of the Gilcrux Fault the Carboniferous strata dip gently westwards towards the neighbourhood of Dearham where there is a broad south-plunging syncline adjacent to the large Dearham Fault, which throws down over 200 m to the east. West of this fault dips in the Hensingham Group and the overlying Coal Measures swing round towards the south-west. The Gilcrux Fault and its western offshoots have a general downthrow to the north of approximately 400 m. Between this important dislocation and the Maryport Fault the Coal Measures lie in structural basins truncated by the Mother Pit and Birkby faults, but possibly formerly co-extensive with the synclinal structure at Dearham. A considerable number of the faults affecting the Carbonifeorus rocks are shown on the geological map as terminating against the Maryport Fault. It is not known for certain how they relate to this structure and the fault pattern in the Carboniferous rocks below the Triassic is unknown. The fault-zone of the Maryport Fault has been detected only at the end of an inclined cross-cut driven north-westwards from Crosby Pit. The sparse data available suggest that the St Bees Sandstone north of the Maryport Fault dips to the north-west at angles up to 20 degrees. The south-easterly dips on the north-west flank of the synclinal structures adjacent to the Maryport Fault may well give way north-west of the fault to north-westerly dips as suggested by Eastwood (1930, p. 98).

MINERALISATION

Vein mineralisation is common particularly in the Lower Carboniferous rocks of the district though locally there is also evidence of mineralisation adjacent to faults in the Coal Measures. The distribution of mineralisation is shown on the Mineralisation map. Baryte is the commonest introduced mineral but copper, zinc and iron minerals are also known and traces of hydrocarbon mineralisation have been found. Nickel mineralisation within the Coal Measures is likely to be of diagenetic origin (ie the result of chemical and mineralogical changes within the strata since their initial deposition). Brief descriptions of the district's mineralisation are presented in Appendix 5.

Origins of the mineralisation

With the exception of the small amounts of sulphides present in clay ironstone nodules in the Coal Measures, the mineralisation in the district is clearly epigenetic (ie it post dates the host rocks). There is no evidence within the district to fix the date of the mineralising episode more precisely than post Carboniferous. However the mineral assemblages closely resemble those in many other deposits in and around the northern fringes of the Lake District such as those of Potts Gill and Ruthwaite. The mineralisation of the present district is thus likely to form part of this province. In a recent genetic classification of Lake District mineralisation Stanley and Vaughan (1982) proposed a late Carboniferous (Stephanian) to Permian date for this episode.

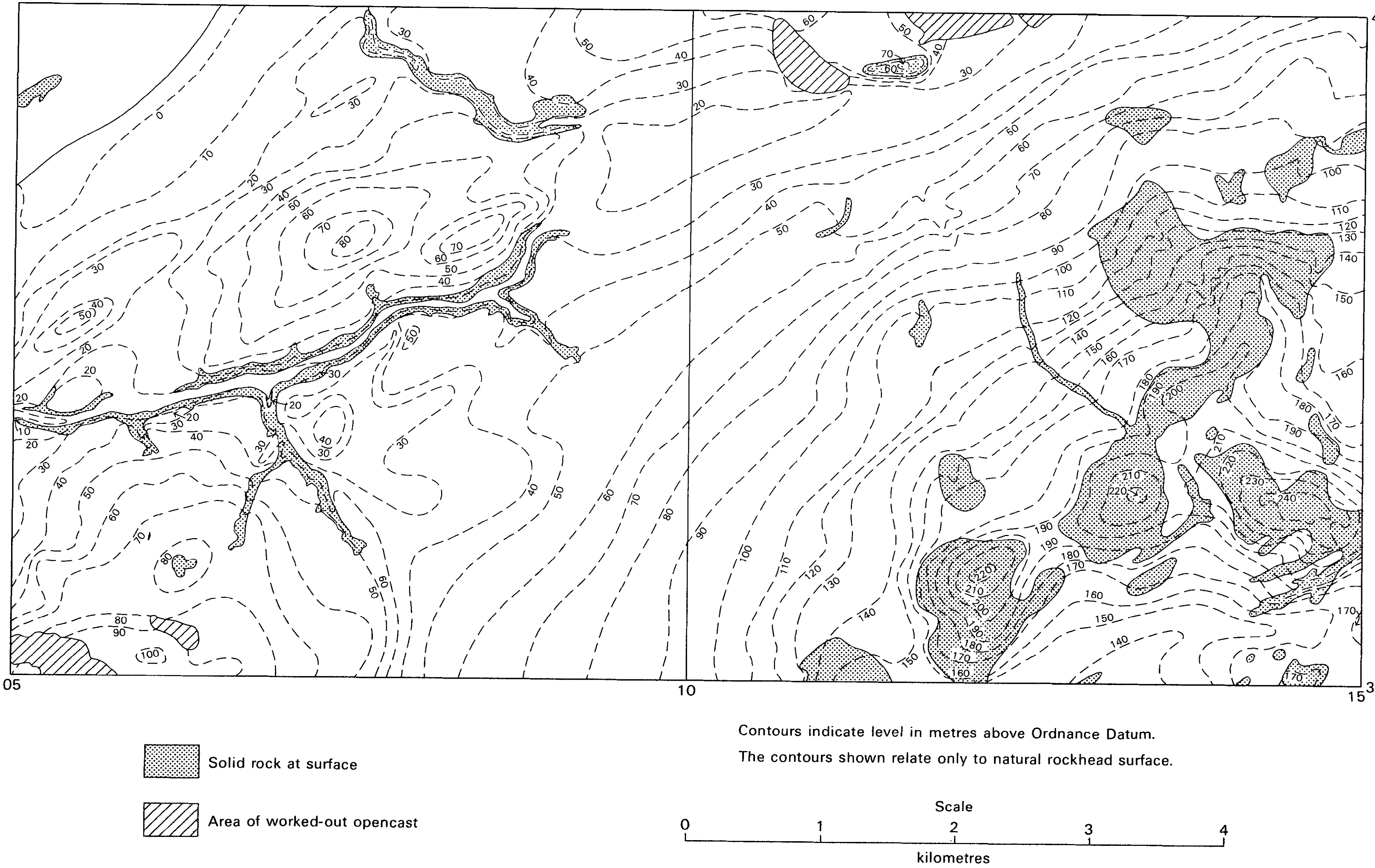
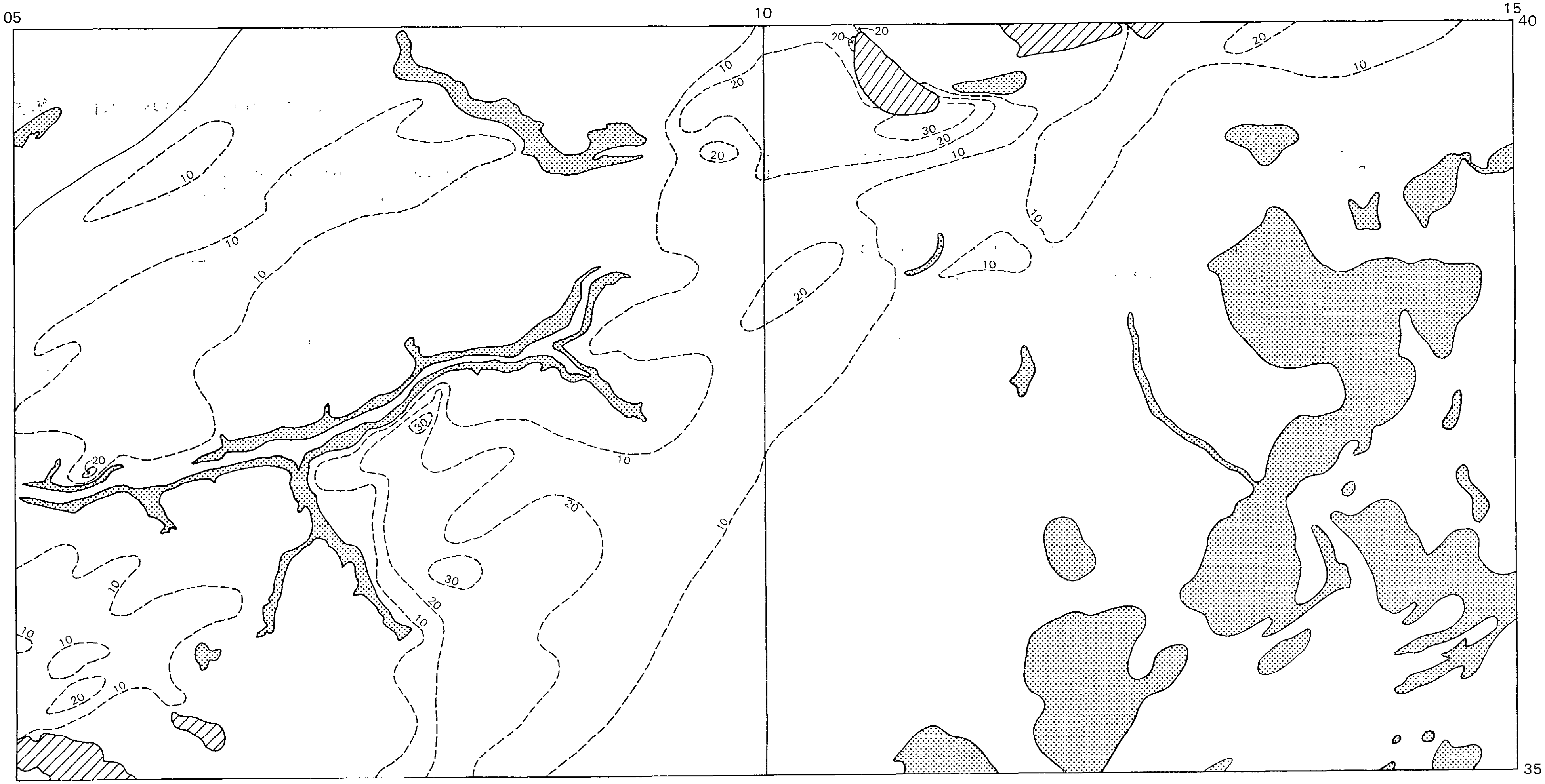


Figure 13 Rockhead elevation



Isopachytes at 10 metre intervals

The contours shown relate only to drift deposits and do not take into account made ground

Solid rock at surface

Area of worked-out opencast

Scale

0 1 2 3 4

kilometres

Figure 14 Drift thickness

It has already been mentioned (p 21 above) that the district lies astride an E-W belt of major faulting. Faults within this may have been active during Carboniferous sedimentation forming a hinge line separating an area of shallow water deposition to the south from a relatively deeper basinal environment to the north. The district thus has important similarities to such areas as Navan and Silvermines in Ireland (eg Hitzman & Large 1986, Phillips & Sevastopulo 1986 and Russell 1986) where major stratiform lead-zinc deposits occur in Lower Carboniferous limestone host rocks adjacent to faults which may have been active during sedimentaiton. Mineralisation seen at outcrop in the present district could be an expression of much more extensive mineralisation at depth, perhaps remobilised and introduced to the present structural level during very late Carboniferous or Permian times.

Resources

The district and adjoining areas could merit systematic investigation, initially by geophysical and geochemical methods, to investigate further the possibilities of base metal deposits at depth. The widespread occurrence of baryte in limestone wallrocks encourages search for economic concentrations of the mineral in this part of Cumbria.

QUATERNARY

Quaternary deposits include sediments of glacial and post-glacial origin (Figure 12). Glacial deposits consist mainly of boulder clay or till which was laid down by ice sheets of Devensian age which invaded the area during the last 100 000 years. The till mantles much of the district, together with smaller areas of glacial sand and gravel. The most widespread post-glacial deposit is alluvium, belts of which flank long stretches of the River Ellen and several minor streams. Small areas of river terrace deposits have been mapped in places in the Ellen valley and small alluvial fans have also been recognised. Along the coast present day beach deposits are succeeded inland by belts of raised beach deposits. Other post glacial drift deposits which occupy very small areas include lacustrine alluvium and calcareous tufa.

Only in the valleys of a few streams in the west of the district and on the higher ground in the east has erosion removed the superficial deposits to reveal solid rocks. However it is unlikely that a significant thickness of drift was ever deposited on some of this eastern higher ground.

Rockhead

Rockhead elevations are shown in Figure 13 and drift thicknesses in Figure 14. Although for much of the district there is only a limited amount of borehole information it appears that the rockhead surface broadly reflects the present topography though, in common with other similar glaciated lowlands, this surface may locally exhibit a somewhat greater relief. Drift cover is generally less than 15 m over much of the area though areas with up to 30 m or more of drift have been identified, for example to the east of Dearham and in the Ellen Valley north of Oughterside Mill. On the higher ground of the district, east of Gilcrux and Tallentire, drift cover is generally less than 5 m with large areas clear of drift deposits. On some of the limestone outcrops small areas of bare limestone occur.

The modern Ellen valley appears to be essentially coincident with a pre-glacial valley though between Oughterside Mill [1110 3900] and Ellenhall Bridge [1165 3907] the present day river course has clearly been deflected slightly to the south of its former course. Downstream from Bullgill [096 384] post glacial erosion has removed superficial deposits from the valley sides for much of its course. Upstream from Bullgill the pre-glacial valley is infilled with glacial deposits to depths of over 30 m locally and there is limited evidence to suggest a local deepening of the solid floor of the valley hereabouts.

Quaternary deposits

Boulder clay

Boulder clay mantles much of the district. Over parts of the western half of the district its surface exhibits well developed low elliptical drumlin ridges with a general NE-SW alignment which in part reflects the trend of ridges in the underlying rockhead surface. Elsewhere, for example on the Hensingham Group outcrop north of Tallentire and on the hill slopes south of Gilcrux, the boulder clay surface is typically featureless. There are few good natural exposures of boulder clay though large sections are occasionally exposed in the workings of the Oughterside Opencast Coal Site [110 395]. From the limited evidence available the boulder clay of the district appears to be a lodgement till, that is till deposited beneath a glacier, which consists mainly of sandy, stony clay. Most commonly the boulder clay is grey to brownish grey in colour though in places in the north of the district, where the St Bees Sandstone or reddened Coal Measures have contributed significantly to its composition, it assumes a distinctly red or reddish brown colour. Included erratics are characteristically rounded to sub-rounded and commonly show striated surfaces.

Boulders up to 2 m across have been noted but most are below 0.75 m in diameter. Common rock types include a variety of Lake District rocks amongst which several distinctive lithologies have been recognised. These include Carrock Fell Gabbro, chiastolite hornfels, granophyre and granite the Carrock Granophyre and Skiddaw Granite and numerous boulders of porphyritic 'Eycott type' basalt. Clearly many of the erratics have been derived from the northern Lake District. A few boulders of Criffel granodiorite from SW Scotland have been noted. These become more numerous towards the west of the district and are dominant in the ground west of the River Ellen. Limestone and sandstone boulders are also common in the boulder clay though these give no specific indication of provenance.

Glacial sand and gravel

Glacial sand and gravel occurs locally as small outlying patches on the boulder clay surface to the north of the River Ellen. At least 3m of sand and gravel are exposed in a disused pit [0940 3853] north west of Bullgill. In general however the thickness is less than this.

Alluvium occupies an almost continuous belt of flat ground flanking the River Ellen along most of its course through the district. Small sections through these sediments at numerous points along the river banks show up to 1.0m of dark brown silt. Trial bores for the diverted minor road north east of Ellenhall Bridge [1165 3907] provide details through the margin of the alluvium. Here the alluvium consists of up to 2.1 m of silty clay above silty sands and gravels which may be up to 1.8 m thick overlying boulder clay. Thin alluvial deposits occur in numerous stream valleys throughout the area.

River terrace deposits

River terrace deposits are restricted to a small number of places along the Ellen valley. East of Bullgill terrace deposits have been mapped on both sides of the river where they form bench-like features which reach up to 3 to 4 m above the level of the alluvium. The rather degraded sides of the railway cutting east of the site of Bullgill Station [1037 3891] show about 1.0 m of silty, gravelly sand. Sandy and gravelly soil may be seen in the arable fields further to the west.

Alluvial Fan deposits

Alluvial Fan deposits have been mapped at several points where tributary streams join the main valley. In composition these deposits are similar to the alluvium: they are distinguished principally on their surface morphology. No precise thicknesses can be given for the fan deposits within the district though they are unlikely to exceed 3-4 m.

Lacustrine alluvium

Lacustrine alluvium has been distinguished in the flat-lying ground immediately south of St Cuthbert's Church, Arkleby [1415 3920]. Where seen in ditches on the edge of the deposit it consists of dark brown generally stoneless silt. Up to 1.5 m of this silt were seen at one point [1414 3902] though the maximum thickness of the deposit is unknown. It is however unlikely to exceed 2-3 m.

Marine and Estuarine Alluvium and associated peat deposits

Extensive deposits of alluvium are situated in the areas of low ground on the landward side of coastal drumlins in the ground west and north-west of Crosscanonby [065 392]. These predominantly non-marine accumulations are composite and contain the stratigraphical record of a marine incursion into the area at a time of former high sea level. After the last glaciation the land was progressively drowned during the eustatic rise of the sea from its glacial low level. As the sea rose it induced a rise of water table in the adjacent low ground, thus initiating peat growth, but progressively drowning peat on the rise of the sea to still higher levels. Eventually the inter-drumlin hollows at Crosscanonby were flooded by the sea and the deposition here of organic clays was succeeded by the deposition of silty clay with marine diatoms. According to Huddart and others (in Kidson and Tooley 1977) the sea had access between 6810 years and 6495 years before present, after which the sea level fell as post-glaciation land uplift began to exceed the rate of eustatic sea level rise, and organic clays began to accumulate again. The top of the marine deposits, at 4.44 m above OD is well below the present surface of the alluvium at 5.50 above OD.

Peat

Peat, with the tree stumps in position of growth, which accumulated on the site of the present intertidal zone as the sea rose towards its highest level, now emerges from beneath a cover of modern beach deposits west of Crosscanonby [053 392]. This 'submerged forest', of unknown thickness but probably less than a metre thick, is currently exposed over a wider area than has been previously recorded on this coast.

Raised beach deposits

On the seaward side of the coastal drumlins at Crosscanonby prominent raised cliff-lines have been cut by the sea as it stood at a former high level. Beach deposits, including the sand and shingle deposits of storm beaches, are banked up against these old cliffs at levels up to 7.5 m above OD. This is substantially higher than the highest level to which contemporaneous clays were deposited on the tidal mudflats in the sheltered areas protected by the drumlins.

Blown Sand

Elongate areas of blown sand, quarried in places, occur along the inner margin of the raised beach west and north-west of Crosscanonby.

Calcareous tufa

Calcareous tufa is currently being deposited in the lower courses of several of the un-named left bank tributaries of Leathers Gill Beck, north of Gilcrux. In the northernmost of these [1171 3860] pale brown cellular crusts of tufa up to 0.3m thick coat moss, twigs and boulders and form extensive terraces in the stream bed. In the easternmost stream [1207 3849] tufa fragments form a gravel bed to the stream. Hazel nuts and small twigs coated in tufa are particularly common here.

All of these streams rise as springs from the Gilcrux Fault. No sign of tufa deposition has been observed around any of the springs and it is only in the lower courses of the streams that this deposition is taking place. It seems likely therefore, that much of the calcium carbonate now being deposited has been leached by the streams from the limestone-rich boulder clay in their short upper courses.

Karst features

Geomorphological features characteristic of terrain consisting predominantly of bedrock with a high degree of solubility in natural groundwater are collectively known by the German term 'karst'. Within the eastern part of the district the Lower Carboniferous outcrop, which consists mainly of a thick sequence of limestones exhibits certain typically karst features. These features were initiated during interglacial periods of the Quaternary when availability and movement of groundwater was at a maximum.

Most conspicuous of these are numerous swallow holes or dolines. Their distribution is shown on the Swallow Holes map. Eastwood *et al.* (1968, p.156) comments on the concentration of swallow holes at about the top of the Rough Limestone, which forms the basal member of the Fourth Limestone. Within the present district no such concentration has been observed and swallow holes are developed at almost all stratigraphical levels within the limestone sequence. They are however rather more numerous in the lower part where the proportion of limestone in the succession is greatest. Although most occur now on outcrops of bare limestone, a few swallow holes penetrate a metre or so of other lithologies of the overlying beds and several penetrate the thin cover of boulder clay which commonly overlies the limestone surface. Most swallow holes in the district are roughly conical in form and are up to 30 m across at their widest point. They are generally less than 5 m in depth and are usually floored with collapsed boulder clay or other superficial material. In a few instances for example on Wardhall Common [1358 3732] and at Millstone Moor [1359 3624] the floors are wet and boggy and after prolonged rain tend to hold a shallow depth of water.

Swallow holes with bare limestone visible in the base may be seen in the Fifth Limestone east of the B5301 road in the extreme east of the district [around 150 374]. Streams may be seen descending into swallow holes at [1214 3604, 1287 3528, 1276 3561 and 1499 3751]. The un-named stream draining the south side of Moota Hill sinks at various points [eg 1400 3543] along its course depending on weather and groundwater conditions. In other cases swallow holes are apparently unconnected with current drainage. Little is known about the district's underground drainage. However no evidence of any form of cave system has been discovered in any of the numerous quarries in the limestone outcrop. It is thus likely that no major cave system is present and that drainage is effected by numerous narrow channels along and between joint and bedding planes. The swallow holes of

Table 2. Former collieries with a take within the district

Colliery name, including individual shaft names[1]	Approximate Grid Reference of main mine entrance	Seam(s) worked	Date of abandonment as given in British Coal catalogue of abandoned mines[2]
Birkby (Albright, Florence, Orchard)	Florence 0798 3630 Orchard 0729 3651	Upper Three Quarters	1938
Birkby (Nos 1 & 2)	No 1. 0750 3741 No 2. 0757 3747	Lickbank Upper Three Quarters Lower Three Quarters Albrighton	1949 1950 1949 1950
Birkby (Mother)	0724 3742	Mother or Little Main Number 1 Number 2 or Lickbank Upper Three Quarters	unknown unknown unknown unknown
Brayton Domain (Hall)	1299 4016	Yard	unknown
Brayton Domain (No 3)	1600 4152	Yard	1902
Brayton Domain (No 5)	1388 4017	Yard	1942
Bullgill, (Ash, Broad-meadow, Bullclose, Crosby Eliza, Ellen, Jane, Lodge, Ten Quarters)	mainly in square 10 38	Ten Quarters Rattler Thirty Inch Metal Yard Little Main	1910 1910 1910 1910 1910 1910
Crosby (Ellen)	0973 3855	Ten Quarters Rattler Thirty Inch Metal Yard Little Main Number 1 Number 2	1898 1898 1898 1898 1898 1898 1898 1898
Crosby & Gilcrux	mainly in square 10 38	Ten Quarters Metal Un-named	1888 1888 1888
Crosby & Rosegill Ellen, Rosegill No 2)	Rosegill No 2 0841 3788	Ten Quarters Thirty Inch Metal Yard	c1897 c1897 c1897 c1897
Dearham (Croft, Hope Lonsdale, Lowther, Parkin, William, Wright)	Lonsdale 0694 3573 Lowther 0676 3623	Ten Quarters Rattler Metal Cannel Yard Little Main Lickbank	1894 unknown 1894 1894 1894 1894 unknown

Table 2 (continued).

Colliery name, including individual shaft names[1]	Approximate Grid Reference of main mine entrance	Seam(s) worked	Date of abandonment as given in British Coal catalogue of abandoned mines[2]
Ellenbank	0617 3758	Upper Three Quarters	1952
		Lower Three Quarters	1952
Ellenborough & Ewanrigg (Cass, Far, Gravel, Henry, High, Jacob's Well, John, Lady, Mall, Scott, Middle, Rough Ground, Thompson, Watergate, William)	mainly in squares 05 35, 06 35 & 07 35	Virgin (?)	unknown
		Ten Quarters	unknown
		Rattler	unknown
		Metal	unknown
		Cannel	unknown
		Yard	unknown
		Lady Pit (?)	unknown
Ellenhall	1173 3855	Metal	1938
Gilcrux (Ashtree Broadmeadow, Brow, Bulls Close, Croft, Crooks, Damside, Ellen, Eliza, Fretchville, Jackson, Jane, Lady, Lord, Mirehouse, Morrison, Sellby, Skelbrow, Smith)	mainly in square 10 38	Ten Quarters	unknown
		Thirty Inch	1854
		Metal	1854
		Yard	unknown
Isa	0765 3787	Cannel	1932
Mill (Paitson, Bell)	0755 3590	Crow	1928-9
Oughterside	1131 3990	Ten Quarters	1930-3
		Rattler	1930-3
		Thirty Inch	1933
		Metal	1933
		Yard	1933
		Little Main	1930
Rosegill	0841 3788	Ten Quarters	1897
		Rattler	1897
		Thirty Inch	1897
		Metal	1897
		Yard	1897
		Little Main	1897
Townhead	0755 3590	Crow	1903
Westmoor End	1055 3976	Ten Quarters	1939
		Rattler	1939
		Thirty Inch	1939

1. The names quoted are those given in the British Coal catalogue of abandoned mines. Some duplication occurs with certain individual shafts included in one or more groups of plans.

2. The dates given are those registered in British Coal catalogue of abandoned mines. In certain cases the date may be the date of registration of the plan rather than the date of abandonment of mining.

the area appear to resemble the 'solution dolines' of Cramer (1941). These are developed by pronounced surface solution of the bedrock at or around some favourable point such as a joint intersection. There is no evidence that any of the district's swallow holes result from collapse into solution voids, the 'collapse dolines' of Cramer (op.cit.). The disappearance underground of the stream south of Moota Hill may provide an example of the 'alluvium stream sink doline' of this classification.

Where free of superficial deposits several limestone formations form bare craggy outcrops typically with little or no soil cover. No limestone pavements of the type characteristic of south Cumbria or the Yorkshire Pennines occur in the district. However several natural outcrops exhibit solution sculpturing of the type described by Bogli (1960) and this feature has been observed on a few older quarried surfaces, indicating that this process can develop within a few decades.

Deposition of calcite in the form of tufa around boulders, twigs and moss occurs in several streams north of Gilcrux (see above). The calcium carbonate is believed to have been leached from limestone-rich boulder clay.

MADE GROUND AND BACKFILLED OPENCAST SITES

These cover only a very small proportion of the district although there are locally some significant areas of colliery spoil. Areas of this material are present around the disused sites of Crosshow Colliery [069 366], Birkby Colliery [077 375], Rosegill Colliery [085 380] and Bullgill Colliery [098 385]. There are numerous small heaps of spoil associated with other old workings throughout the Coal Measures outcrop but these are generally much too small to be mappable. Colliery spoil heaps are composed principally of shale waste together with minor amounts of sandstone. Spontaneous combustion of pyrite-rich shale has occurred in the spoil tips at Birkby and Bullgill collieries giving the remaining spoil its characteristic brick-red colour. Most of the heaps of colliery spoil within this district are relatively inconspicuous features in the landscape and in some cases, eg Crosshow Colliery, large areas of spoil have become heavily vegetated. The large conical tip at Birkby Colliery is however a prominent landscape feature. Spoil associated with the former Oughterside Colliery [1132 3990] has been used in restoring the adjacent Oughterside Opencast Coal site.

Within the present district other forms of made ground are of limited extent. The disused High Close Limestone Quarry [147 382] is currently being infilled with domestic refuse.

At Moota Quarry [146 362] made ground consists of quarry spoil.

Backfilled opencast sites are of limited extent and are confined to the former Blooming Heather [053 351 and 062 353] site south-west of Dearham and parts of the Oughterside site [120 400 and 126 406] north of Gilcrux. At the former site backfilled ground amounts to approximately 20 hectares to a maximum depth of 25 m. At Oughterside the extreme southern portions of areas B and C amounting to a total of approximately 9.5 hectares extend into the district. Maximum thickness of backfill here amounts to approximately 45 m.

Opencast excavations are filled with the overburden which was originally taken from them. Where spoil heaps remain from nearby abandoned deep mines, as at Oughterside, this material is used as part of the fill.

MINERAL RESOURCES AND GROUNDWATER

By far the most important mineral produced in the district in terms of overall tonnage, value and area of working is coal. Underground mining ceased some years ago and working by opencast techniques ended recently though some reserves remain and may be extracted in the future. Limestone was formerly an important product of the eastern part of the district as evidenced by numerous abandoned quarries. Production continues today from one quarry and at the time of writing (June 1988) limestone is the district's sole mineral product. Small quantities of sandstone have been worked for building stone in the past but a resumption of working is very unlikely. Trials have been made on two small veins of baryte though only very small amounts were produced. The widespread occurrence of this mineral both in this and adjacent districts suggests that some further investigation of this type of mineralisation may be justified. Small deposits of sand and gravel have provided a small local supply in the past but no worthwhile reserves are known to remain. Whereas sedimentary ironstone, fireclay and ganister all occur in the district there are no records of these ever being worked here and reserves are very unlikely to attract commercial interest under foreseeable economic conditions.

Some supplies of good quality water may be obtainable from the Lower Carboniferous formations of the eastern part of the district though contamination by mine workings renders the groundwater of the Coal Measures unsuitable for use.

Coal

Coal remains the most important economic mineral of the district. Seams of economic importance occur within a sequence approximately 260 m thick in the Lower and Middle Coal Measures. The major production has come from several principal seams, namely the Ten Quarters, Main and Little Main, which vary in thickness and quality throughout the district and are not economically workable in all places (Table 2). Smaller amounts of coal have been produced locally from other seams. In places even the better seams deteriorate in quality or thickness and may become unworkable. Shale partings are present in some seams notably the Slaty, Ten Quarters and Metal, and washouts, known locally as 'nips' may be present in certain seams, for example the Bottom Bannock. Calcareous mineralisation adjacent to faults in several seams in the Oughterside Opencast site has rendered parts of these seams unworkable. A more widespread effect, involving Coal Measures strata above the Ten Quarters Seam in the Dearham, Rosegill, Bullgill and Oughterside areas, is secondary reddening. This feature is the product of intense oxidation prior to the deposition of the Permo-Triassic formations. Not only has the process resulted in the oxidation of iron minerals within the Coal Measures sediments but in many cases whole coal seams have been destroyed by oxidation. Certain seams may therefore locally be absent within the reddened sequence.

The Cumbrian Coalfield has had a long history of coal production. Most seams yielded bituminous coals of high volatile content and with strong coking properties, perhaps best described as 'general purpose' coals. They were ideally suited to coking, gas making, steam raising and household use. Few recent analytical data have been published though Taylor (1978, p185) notes that volatile contents of Cumbrian coals calculated on a dry ash-free basis vary from 32 to 39 per cent. Brief descriptions of the characteristics of Cumbrian coals were given by Jones (1957, pp 83-4).

The heyday of coal mining in the district was during the latter half of the nineteenth and first half of the twentieth centuries. During this period large tonnages were supplied to the heavy industries of west Cumbria, mainly for coke making and steam raising. A considerable proportion of the district's output was exported through the formerly large coal handling port of Maryport. Heavy industries were not established in the present district in contrast to areas further south.

Underground coal production within the district went into decline in the 1930s and 1940s and became extinct with the abandonment of the last colliery, at Ellenbank in 1952.

The volume of individual blocks of unworked coal and the presence of old workings make any resumption of underground coal mining within the district very unlikely under presently foreseeable economic conditions.

Interest in opencast coal production arose during World War II and resulted in exploration of a number of sites in Cumbria. Several sites within the district were prospected but production did not start until 1964 with the development of the Blooming Heather Site [053 351] SW of Dearham. Coaling from this site continued until 1969. Opencast extraction at Oughterside [110 395] in the north of the district ended in July 1988. Further possibilities exist within the district for opencast extraction and prospecting for further reserves near Dearham is in progress.

Limestone

Limestone is the district's second most important mineral product after coal. Much of the Dinantian and lowest part of the Namurian sequence consists of limestone and there are wide and commonly relatively drift-free outcrops to the east of Tallentire and Gilcrux. These outcrops are scarred by numerous old quarries, though limestone extraction is today confined to one large quarry at Moota [143 363]. Small quarries are present in all of the main limestone formations of the district and these no doubt formerly supplied small local needs for building stone and lime. The largest excavations are confined to three of the formations; the Namurian First Limestone and the Dinantian Fourth and Fifth Limestones. Of these by far the greatest production has come from the Fourth Limestone and it is this formation which is today worked at Moota by the Bothel Limestone and Brick Co Ltd. Quarry development here in recent years has advanced the workings northwestwards in the upper part of the Fourth Limestone. This quarry produces various grades of crushed raw limestone for use as roadstone and concrete aggregate and in addition some tar-coated roadstone is produced. Finely crushed limestone is also produced and used on site in the manufacture of lime-silica bricks.

Three limestone units within the Fourth Limestone were formerly worked on a large scale at the Wardhall group of quarries [centred around 138 382] between Gilcrux and Parsonby. The quarries were served by an inclined tramway which conveyed stone to a loading bay on the Carlisle to Barrow in Furness railway [1240 3960]. Some of the limestone was burnt to produce quicklime and the large limekilns may still be seen adjacent to the railway. Much of the output however was supplied as a flux to the iron works at Maryport. According to Eastwood *et al.* (1968, p 243) the closure of this works led to the abandonment of the quarries. The Fifth Limestone was formerly worked for ground limestone, road-metal and flux at High Close Quarry [147 382] south of Parsonby. This quarry is today used as a domestic refuse tip.

Large quantities of limestone undoubtedly remain in the district.

Building Stone

Building Stone has been obtained from a number of sources within the district. The numerous dry stone walls have been built mainly of stone obtained either from small quarries specially opened to supply the immediate need or from loose 'clearance' stones gathered from the adjacent fields. Quarried stone for this purpose includes both limestone and sandstone; 'clearance' stones include weathered blocks from outcrops and a wide variety of glacial erratics. Several of the district's older buildings are built of heterogenous mixtures of locally available stone.

The Orebank Sandstone has been worked in two moderate sized quarries to the south of Tallentire Hill [1210 3550 and 1200 3530]. No information has been discovered about the date of working or the type of product or quantity produced but the size of the workings suggests that they fulfilled rather more than the immediate local demand. The Hensingham Grit has been worked in several pits south of Gilcrux [1170 3755] which may have supplied some of the stone used in cottages in the village. Blocks of coarse-grained sandstone with pellets of hematite and coatings of baryte in the walls of an old building [1418 3915] immediately south of St Cuthbert's Church, Arkleby are almost certainly from the Hensingham Grit and resemble closely the stone formerly quarried in old shallow pits [1329 3659 and 1325 3640] on the hill to the south of Grange Grassings. Reddened Coal Measures sandstones, formerly referred to the Whitehaven Sandstone, have been quarried on a small scale at several places most notably Garley Gill, Dearham [0667 3612] and on the west bank of the River Ellen [0874 3822] east of Crosby. According to Eastwood (1930, p 125) this stone was much used in buildings in Dearham village and in the construction of several railway bridges. Other Coal Measures sandstones are generally less satisfactory as building stones but material of reasonable quality was quarried on the west bank of Row Beck [0685 3695] north of Dearham. Small quantities of stone have been obtained from a few pits elsewhere for local use.

Many old cottages in the district incorporate sills and lintels of dressed St Bees Sandstone, no doubt obtained mainly from quarries at Maryport immediately to the west of the district. Within the district the St Bees Sandstone has been quarried on both banks of Brunshaw Beck [0760 3990] north-east of Crosscanonby, and in a small working [0896 3932] south of Allerby.

None of the formations within the district is likely to provide building stone suitable for modern requirements though small pits will no doubt continue to provide stone for the repair of dry stone walls.

Sand and gravel

The district contains no appreciable deposits of sand and gravel. The only deposits to have been worked are in the Bullgill area [0940 3853] though the quantity obtained must have been small. Reserves are likely to be too small to be of commercial interest today.

Fireclay and shale

Several shales and seatearths within the Cumbrian Coal Measures have been used for the manufacture of buildings bricks, refractory products and sanitary ware. Suitable clays and shales may exist within the district. However apart from small scale brick making for local use in the past there are no records of the extensive working of such products. If suitable material could be identified, brick clay and refractory clays could perhaps be obtained as a by-product of opencast coal mining.

Many Coal Measures shales contain appreciable quantities of pyrite and marcasite. Oxidation of these minerals is an exothermic reaction which in the presence of carbonaceous matter in the shales may result in spontaneous combustion. This is a common feature of colliery spoil heaps. The product of this process is a red brick-like shale in which significant quantities of sulphates such as gypsum and residual unaltered iron sulphides may be present. Such "red shale" may provide a useful fill material for rough tracks or as a sub-base or hard core in foundation work. Care must be taken to establish the content of sulphates or residual sulphides if this is to be used with concrete. The spoil tips of Birkby and Bullgill Collieries [0775 3759 and 0980 3852] contain appreciable quantities of this material. Shale from the latter source has been used for fill in recent years.

Ganister

Siliceous sandstone or ganister has been worked for refractory purposes from both the Coal Measures and Hensingham Group in neighbouring districts. Although ganister sandstones are present in the district none has been worked except for local use as rough building stone.

A fine-grained, rather sugary textured, white siliceous sandstone within the Fourth Limestone on Moota Hill has been quarried [1434 3603] for walling stone. Hard fine-grained pale brown siliceous sandstone underlies the Third Limestone at Millstone Moor and has been dug for walling stone in small pits NW and NE of the farm [1339 3595, 1387 3667 and 1395 3659]. Sandstone, of ganister type, was formerly exposed at two localities [065 354 and 062 358] within the Hensingham Group, south west of Dearham. Very hard fine-grained pale brown siliceous sandstone occurs near the base of the Lower Coal Measures east of Arkleby and may be seen in spoil excavated from Flatts Beck [1445 3923] and as abundant soil brash east of Arkleby Hall [1460 3973].

There are unlikely to be sufficient reserves of siliceous sandstone within the district to attract commercial interest.

Iron ore

Nodules of impure siderite or 'clay ironstone' are common in many of the Coal Measures mudstones. Such ironstones contain up to 25% metallic iron (Cantrill 1920, p98) and have been worked elsewhere in the Cumbrian coalfield. There is however no record of exploitation in the present district and future economic interest is most unlikely.

Small amounts of goethite and hematite, which occur with other vein minerals on Tallentire Hill, are of no economic interest.

Barytes*

Barytes has been worked on a small scale from two narrow fault-veins in the Hensingham Group at Rosegill, west of Gilcrux. Brief descriptions of the Gilcrux workings were given by Wilson *et al.* (1922, pp 27-28). The western vein formerly exposed in Rosegill [0912 3741] was up to 0.61m wide over a strike length of a few metres only. A trial below stream level to a depth of 5.5 m showed good baryte but flooding prevented further exploration. The eastern vein showed a similar width of baryte in an 8.8 m deep trial pit on the north side of Greengill but again work was stopped by flooding. Attempts to locate the vein by means of shallow shafts on the south side of the stream were unsuccessful. In both veins, baryte is the only mineral present and varies from white to pale pink. The precise date of these operations is unknown but was probably late last century. Wilson *et al.* (loc. cit.) report a total production of only 25 tons of barytes product.

Baryte mineralisation is widespread throughout the Lower Carboniferous rocks of the district. Details of individual occurrences and a discussion of the significance of this and other mineralisation are given on p 50. No workable deposits have been identified. However, the wide distribution of the mineral, when considered in the context of the regional geology suggests that the present district and adjoining areas of Lower Carboniferous rocks may merit further investigation for this mineral.

*In this account barytes and baryte are used in the sense of Dunham & Wilson (1985). Baryte is the pure mineral: barytes is the commercial product which is, of course, not necessarily the pure mineral.

Non-ferrous metalliferous mineralisation

Minor amounts of copper mineralisation and the occurrence of small quantities of zinc and nickel minerals are described on p 51. No workable deposits of these metals are known in the district nor is it likely that any will be found at present levels of exposure. However there are grounds for considering this part of Cumbria as a potential target area for exploration for deposits of Irish type as discussed on p 25.

Groundwater

The main centres of population are served with mains water from sources outside the district. Several farms on the Lower Carbonifeorus outcrop have their own private supplies from springs. The outcrop of the Gilcrux Fault is marked by a prominent line of strong springs, several of which may be seen rising in Gilcrux village [eg 1149 3806, 1159 3810 and 1174 3815]. Much of this water discharges into the natural surface drainage. A trout farm to the north of the village is supplied from one of these springs. Nothing is known about the quality of water but one of the springs [1212 3827] east of the village, and known locally as "Tommy Tack", is said to be saline. The rate of flow of these springs has not been determined but appears to be constant throughout the year. Other springs rise from the north-north-west trending Scuskeld Fault. The strongest and most prominent is the Scuskeld Spring [1091 3657]. Several springs rise from the base of limestone units. Sink holes mark the outcrops of many parts of the Dinantian strata. Surface streams flow into several of these, for example at [1288 3527, 1274 3560 and 1500 3752], though most of the sink holes in the district have no contributing streams. Aspects of sink holes are discussed further on p 38.

In common with other formerly extensive coal mining areas, large supplies of potable groundwater are unlikely to be obtainable. Widespread old workings lower the quality of the groundwater and disturb the natural hydrogeological regime. Water issuing from old workings is generally heavily charged with ferric salts. Within the coalfield the considerable cover of boulder clay effectively limits the potential for natural recharge. Additional supplies of groundwater may be obtainable from the Lower Carboniferous outcrop though the limited demand in the district gives little impetus to investigation.

GEOLOGICAL IMPLICATIONS FOR LAND USE PLANNING

Ground conditions

Individual geological formations and deposits possess certain features which should be considered in planning and execution of engineering projects.

The characteristics of the deposits of the adjacent district (Sheets NY02NW, 03NW, SW, NX92NE and part of 93SE, Barnes, *et al.* 1986) is equally applicable to much of the present district and is repeated here with modifications.

It must be stressed that the comments presented here are for general guidance only and should in no way be regarded as substituting for on site investigation. Appropriate site investigation proceedures are recommended as part of the planning process for all civil engineering or building projects.

1. *Made Ground* may pose problems because of its unconsolidated nature, its variability of composition and, in places, because it may contain sulphur, sulphates and/or methane generating material. Consolidation of made ground may present settlement problems. In other places for example, where the made ground is variable in nature or on the edges of made ground, differential settlement may occur
2. *Alluvium and Lacustrine Alluvium.* Where it comprises sand and/or gravel, alluvium will pose few engineering difficulties, but beds of peat, silt or soft clay if present will compact or shear if loaded. Alluvium is up to 5 m thick in the Ellen valley. In the small valleys it is proportionally thinner.
3. *Raised Beach Deposits* consist mostly of sand and gravel and provide generally good foundation conditions.
4. *Till or boulder clay* mantles much of the district. In its unweathered state it is a stiff over-consolidated lodgement till. Typical undrained shear strengths are in the range 100-350 kn/m^2. It is a good foundation material which presents few problems in trenching, tunnelling and excavation. However, erratic boulders of hard rocks within the till are unpredictable in size and location and may cause problems in site investigation boring, piling, excavation and tunnelling. Individual boulders up to 1.5 m across have been noted locally.

The uppermost 1 to 2 m of the till is commonly weathered to a reddish-brown and yellow stony clay, which possesses different geotechnical properties, and is inherently weaker than the fresh material. If disturbed or moistened during site investigation or development, this uppermost till will have its shear strength rapidly reduced, becoming soft and plastic. Care should also be taken at contacts between till and sand where a spring line often develops and results in local weakening of the clays.

5. *Glacial sand and gravel* generally provide good foundation conditions and, where dry or confined, can support considerable loads. Problems may be encountered in these deposits if they are water-bearing. In these conditions excavation in sand and gravel may be especially difficult. Oversteepening of slopes may produce slipping particularly if a spring line is present at the base of the deposit. Silt, peat and organic clays which may be present as lenses within the sand and gravel can also give rise to foundation problems particularly those related to compaction and differential settlement.

6. *Mudstones and siltstones.* Reference has already been made (p 11) to the possible presence of bentonitic clays within the Lower Carboniferous of West Cumbria. Such clays can give rise to ground instability due to low shear strength in both excavations and over natural or man-made cavities. There is also a potential for swelling or heave in excavations. Particular attention should therefore be paid to the physical properties of clay beds within the Lower Carboniferous sequence when designing foundations particularly those suspected of containing bentonitic material.

   Mudstone and siltstone together comprise a large proportion of the Coal Measures lithologies. Their clay minerals are stable but disseminated pyrite is commonly present, rapid weathering of which leads to ground water of high acidity ($pH<4$). The presence of abundant sulphate ions in the weathered mudstones, together with such soluble secondary sulphate minerals as epsomite ($MgSO_4.7H_2O$) and gypsum ($CaSO_4.2H_2O$) must be considered when placing concrete as aqueous solutions of sulphates are known to attack concrete. A useful discussion of the nature of this problem and recommendations for the type of concrete to be used where such attack is likely is contained in Building Research Establishment Digest No 250 (1983). Even when covered by a substantial thickness of drift, the topmost 1 - 3 metres of mudstone are generally weathered. Trenching is relatively easy but tunnelling at depths of 12 m or less presents substantial support problems. Mudstone when exposed to water expands and is liable to heave. The mudstones and siltstones generally pose few problems in excavations by normal ripping methods.

7. *Sandstones.* Excavation and tunnelling in sandstones present few support problems but generally requires explosives for depths below 2 - 3 m. Some of the coarser-grained sandstones are gritty and highly abrasive and some sandstones are silica cemented and extremely tough. Ganister, a variety of sandstone seatearth found beneath some coals, is a particularly tough rock.

   Joint bounded masses that have been weakened by subsidence over old coal workings may require support in deep excavations and the presence of deep open joints may necessitate special precautions.

8. *Seatearths* mudstones are probably the commonest lithology immediately underlying coal seams though locally they may occur unaccompanied by a coal. They are strikingly different from the sandstone seatearths or ganisters noted above and typically consist of readily-weathered clay minerals, which with abundant random internal polished ("listric") surfaces, make them unstable both in excavations and under load. Disseminated pyrite may also be present and comments made above concerning the weathering of this mineral apply here too.

9. *Limestone.* Excavation and tunnelling in limestone present few problems but the presence of joints may require the installation of support. Strong inflows of water may be encountered in some situations. In addition several limestones contain thin clay or marl partings, commonly less than 0.1 m thick, which may cause bedding plane slip where exposed in excavations. Many of the massive, poorly-bedded limestones are particularly hard and may require the use of explosives in large or deep excavations. Solution cavities may be encountered locally.

Mining

One of the purposes of land use planning is to ensure, so far as possible, that potential mineral deposits are not knowingly sterilised by an alternative and possibly less economic use of that land.

There are no known large deposits of sufficient economic importance in the district to warrant widespread restriction of development. However if planning consent is sought for future development a restrictive covenant may be considered applicable in certain areas to allow the working of any minerals prior to that development. In this district the most likely minerals to which this may apply are coal and limestone. This procedure would, in the case of coal, have the added advantage of locating any shallow workings or access shafts and adits thereby enhancing foundation prospects without the additional cost of boreholes for site investigation.

1. *Coal Mining.*

Although there is no direct evidence it is probable that mining of several seams from near outcrop and in areas of thin drift began in this district before the 18th century. It is likely that the earliest such workings were small adits into a valley side, usually at or near the seam crop, and bell pits, which were generally less than 12 m deep and from which the area of coal extraction was about 20 m wide. Later, deeper seams were extracted by the pillar and stall method with extraction rates of up to 50%. Panel working was probably introduced into some pits early in the 19th century and resulted in an increase in the proportion of extraction. This method sometimes involved reworking or 'robbing' earlier pillar and stall workings. The longwall technique later replaced these earlier methods and resulted in the highest ratio of coal recovery. This was the method employed in the final years of underground mining.

It is clearly important for the planner, developer or civil-engineer to appreciate the extent of individual seam outcrops and the various methods of coal extraction practised in the past, each of which carried its own potential problems. One of the commonest and most serious hazards presented by old workings is that prior to 1900 few reliable documentary records were kept and of those which do exist, few are likely to be accurate. Although in 1872 it became a statutory requirement for abandonment plans to be deposited with the Mines Record Office the plans commonly showed only the maximum extent of coal extraction and information was rarely given on levels or geological observations. In some cases different versions of a plan of one mine show different positions for the extent of workings and in some cases the positions of access shafts. The positions of many shafts, adits and bell pits is unknown or at best very unreliably recorded. Until comparatively recent times shafts were inadequately sealed. Most commonly they were capped at or near surface often with timber. These shafts may remain open below what may now be a very unstable surface covering.

Particular difficulties associated with pillar and stall workings include:

1. Up to 60% of the coal may remain *in situ.* As a result site investigations may fail to identify such mined areas as only a proportion of trial bores are likely to penetrate the old worked areas.
2. Packing of the worked areas was not always necessary, nor was it always practiced. Where roof measures have subsided into such an open void to rest on the seatearth or seam floor only slight disturbance of the strata may be apparent. The only evidence present in a borehole core may therefore be a little fragmentary coal or coal dust on a slightly weathered and possibly rather rusty seatearth.
3. Collapse of pillars commonly results in cavities and breccia zones or 'pipes' in the overlying strata caused by upward propagation of the mined void.
4. Competent roof measures, for example sandstone, may resist collapse for considerable periods. When roof failure occurs it may take place in a sudden and unpredictable pattern and timescale.

Areas of longwall extraction generally may be assumed to present less cause for concern at surface for the following reasons:

1. The method was usually restricted to deeper seams.
2. Longwall extraction was more recent in its application and the workings were usually accurately surveyed and documented.
3. Although subsidence may be substantial and will be proportional to the thickness of coal extracted it is generally assumed to be largely contemporaneous with working and is expected

to be complete within a few years of extraction.

Coal production in the district came from about 10 principal seams though other seams were important locally. All underground mining came to an end in the early 1950s. A large area of the Coal Measures outcrop has been undermined by workings in at least one seam and in some areas several seams have been worked. Most of the extraction methods outlined above have been employed.

Old shallow mine workings can have major implications for the surface stability (Healy & Head 1984). Workings at any depth can cause subsidence at the ground surface but the thickness of the mined seam, the nature and condition of the overlying strata and the type of workings all have an influence on the height to which voids can migrate and the effects at the ground surface.

Several general "rules" have been used to indicate the depth above which the majority of subsidence events which affect the surface are initiated. However, some of these may be of local use only and exceptions to almost all have been noted. It is necessary therefore to adopt an approximate "rule" which can be used by planners and developers so that potential instability can be reasonably taken into account prior to the development of the land.

In this study the commonly accepted basis that 10 times the seam thickness represents the maximum height of collapse through typical Coal Measures strata (Piggott *et al.* 1977) has been adopted. However, users of the results should always be aware that there will be exceptions to this "rule".

In the Cumbrian Coalfield the maximum thickness of a worked coal seam is about 4 m but the usual thickness varies between 0.5 m and 3 m. Thus in this area 30 m is taken as an appropriate depth to coal seams above which particular attention should be paid to the potential for ground subsidence. Areas of known or potential coal extraction at a depth of less than 30 m below ground level are indicated on the shallow coal workings map (in pocket).

The areas delineated are generalised and in considering particular sites it is essential to consult the original documents (held by British Coal) from which information has been abstracted. Workings known from mine plans (held by British Coal) can be anticipated and taken into account when planning, but areas of probable or possible working are much less predictable.

Evidence for shallow mining not recorded on plans is derived from such surface features as old shafts or bell pits and collapsed ground. Ancient, unrecorded workings may occur at shallow depth in any area where a coal thick enough to be worked lies near the surface. The possibility of shallow workings near the outcrop of coal seams must always be borne in mind in both the planning and construction phases of any development and appropriate site investigation should be carried out. Mine shafts are shown on both the geological map and the borehole and shaft site map. The sites of all shafts known to BGS and British Coal have been plotted, but others may exist.

Barytes Mining. Small scale workings for barytes are known in the Rosegill and Greengill areas (see p 50). The deposits occur here as vertical veins up to 0.61 m wide in faults. Several shafts up to 12.8 m deep were sunk. The extent of workings is unknown but was certainly small and is likely to have been confined to driveages no more than 1 m wide across the vein, probably amounting to a maximum of 100 m along each vein. No stoping is known to have taken place. Small voids may remain in these old workings but they are unlikely to present a significant hazard unless development is considered in their immediate neighbourhood.

Other features to be considered in development

1. *Landslips* have been mapped on the north side of the River Ellen at [0780 3783] The slips have occurred in Boulder Clay at locations where the valley slopes have been oversteepened and the banks undercut by river erosion. The presence of sand and gravel lenses within the Boulder Clay, which covers most of the valley slopes, may promote the infiltration of groundwater leading to softening and weakening of the clay mass and localised zones of increased pore pressures. Oversteepening and undercutting of the lower slopes by river erosion, which effectively stresses the slopes by removal of support, may lead to mass movements in the form of shallow translational and/or rotational landslips. Care should be taken not to undercut further the toe of the bank or load the top in slipped areas, or in other locations where similar geological conditions exist, as this may re-activate existing slips or trigger new ones, unless appropriate remedial measures are taken.

Where construction activities are proposed, a site investigation and subsequent appropriate stability analysis should be carried out to assess the effect of the construction work on the stability of the slope.

2. *Swallow holes*. Swallow holes are numerous on the exposed limestone outcrops and in addition several are known to penetrate a few metres of the overlying solid strata or drift. Sites of individual swallow holes and areas in which they are particularly numerous are shown on the accompanying swallow hole map. Other swallow holes may be present beneath drift deposits and their detection is often difficult. No large voids or caves are known in the limestones of the district. However their possible presence and that of drift-covered swallow holes should be borne in mind when planning construction work in limestone country.

3. *Flooding*. The villages of this district are sited well above river levels and flooding is not a major problem. The largest river, the Ellen, even during the wettest periods of the year, now has a regulated flow so most surface run-off is discharged without flooding the flat alluvial tracts along its course.

   Where minor flooding does occur in the district it is caused by artificial disturbance of the natural drainage. Examples are present around some pit tips and railway embankments.

4. *Seismicity*. The only known records of seismic activity originating within the district are those of two very minor earthquakes with epicentres in the Maryport area; they may have been a result of collapse of old mine workings, though the possibility of a connection with the Maryport Fault or a related major fracture is not inconceivable. The effects of larger earthquakes have also been felt in the district (Musson 1987). The Carlisle earthquake of 26 December 1979 caused minor damage at Dearham (Musson, Neilson and Burton 1984). This is not justification for regarding the district as exceptional and prone to seismic activity but here, as elsewhere in the country, the possibility of seismic events of unusual intensity does exist and should be taken into consideration when designing sensitive structures.

5. *Waste disposal and ground contamination*. The suitability of old excavations in the district for disposal of waste is limited. As most of the excavations are in permeable formations, for example limestone or sandstone, the type of waste material must be carefully monitored to ensure that the leachate does not contaminate nearby streams or groundwater. Similarly percolation into the underlying formations must be slow enough to ensure natural detoxification and adequate dilution.

   At the time of writing (June 1988) the only active waste disposal site is High Close Quarry [146 381] in the Fifth Limestone, which is being filled with domestic refuse.

CONCLUSIONS AND RECOMMENDATIONS

1. Extensive coal mining in the past now places restraints on planning or development, especially in areas where coal has been mined at shallow depth. Subsidence associated with the collapse of old workings will be greatest over areas of shallow ancient pillar and stall workings, some of which may be unrecorded. The possible presence of unrecorded shallow workings should be taken into account before any development is contemplated in such areas as those near the outcrop of coal seams and appropriate site investigation carried out. There are numerous shafts, many of which are poorly documented. Many shafts are likely to have been left untreated, or inadequately treated after abandonment.

2. Subsidence from deep mines is likely to be complete but local settlement may still be anticipated.

3. Particular attention should be paid to the physical properties of clay and mudstone formations especially in the Lower Carboniferous where certain beds may exhibit bentonitic characteristics. These may require that special consideration is given to the assessment of excavations and foundation conditions.

4. The groundwater chemistry of all mudstones and siltstones should be established where significant sulphate content may require particular precautions regarding concrete type.

5. The till which covers much of the district generally provides good foundation conditions. Slopes in drift may fail if overloaded or over-steepened or if the clay mass becomes locally weakened.

6. Made ground, particularly that filling old quarries, poses problems of uneven settlement and of differential settlement for structures straddling the boundary of any backfilled site. There are a few backfilled opencast coal sites but the positions and former depths of these are well documented.

7. Numerous swallow holes occur in areas of the Dinantian and Namurian limestone outcrop. These may be concealed beneath superficial deposits. Their possible presence should be taken into account before any development is contemplated in these areas and appropriate site investigatins should be carried out.

8. The district contains resources of coal which could be worked by opencast methods.

9. The district contains resources of limestone.

10. Resources of sand and gravel are restricted to a small area near Crosscanonby though the amounts present are very limited.

11. Sandstone and limestone have been quarried locally for building stone. Large scale working for building stone is unlikely in the future since most of the rocks are unlikely to meet present day specifications. However they could be worked for low quality aggregate or constructional fill.

12. The present district and adjoining areas may be worth investigating for economic deposits of barytes and research of the area's potential for buried base metal deposits should be considered.

13. Widespread old mining in the coalfield areas has disturbed the natural hydrogeological regime and lowered the quality of groundwater. Significant quantities of potable groundwater are unlikely to be obtained from these areas although additional supplies may be available from the Lower Carboniferous outcrop.

14. The potential for waste disposal in old excavations is limited as most of these excavations are in permeable formations. Careful selection and monitoring is required to ensure that leachate from waste materials does not contaminate nearby streams and groundwater.

15. The results of this study give a basis for assessing in general terms parts of the area in which significant mineral resources might be sterilised by other types of development. This could give opportunities for options such as avoidance of development, or extraction prior to development, to be properly examined.

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APPENDIX 1. Details of Lower Carboniferous (Dinantian) stratigraphy.

The stratigraphical classification adopted here for the Lower Carboniferous has been outlined above. Descriptions which follow are based both on observations made during the resurvey and those given by Eastwood *et al.* (1968) some of which have been revised in the light of more recent work. Faunal lists given here have been obtained from existing publications and have been revised.

Dinantian

Lower Liddesdale Group

Sixth Limestone and overlying beds. Only the upper 20 m of this formation crop out in the east of the district at Parsonby and in the extreme south, south of Moota Hill. Much of the outcrop is concealed beneath boulder clay but the limestone has been worked in the large but now considerably overgrown quarry at Parsonby [1453 3826], where Eastwood recorded the following section:-

Fifth Limestone:	
Limestone, dark grey	2.74 m
Sandstone, fine-grained	1.52 m
Limestone conglomerate	0.46 m
Shale	0.91 m
Sixth Limestone:	
Limestone, dark grey	11.89 m seen

Today only the lowest limestone is clearly exposed though traces of the overlying beds may be seen in places in the degraded and overgrown upper parts of the face.

In the extreme south of the district a bed of fine-grained pale fawn and brown speckled sandstone overlies the Sixth Limestone.

Fifth Limestone and overlying beds. The outcrop of this limestone is, like that of the Sixth Limestone, largely concealed beneath boulder clay. Its thickness is therefore difficult to estimate accurately though seems to be up to 40 m. The lowest beds were formerly exposed in the top part of Parsonby Quarry (see above) and High Close Quarry [1461 3809] once provided a good section through part of the formation. This quarry is today used as a domestic rubbish dump. The following section was recorded in 1987:

Limestone, medium grey, thickly bedded, alternately massive and nodular beds	3.00 m
Mudstone, pale grey, calcareous, abundant irregular limestone nodules	approx 1.00 m
Limestone, medium grey, nodular beds common	4.50 m
Limestone, medium grey, thickly bedded	approx 8.0 m

Eastwood *et al.* (1968, p 163) record *Lithostrotion junceum, L. [Nematophyllum]* cf. *minimus, L. pauciradiale, Echinoconchus punctatus, Gigantoproductus* cf. *edelburgensis* and *G.* cf. *latissimus.*

The uppermost 5.8 m of the Fifth Limestone, consisting of thickly bedded medium grey limestone, are exposed in the old quarry [1433 3833] at the foot of Parsonby Brow. Eastwood *et al.* (1968) described 1.8 m of shales overlying the limestone though these are not clearly visible today.

Other quarries showing up to 5.0 m of medium grey limestone within the upper part of the Fifth Limestone may be seen south of Parsonby Brow [eg 1464 3745 and 1477 3684].

Up to 14 m of beds, probably mainly mudstone, are interpreted as overlying the Fifth Limestone in this district.

Upper Liddesdale Group

Fourth Limestone and overlying beds. Following the practice of previous workers, notably Eastwood *et al.* (1968), the term Fourth Limestone has been retained for the 130 m or so of strata, composed predominantly of limestone, which overlie the Fifth Limestone and mudstone. These beds comprise the lowest formation of the Upper Liddesdale Group as recognised in the present district. In detail the stratigraphy of the Fourth Limestone is rather complex. The Fourth Limestone sequence of the Cockermouth area, immediately to the south of the district is a little over 50 m thick and is almost exclusively limestone. Within this Eastwood *et al.* (*op cit)* have distinguished the individual units named by Edmonds (1922) in the Fourth Limestone of the Egremont-Lamplugh area. Traced north-eastwards across the present district individual limestones and interbedded strata thicken with the incoming of Yoredale cyclical sedimentation. Figure 7 illustrates the passage from the dominantly limestone facies of west Cumbria to the typical Yoredale facies of east Cumbria and the northern Pennines. North of Wardhall

Common four limestones separated predominantly by mudstones are mappable. In the neighbourhood of Moota Quarry [146 363] these interbedded strata are less clear and appear to be thinner though a ganister-sandstone is prominent on the south side of Moota Hill [eg 1434 3603]. Around Millstone Moor [1365 3590] the Fourth Limestone is generally concealed beneath boulder clay and details of the stratigraphy are unknown.

There are numerous exposures of Fourth Limestone within the district. Many quarries have worked the formation in the past and extraction continues today at Moota Quarry [146 363]. The lowest few metres of the limestone exposed in small outcrops [1488 3561 and 1477 3573] on the south side of Moota Hill contain a few chert nodules. The abandoned eastern quarry at Moota [148 362] provides the following section through the lower part of the Fourth Limestone:

Limestone, medium grey, massive, some large *Productids*	1.30 m
Limestone, medium grey, thickly bedded, locally nodular	1.10 m
Mudstone, dark grey, laminated non-calcareous, appears to die out to east	0.03 m
Limestone, pale fawn, compact, locally porcellanous, shell and crinoid debris common	2.75 m
Mudstone, pale grey and fawn, plastic	0.25 m
Mudstone, pale grey, abundant partially rounded limestone nodules	1.00 m*
Limestone, pale grey, nodular	1.50 m*
Limestone, medium grey, thickly bedded, shell debris	1.30 m
Limestone, pale grey, nodular	0.20 m
Mudstone, pale grey, laminated	0.10 m
Limestone, pale grey, nodular	0.30 m*
Limestone, medium grey, thickly bedded, some nodular beds	5.30 m
Sandstone, dark grey, fine-grained, wispy-bedded, coaly streaks	0.06 m
Mudstone, pale grey, fine-grained sandstone lenses	1.30 m*
Limestone, pale grey, nodular	0.30 m*
Limestone, medium grey, thickly bedded, some large *Productids*, becoming compact and splintery in lowest 1.0 m	4.00 m*
Sandstone, pale fawnish grey, fine-grained, wispy bedded	0.10 m
Mudstone, dark grey, some fine-grained sandstone laminae	0.15 m
Mudstone, pale fawn, faintly laminated	0.60 m
Limestone, pale fawn	0.12 m
Limestone, pale grey, nodular	1.50 m seen

*These beds are inaccessible in the quarry face

Sections through progressively higher parts of the Fourth Limestone were formerly visible in the extensive abandoned Wardhall Quarries. These are overgrown today and the following records are taken from Eastwood *et al.* (1968, pp 163-164).

Eastern quarry [139 382]:

Limestone, dark, weathers rough	0.90 m
Limestone, pale grey, brown-skinned, sandy	0.30 m
Limestone, compact, light grey, some dusky patches	0.90 m
Limestone nodules in shale	0.30 m
Sandstone, fine, grey-blue, with brachiopods	0.20 m
Shale and clay, soft, sandy, with nodules of pyritous limestone	0.50 m
Sandstone, hard, fine, white	average 0.20 m
Fireclay, white, sandy	0.90 m
Sandstone, pale blue, shaly	0.90 m
Shale, sandy, pale blue with occasional dark bands	0.60 m
Limestones, grey to white, occasionally nodular with abundant *Saccamminopsis fusinaformis*	10.10 m
Shale, dark	0.20 m
Limestone, grey, pseudobreccia	0.60 m seen

Fossils recorded from here include *Caninia juddi*, *Corwenia rugosa*, *Lonsdaleia duplicata*, *L. floriformis*, *Nemistium edmondsi*, *Echinoconchus punctatus*, *Productus* (*Gigantoproductus*) cf. *edelburgensis*, *P.* (*G.*) *latissimus*, *Spirifer* cf. *duplicostata* and *S.* cf. *trigonalis*.

Middle Quarry [1393 3803]:

Sandstone, thin-bedded	0.90 m
Shale, grey-black, slightly sandy	0.90 m
Shale, soft, black	0.60 m
Coal, inferior, with sandstone floor	0.15 m
Not exposed	1.20 m
Limestone, mostly blue-grey, frequently nodular and in part "spotted"	9.60 m
Limestone, pale grey	0.30 m

The lowest limestone of Middle Quarry section is almost certainly the highest bed of the Eastern Quarry.

Saccammiopsis is reported to be abundant almost throughout the sequence. Other fossils recorded include species of *Lithostrotion*, *Aulophyllum fungites*, *Avonia davidsoni* and *Echinoconchus elegans*.

Western quarry [1357 3819]:

Sandstone, white to pink, fine to coarse	2.40 m
Shales, dark, with thin earthy limestones rich in *Lithostrotion junceum*	3.70 m
Limestone, thin-bedded in upper part, many fossils	4.60 m
Shales, dark, with thin pyritous limestones at top, small ironstone nodules below; many fossils	2.70 m
Limestone, thin-bedded	1.10 m
Shale, dark, blue-grey	0.60 m
Limestone, compact, pale grey with dark spots; nodular and brown-skinned in places	0.30 m
Shales, dark, with earthy limestone in middle	1.20 m
Limestones, mainly grey, with two shale bands in upper half	7.60 m
Coal, top poor and smutty, better below	0.15 m
Fireclay, dark, weathering yellow	0.05 m
Shale, dark	0.30 m
Limestone, earthy, nodular in part, many large *Productids* including *Gigantoproductus latissimus*	0.15 to 0.2 m
Coal, good, bright	0.18 to 0.2 m
Fireclay, dark grey	0.05 m
Limestone, dark, earthy	0.30 m seen

Fossils recorded from the beds above the upper coal include *Fasiculophyllum* cf. *densum*, *Lithostrotion junceum*, *Echinoconcus elegans*, *Gigantopdoductus* cf. *latissimus*, *Phicochonetes* cf. *buchianus*, *Pustula pustulosa* and *Phipidomella michelini*.

The quarry on Parsonby Brow [1434 3828] is reported by Eastwood *et al.* (1968, p 163) to yield *Girvanella* though the fossil is said to have been rare. Doubtful specimens of *Girvanella* were also noted in the large quarry [1398 3863] west of Parsonby Farm. No specimens were found at either locality during the resurvey.

Up to 6.1 m of shales and sandstones which overlie the Fourth Limestone were noted above in the western quarry section at Wardhall. Mapping in the rather poorly exposed ground to the west and south of this quarry indicates that as much as 40 m of generally fine to medium grained, and locally coarse-grained sandstone, occupy the interval up to the base of the Third Limestone.

South of Wardhall, around Millstone Moor an appreciably thinner fine grained siliceous sandstone or ganister separates the Fourth and Third Limestones. This sandstone forms a conspicuous line of crags to the north of Millstone Moor Farm [1365 3615] and has been quarried at several places [1340 3594, 1388 3666 and 1396 3659].

Third Limestone and overlying beds. The Third Limestone is up to 10 m thick. It is generally poorly exposed though small outcrops may be seen in an un-named stream at Wardhall Gate [1296 3832] and in small, and now largely obscured quarries near Eweclose [1335 3802]. On the south side of Tallentire Hill the limestone is overlain by the Orebank Sandstone which here may be up to 50 m thick. This sandstone has been worked in two quarries [1210 3551 and

1200 3530] where somewhat overgrown sections today show a few metres of fine-grained white sandstone. In the northern quarry the sandstone is overlain by a few metres of sandy and silty mudstone. All the beds above the Third Limestone were termed Orebank Sandstone by Eastwood *et al.* (1968, p 159) though the term is preferred in this account only for the sandstone. Traced north-eastwards towards Gilcrux these beds maintain, or slightly increase in thickness, but sandstone is largely replaced by mudstone. A sandstone was formerly worked in small pits [1318 3800] south of Wardhall Gate, though these have now been obliterated.

Second Limestone and overlying beds. The second Limestone is up to 8 m thick. The best exposures are on Tallentire Hill where it has been quarried near the top [1218 3571]. It consists of pale grey thickly bedded limestone with abundant crinoid debris. The limestone forms a low but conspicuous bench feature to the south and east of Top Wood [134 364] and also to the east of the radio beacon on Wardhall Common [138 373]. Little is known about the estimated 7 m of beds above the Second Limestone as they are rarely exposed. Up to 0.5 m of fine to medium-grained brown sandstone is exposed immediately beneath the First Limestone in an old quarry [1186 3555] on the south west side of Tallentire Hill.

APPENDIX 2. Details of Upper Carboniferous (Namurian) stratigraphy.

First Limestone. This unit is up to 15 m thick. It is well exposed in numerous old quarries on Tallentire Hill [120 358], near Tallentire Hill Farm [120 364] and on Wardhall Common [1370 3719]. In all of these localities it is a medium grey, thickly bedded fossiliferous limestone, locally with thin shaly partings along uneven or wavy bedding planes. Scattered crinoid debris is common and brachiopods and corals may be seen in places.

Hensingham Group

Hensingham Grit. A maximum thickness of about 25 m is estimated for this unit which overlies the First Limestone. There are no good exposures in the district but small sections of sandstone may be seen in old pits south of Gilcrux [1167 3763]. Coarse gritty sandstone and flaggy sandstone are exposed in rather disturbed sections beneath boulder clay in the stream [1152 3722] to the south west.

Between Grange Grassings [132 369] and Top Wood [132 363] the wide outcrop of Hensingham Grit has been worked in numerous small pits. Almost all are now degraded or filled but abundant spoil shows massive coarse-grained rather feldspathic sandstone. At several pits near Top Wood the sandstone contains impregnations of pink baryte.

Strata above the Hensingham Grit. In the ground north and west of Tallentire exposures of the Hensingham Group are almost entirely confined to the neighbourhood of Rose Gill and its tributary Greengill Beck. In the general area of the confluence of these two streams, strata dipping westwards at from 10 to 17°, are cut by two faults trending about north-north-westwards and both carrying baryte (p 0). In Rose Gill the lowest visible bed, its top located in the stream about 100 metres upstream from the Greengill Beck confluence, is a sandstone which is presumbed to be some distance stratigraphically above the limestone recorded in the footwall of the Greengill Vein. A section upwards from this sandstone bed to strata immediately east of the Rose Gill Vein is as follows:

Mudstone, grey with brachiopods in lower part at least	5.50 m
Limestone, grey with brachiopods	c1.80 m
Mudstone, grey	c1.00 m
Sandstone	0.75 m
Mudstone	c2.00 m
Sandstone (ganister) with root markings	at least 1.50 m

These beds, notably the limestone and its associated mudstones are also exposed along the lower part of Greengill Beck.

Immediately to the west of the fault and barytes veins in Rose Gill, Eastwood (1930) recorded about 4.65 metres of sandstone and mudstone overlain by 0.38 m to 0.60 m of dark fossiliferous limestone. From this limestone [0910 3740] Eastwood (*op. cit.*) listed *Aulophyllum fungites* (Flem.) *Caninia* cf. *denticulata*, *Productus costatus*, *P.* cf. *longispinus*, *Pustula punctata*, and *Spirifer* sp. (*bisculatus* group). He estimated that the strata in the Rosegill-Greengill Beck outcrops lay about 100 m below the base of the Coal Measures.

Further west, in a gully [0870 3770] west-south-west of Rosegill Hill a bed of dark-grey limestone, 0.6 m thick, is considered to lie within the Hensingham Group. The strata in this area lie between the Mother Pit and Birkby faults, and are thought to be separated by a north-north-westwards trending fault from the Coal Measures of the former Birkby Colliery.

West of Dearham, strata of the Hensingham Group occur in an elongated north-north-westwards trending fault-bounded outcrop with exposures in the railway cutting east of Birkby Mill and along the valleys of the River Ellen, and its tributaries. The strata in these localities dip south-westwards at angles from 5 to 20°. The lowest beds exposed, on the south bank of the River Ellen and immediately west of the Dearham Fault, consist of 5 m of siltstone, silty mudstone and fine-grained sandstone overlain by hard (?silica-cemented) of fine- to medium-grained sandstone with intercalations of silty mudstone in its lower part. Higher beds in the railway cutting include mudstone and sandstone overlain by a coal about 0.15 m thick. This coal is probably that recorded west of Birkby Mill in the Birkby Mill borehole [0520 3695] at a depth of 25 m (see Appendix 6).

Loose blocks of decalcified shelly limestone recorded by Eastwood (1930) in the tributary valley north of the borehole site may represent an 'ironstone' bed, one metre thick at a depth of 7.6 m in the borehole. A similar rock, higher in the sequence was formerly exposed "in a highly disturbed condition" on the north bank of the River Ellen, south of Ellen Bank. Both occurrences are associated with mudstones. From the second locality [0508 3695] Eastwood (*op. cit.*) records: *Buxtonia scrabicula*, *Choenetes hardrensis*, *Productus latissimus*, *Productus* cf. *longispinus*, cf. *Schellwienella crenistria*, *Sanquinolites striato-lamellosus*. On the south bank of the river and in cliffs to the west interbedded sandstones and silty mudstones with ironstone concretions are overlain by several metres of hard, fine to medium-grained, possibly silica-cemented, sandstone.

A borehole [0589 3600] drilled near Hayborough penetrated a sequence mainly of sandstone and mudstone in the upper part of the Hensingham Group (see Appendix 6). Eastwood (1930) suggested a correlation of the highest sandstones on the south bank of the River Ellen with beds in the lower part of the Hayborough borehole. This correlation which includes strata containing the decalcified limestones described above is acceptable, but only if there is a smaller thickness of limestone between Hayborough and the valley of the Ellen. A limestone 4 m thick at a depth of 135.32 m in the Hayborough borehole cannot be matched in the Ellen valley sequence. It is possible that the mudstones and limestones in the borehole are stratigraphically higher than any beds exposed in the valley of the Ellen.

The sum of the Hensingham Group thicknesses in the Hayborough and Birkby Mill boreholes, a figure in excess of 400 m, provides a reasonable minimum thickness for the group in this general area. Below the level of the limestone beds near the top of the bore, the Birkby Mill sequence is an alternation of mudstone and sandstone with occasional thin coal seams.

North-west of the Maryport Fault, the Bankend Borehole (see Appendix 6) [0512 3845] (Smith 1921), proved a minimum thickness of 511 m for the Hensingham Group. It comprises mainly mudstone and sandstone with a few thin coals, comparable with the succession at Birkby Mill.

About 4 km ENE of Bankend, the strata between the base of the Coal Measures and the First Limestone comprise some 150 m of mainly sandstone and mudstone. It was proved in the Crosby Borehole [0824 3961], and in a drift north west of Crosby Colliery [0912 3859] (see Appendix 6). The Crosby Borehole was almost devoid of limestone above the First Limestone but the Crosby Drift passed through a number of limestone horizons within the Hensingham Group.

It would appear that a distinction can be drawn in the district between the Hayborough-Birkby Mill Bankend-Blue Dial area, in which the Hensingham Group is of the order of 500 m+ thick and the Allerby-Rose Gill-Tallentire area in which the thickness is little more than 150 m.

Mudstones, in places with clay ironstone nodules, and sandstone laminae, are exposed in Leathers Gill between the Gilcrux to Arkleby road [1243 3805] and Grange Grassings [1317 3701]. At the time of the previous survey Eastwood noted brachiopods in these shales but gave no identifications. In addition Eastwood noted a 0.1 m thick "de-calcified limestone with shells" in Leathers Gill [1313 3702] though this was not confirmed during the re-survey.

A sandstone, up to 12 m thick, is exposed in Leathers Gill south of High Flatt Farm [1250 3785] and has been quarried [1249 3766]. The sections are overgrown but both show massive coarse and fissile fine-grained sandstones.

Medium-grained flaggy sandstones, a few metres beneath the inferred base of the Coal Measures, are exposed in Flatts Beck, east of Arkleby [1481 3943].

APPENDIX 3. Details of Upper Carboniferous (Westphalian) stratigraphy.

Lower Coal Measures

The **Subcrenatum Marine Band** has not been recorded within the Dearham-Gilcrux district. Its position at outcrop shown on the geological map is therefore conjectural. The strata between the assumed stratigraphical position of the marine band and the Albrighton Seam are about 13 - 18 m thick and include sandstone. In the area east of Crosby a 0.45 m coal, which occurs about 9 m below the Albrighton coals, probably represents the **Harrington Four-Foot Seam** but is not present further to the south-west.

The **Albrighton seams** with associated marine bands are well-developed in the Crosby area and coal at this level has been extensively worked south of the River Ellen from Birkby Colliery. North of the river the two principal Albrighton seams are each about 0.45 m thick and separated by 1.68 m of seatearth. The **Albrighton Marine Band** is recorded above the higher of these two seams. The **Templeman's Marine Band** was proved only 2.10 m above the Albrighton Marine Band immediately overlying a 0.20 m coal. These marine horizons have not been detected in the sequence to the north-east and may die out within the Crosby area. The **Albrighton Marine Band** has yielded *Lingula* and **Templeman's Marine Band** *Lingula* and *Rectocornuspira*. Strata between the Albrighton group of seams and the **Lower Three Quarters Seam** are about 13 - 16 m thick, with mudstone overlain by sandstone. The mudstones carry a substantial non-marine fauna assigned to the lower part of the *Communis* zone. A faunal list for the Crosby are and localities at this horizon south of Maryport comprises *Anthraconaia sp.*, *Curvirimula* cf. *trapeziforma*, *Carbonicola bipennis*, *C. torus*, *C.* sp. *cristagalli*, *C. communis*, and *Naiadites flexuosus*. Fish scales and ostracods occur at the base.

The **Lower and Upper Three Quarters seams** are separated by 15 m of strata, mainly sandstone, in the western part of the area near Birkby. The thickness diminishes, with loss of sandstone, to about 10 m southwards towards Dearham, and to about 12 m towards the north-east. In the area south of Dearham the Lower and Upper Three Quarters seams are 0.38 m and 0.41 m, increasing north and east to 0.58 m and 0.76 m respectively in the Crosby area.

Strata between the Upper Three Quarters Seam and the Six Quarters Seam show a northerly increase in thickness from above 20 m at Dovenby Close, south of Dearham to 34 m at Mother Pit in the Crosby area. There is an accompanying increase in the proportion of sandstone in the lower part of this sequence. A mussel band occurs in mudstones above the Upper Three Quarters Seam. *Carbonicola* and fish scales have been recorded at this horizon. A 0.23 m coal, 7.6 m above the Upper Three Quarters Seam, is present south of Birkby. In the area north of the River Ellen the **Six Quarters Seam** is 0.65 m thick west of Mother Pit. In the shaft section the thickness is 0.53 m separated by 0.66 m of seatearth from a leaf of coal 0.05 m thick below. Farther east in the ground south-east of Crosby the coal is absent owing to washout. Strata between the Six Quarters and Lickbank seams are mostly sandstone, and about 10-12 m thick. The sandstone commonly descends through the sequence to form the roof of the Six Quarters Seam, hence the name **Six Quarters Rock**, and is in places associated with a washout in that seam. However west of Mother Pit a mudstone roof with fish remains and non-marine shells is preserved above the Six Quarters Seam. At this horizon, in Crosby No. 6 Bore, *Carbonicola* cf. *cristogalli?* and *C.* aff. *pseudorobusta* were recorded. Midway between the Six Quarters and Lickbank seams there is a coal, 0.18 m thick.

The **Lickbank Seam** varies in thickness from 0.45 m - 0.82 m and has been worked in the Dearham area. The thickest coal is near Mother Pit and Bullgill.

Between the Lickbank and Eighteen Inch seems the strata, including sandstone, are about 14 m thick in the neighbourhood of Crosby, diminishing southwards to 8 m near Dovenby Close and to 10 m in an east-north-easterly direction towards Bullgill.

The **Eighteen Inch Seam** is mostly about 0.50 m thick. There is a mussel band in the roof of the coal. An exposure, probably of this seam, was discovered during this resurvey at the collapsed mouth of an old adit [0754 3744] on the south side of the River Ellen at the former Birkby Colliery. The fauna from the coal roof was identified by Mr P J Brand and includes *Anthraconania* sp., *Anthracosia regularis*, *Anthracosphaerium* sp., *Carbonicola* cf. *oslancis*, *Naiadites* aff. *flexuosus*, *N. quadratus/flexuosus*, *Carbonita* sp., *Grisina arcuata*.

The **Little Main Seam**, up to 0.65 m thick, is a persistent valuable and extensively worked coal. From a mussel band in the seam roof the following fauna has been recorded: *Anthraconaia* sp., *Anthracosia* cf. *regularis, Carbonicola* cf. *bipennis, Geisina arcuata, Carbonita* sp.

The strata between the Little Main Seam and the Vanderbeckei (Solway) Marine Band are estimated to be about 15 m thick and contain two seams near Dovenby Close south of Dearham. The lower of these, the **Two Foot** or **Dovenby Brassy Band** varies from 0.69 m to a thickness in excess of one metre, but with partings. The higher seam, the **Half Yard**, is 0.28 m thick. Sandstone is prominent throughout this part of the sequence in the Dearham area but dies out towards Bullgill. North-east of Bullgill a seam referred to as the **Two Foot** is of uncertain affinities but may be equivalent to the Half yard elsewhere in the Coalfield.

Middle Coal Measures

The **Vanderbeckei (Solway) Marine Band** has not been recognised in the Dearham-Gilcrux area but its position is inferred to lie 13 - 15 m above the Little Main Seam. The strata above the presumed position of the marine band contain a thin seam, 0.15 m thick, about 2 m below the Yard Seam. This is the **Lower Metal Seam** of the Dearham area and possibly represents the Lower Yard further south.

The **Yard Seam** up to 0.86 m thick, has been extensively worked in the Dearham, Rosegill, Bullgill-Gilcrux and Oughterside areas. The strata between the Yard Seam and the base of the group of seams known as the **Main Band** are about 20 m thick, and contain two thin coal seams, the lower of these known as the **Lower Metal** north-east of Bullgill.

The **Cannel Seam** is the lowest element of the group of three seams known as the **Main Band**. In the Dearham area, where there are extensive workings, the Cannel Seam is in close contact with the second seam, the Metal Band, which both to the north and the south is separated from the Cannel Seam by several metres of strata. The aggregate thickness of the Cannel and Metal Band at Dearham is about 2.70 m. At Crosby Pit the separate Cannel Seam is over 2 m thick with partings, diminishing to 0.76 m at Bulgill and 0.45 m at Oughterside where the seam splits into two leaves. The Cannel-Metal Band interval expands to 9 m in the ground north-east of Bullgill where a thin seam known as the **Metal Stringer** occurs near the top of the interval.

The individual **Metal Band Seam** in the Crosby-Bullgill area is up to 1.08 m with partings, and a maximum thickness of 1.04 m has been recorded north-east of Bullgill. The seam has been worked recently in the Oughterside Opencast Site. In the Oughterside area the seam is commonly split by 0.27 m of black mudstone which separates a top leaf up to 0.34 m from a bottom leaf up to 0.43 m. The roof here is typically of dark grey mudstone and the floor of grey seatearth.

The **Thirty Inch (Crow) Seam** which constitutes the top element of the Main Band, is generally a single seam, up to 0.84 m thick in the Dearham area, 0.91 m near Bullgill and 1.10 m at Oughterside Colliery and at the opencast site at Oughterside. There are up to 15 m of strata, mainly mudstone and sandstone, between the Thirty Inch Seam and the Bannock seams. A coal, 0.15 m thick, is present in this interval at Dearham.

The **Bottom Bannock Seam**, probably equivalent to the **Breck Band** of Rosegill Pit and the Jane and Ellen pits at Bullgill, attains a thickness of 1.02 m in the Oughterside area. It has been worked in the Oughterside Opencast Site where the thickness rarely exceeded 0.25 m and is affected by washouts. A thin unworked coal, the **Top Bannock Seam** is present locally between 2 and 4 m above the Bottom Bannock. It is presumed that one of these two coals is the correlative of the Bannock Seam of Dearham. Between 3 and 6 m of strata, mainly mudstone and sandstone separate the Top Bannock Seam from the Rattler Seam.

The **Rattler Seam**, up to 0.82 m thick, was worked in the Dearham area but in the Rosegill and Bullgill areas is a split seam of indifferent quality, which with partings spans up to 1.83 m of strata at Jane Pit, Bullgill, and as much as 3.65 m at the nearby Ellen Pit. The sequence at Ellen Pit may, however, include a representative of the **Top Bannock Seam**. North-east of Bullgill the Rattler Seam reaches a maximum thickness of 0.82 m, although it is generally a little thinner than this in the Oughterside opencast workings. Here the seam is underlain by grey mudstone or seatearth, with a roof typically of black canneloid mudstone.

The strata between the Rattler and Ten Quarters seams vary from 14 m at Dearham, diminishing to 9 m at Bullgill and to 6 m at Oughterside Colliery.

The Oughterside opencast workings exposed medium-grey mudstone with regularly spaced bands of clay-ironstone nodules. Fissures in many of these nodules contain white kaolinite, pale brown siderite crystals and scattered crystals of pyrite and chalcopyrite. One band of nodules contains small clusters of millerite crystals (Young and Nancarrow 1988A).

The **Ten Quarters Seam** is one of the most widely worked and better quality seams in the coalfield. A split seam with partings, it attains a thickness of between 1.50 and 2.10 m in the Dearham and Bullgill areas. It has been worked almost to outcrop from Oughterside, Westmoor and Bullgill collieries and has been extracted at Oughterside Opencast Site where the floor of the coal is of seatearth and there is typically a mudstone roof. In the western part of the opencast workings a lower leaf up to 0.58 m thick is separated by only 0.05 m of mudstone from an upper leaf which is about 1.9 m thick. The split increases to 8.0 m eastwards in the workings though with the upper and lower leaves, retaining more or less their original thicknesses. Spectacular old pillar and stall workings have been exposed in the seam in the Oughterside Opencast Site (see cover photograph). In places the worked-out 'stalls' have remained open and when entered in the course of opencast operations the coal was found to be encrusted in places with creamy-yellow earthy jarosite, vivid yellow copiapite, white epsomite and the rare sulphates pickeringite and rozentite (Young and Nancarrow 1988B).

The strata between the Ten Quarters and Slaty seams are mainly mudstone with an increase of sandstone in the Dearham area, where a thin coal seam occurs about 30 m above the Ten Quarters Seam. At Dearham, the thickness of the Ten Quarters-Slaty interval is 29 m, decreasing north-eastwards to 18 m at Jane Pit, Bullgill and to 10.6 m at Oughterside Colliery.

The **Slaty Seam**, a coal typically split by a parting, varies in maximum aggregate thickness from 0.30 m, locally in the Dearham area, to 1.72 m at Bullgill where at the Jane Pit a lower leaf 0.25 m thick is separated by mudstone from an upper leaf 0.86 m thick. A parting of a little over a metre thick in the Slaty Seam in the western part of the Oughterside Opencast Site diminishes eastwards. This is consistent with the absence of a split in the seam at Oughterside Colliery. Opencast extraction of the two components of the seam was carried out at Oughterside, where old workings in the Upper Slaty Seam have been exposed. Yellow crusts of copiapite have been observed locally on the coal (Young and Nancarrow 1988B). About 5 to 12 m of strata, mainly mudstones and sandstones lie between the Slaty and the succeeding Little Seam.

The **Little Seam**, up to 0.45 m thick at Dearham, attains thicknesses of 0.56 m and 0.51 m at Jane Pit, Bullgill, and Oughterside Colliery respectively. There is no evidence that this seam has been worked. Little more than a metre of strata separate the Little Seam from the overlying White Metal Seam at Crosby Pit. Elsewhere the thickness is greater, reaching about 5 m at Jane Pit and up to 12 m farther to the north-east.

The **White Metal Seam**, 1.05 m thick at Lonsdale Pit, Dearham diminished to 0.35 m at Crosby Pit. It is 0.51 m thick at Oughterside Colliery. It is not reported to have been worked and at Dearham was said to be 'brassy', ie rich in pyrite. Old shafts on the west side of Flatts Beck [1488 3974] were sunk to a coal which may be at the horizon of the White Metal. Two thin coals crop out immediately to the east. They may possibly relate to the horizon of the Little, White Metal or Fireclay seams. Up to 12 m of strata intervene between the White Metal and Fireclay seams, and at Dearham there is a thin coal 8 m above the White Metal.

The **Fireclay Seam** is up to 2.03 m thick, with partings and has been recorded at the Lonsdale Pit, Dearham, Rosegill Pit and Jane Pit, Bullgill. The seam does not appear to have been worked. Ten to 14 m of mainly mudstones lie between the Fireclay Seam and Black Metal Seam. At Dearham and Bullgill there is a thin coal 9 m above the Fireclay Seam.

The **Black Metal Seam (=Brassy Band)** is about 0.15 m thick at Lonsdale Colliery, Dearham. It is thin at Rosegill Pit and unrepresented elsewhere. About 15 m higher in the sequence at Rosegill Pit there occurs another thin coal, the highest seam preserved in the Dearham-Gilcrux area. This may relate either to the Mabel or Brassy seams of the area south of Maryport (Barnes *et al.* 1987) and probably approaches the inferred position of the **Aegiranum (Bolton) Marine Band.**

The upper part of the Coal Measure sequence preserved in the Dearham-Gilcrux area is affected by secondary reddening and is known to be devoid of seams at stratigraphical positions which elsewhere in the coalfield would be occupied by coals. The positions of the surviving seams and the distribution of red colour can be expressed in relation to the persistent White Metal Seam. In the Dearham district the highest known seam is 27 m above the White Metal and is succeeded closely by the incoming of red colour. At the Rosegill Pit the highest seam preserved is 31 m above the White Metal and is succeeded by red strata only 3 m higher. In the Crosby Pit the highest seam is the White Metal itself but the red colouration begins here 20 m above the seam. Again in the Ellen Pit, Bullgill, the highest seam is the White Metal, but red colouration is not recorded until 30 m higher. In the section at the Jane Pit, Bullgill, the red colouration begins just below the highest preserved seam at 23 m above the White Metal. Therefore although the recorded reddening penetrated down generally to a level 20 to 30 m above the White Metal Seam, the related oxidation of the coal seams has been effective in places as far down as the White Metal. The absence of seams in the interval between the White Metal and the Ten Quarters seams at Ellen Pit possibly indicates oxidation of the less resistant seams at even lower levels.

The strata preserved above the White Metal Seam, between the Crosby and Rosegill faults, is shown by the Rosegill Pit section to be at least 114 m thick. The higher reddened mudstones and sandstones of this sequence appear in exposures along the valley of the River Ellen between Rosegill and Crosby pits. The lower beds of the reddened zone include exposed sandstones, formerly mapped as 'Whitehaven Sandstone', at the head of Garley Gill near Dearham. Reddened strata were recorded in the shaft at Oughterside Colliery at levels above the Black Metal Seam.

APPENDIX 4. Details of Permo-Triassic stratigraphy.

St Bees Shales

In south-west Cumbria, the St Bees Shales are considered to span the Permian-Triassic boundary (Arthurton *et al*. Table 4 *in* Moseley 1958).

In the Bankend Borehole [0512 3845] the red mudstones comprising the St Bees Shales are about 81 metres thick, with a thin breccia (0.90 m) at the unconformable base. The Crosby Borehole [0824 3961] near Allerby proved about 50 m whilst a borehole on the coast at Blue Dial, [0724 4066], a short distance north of the area, showed 65.5 m of St Bees Shales (see Appendix 6).

St Bees Sandstone

The principal exposures of the St Bees Sandstone are in the intertidal zone on the coast north of Bankend, and in disused quarries [0760 3990] on either side of Brunshow Beck north-north-east of Crosscanonby. Sandstone was formerly quarried [0895 3933] east of Allerby Hall and poor exposures exist in Garley Gill [0510 3770]. The outcrops show red-brown massive, laminated and cross-laminated sandstone up to one metre thick with thin intercalations of silty mudstone. The sandstone is fine- to medium-grained, mainly quartzose and micaceous in places.

APPENDIX 5. Details of mineralisation.

Baryte ($BaSO_4$) mineralisation is widespread and conspicuous at outcrop throughout the Lower Carboniferous rocks of the district. Trials have been made in two fault veins of baryte up to 0.61 m wide in the Hensingham Group in Rosegill [0912 3741] and Green Gill [0928 3752] west of Gilcrux. Examples of the mineral lining joints and minor fault fissures in limestone may be seen in many quarries. Baryte also coats fissures in some sandstones and locally the Hensingham Grit is impregnated with the mineral. In most exposures the baryte coatings are up to 12 cms thick. They commonly consist of pink, relatively compact crystalline baryte adjacent to the wall-rock, becoming white or colourless towards the centre of the vein. In some instances, notably at Wardhall Quarry [1347 3832], a crudely banded texture is conspicuous with open vugs in the centre of the veins up to 4 cm wide and as much as 3.0 m long elongated parallel to the bedding of the wallrock. Into these vugs project well developed white or colourless tabular crystals in characteristic 'cockscomb' aggregates. In the old quarry in the First Limestone north of the radio beacon on Wardhall Common [1365 3718] baryte forms large imperfectly developed tabular white crystals up to 15 cm across coating joint surfaces. White crystalline baryte up to 20 cm thick fills a small north-north-east trending fault in the northernmost workings of Moota Quarry [1421 3653]: horizontal slickensiding is conspicuous on the baryte. White baryte up to 1 cm thick coats a joint in Hensingham Grit in an old sandstone quarry [1167 3763] south of Gilcrux.

Pale pink baryte occurs as joint coatings on coarse-grained Hensingham Grit in old sandstone pits south of Grange Grassings [1329 3659 and 1325 3640] where the mineral also forms conspicuous but patchy impregnations between the grains of sandstone. From the degraded and overgrown state of these pits it is impossible to assess the proportion of the sandstone so affected but from the remaining debris and from stone incorporated into adjacent dry walls it is clear that baryte is abundant. Similar joint coatings and impregnations in coarse-grained sandstone may be seen in old pits on Wardhall Common [1395 3729]. This sandstone is in an area of structural complexity but is interpreted as the sandstone beneath the Third Limestone.

Baryte has also been noted forming crystalline coatings up to 5 mm thick on ganister excavated from the bed of Flatts Beck [1445 3923] near the outcrop of the Gilcrux Fault.

In all of these occurrences baryte is the dominant mineral: only in Moota Quarry has associated chalcopyrite been observed. The only other associated minerals noted are goethite, in part at least replacing original siderite or ankerite, and a little calcite. These minerals clearly post date baryte deposition. In a few instances the limestone wallrock is partially dolomitised for a few millimetres adjacent to the baryte vein. The baryte mineralisation is clearly epigenetic. In places the mineralisation is developed close to major faults, for instance in the Hensingham Grit near Grange Crossings, in the sandstone and limestone on Wardhall Common and in the ganister in Flatts Beck. Elsewhere the mineralisation is relatively remote from these larger fractures though they could well have acted as feeders for the mineralising fluids.

Baryte found lining fissures in a clay ironstone nodule in the spoil from Fretchville Pit [1045 3807], Gilcrux is likely to be of diagenetic origin.

Copper mineralisation. Chalcopyrite $CuFeS_2$ has been noted *in situ* in several locations and both chalcopyrite and malachite are common in soil brash in places.

Massive chalcopyrite in patches up to 5 cm across and 1 cm thick, locally associated with baryte and dolomite, is present in narrow, almost northerly trending, veins and joint fillings in the Fourth Limestone in the central part of Moota Quarry [1430 3630]. Elsewhere in the quarry [eg 1415 3648] chalcopyrite has been observed, generally as isolated crystals on dolomite and calcite, lining joints which trend betwen 350° - 230° in the Fourth Limestone. A few specimens from Moota show chalcopyrite associated with pale brown sphalerite and a little pyrite. Malachite commonly encrusts the chalcopyrite.

Traces of malachite were seen in a 15 mm wide calcite vein lining a joint in the First Limestone in an old quarry west of Tallentire Hill [1185 3574]. A little dolomite is also present. On the east side of Tallentire Hill malachite, accompanied by a little chalcopyrite is common in blocks of brecciated and reddened sandstone in the base of a hedge [1235 3590]. Other minerals noted in this material include red earthy hematite, goethite, calcite, quartz and a little aragonite. Abundant soil brash approximately 200 m further south [1233 3570] shows much reddened sandstone together with blocks up to 10 cm across composed of pale brown dolomite with some earthy hematite. Some baryte and rare traces of malachite have also been seen here. Blocks of siliceous sandstone in a dry wall [1207 3600] at the foot of the northern side of Tallentire Hill exhibit coatings of quartz, goethite, some of which pseudomorphs pyrite, and some malachite. Tallentire Hill is virtually free of any form of superficial deposit other than weathered bed-rock. The mineralised rock seen at these points appears to have been obtained locally. It is probable that the mineralisation occurs along one or more small faults which have been mapped in this area. The sandstone wall rock seen in the loose blocks is probably the sandstone between the Third and Fourth Limestone.

Scattered crystals of chalcopyrite up to 1 mm across are present in abundant veinlets lined with crystallized siderite, pyrite, millerite and rare sphalerite in a bed of clay ironstone nodules approximately 4.0 m below the Tenquarters seam at Oughterside Opencast Site [110 398]. This mineralisation is likely to be of diagenetic origin (Young and Nancarrow 1988A).

Zinc mineralisation. Pale brown sphalerite (ZnS) has been observed at one point in Moota Quarry accompanying chalcopyrite in dolomite veinlets (see above). A few crystals of sphalerite, probably of diagenetic origin, accompany other sulphides in clay nodules at Oughterside Opencast Site.

Iron mineralisation. A little pyrite (FeS_2) accompanies chalcopyrite and sphalerite in dolomite veinlets at Moota Quarry (see above). Small crusts of dark brown mammillated goethite ($Fe^{+3}O(OH)$) coat the brecciated Fourth Limestone on the west side of the fault between the old and new workings of Moota Quarry [1463 3627]. Goethite and red earthy hematite (Fe_2O_3) accompany copper minerals on Tallentire Hill

[1233 3570] (see above).

Nickel in the form of millerite (NiS) occurs as delicate capillary crystals in clay ironstone nodules beneath the Tenquarters seam at Oughterside Opencast site (Young and Nancarrow 1988A). The mineral is accompanied by pyrite, chalcopyrite and siderite. This occurrence closely resembles those described from the Coal Measures of South Wales by North (1928). These sulphides are likely to be of diagenetic origin.

Hydrocarbons. Small pockets of solid black bitumen have been collected from an outcrop [1334 3801] of Third Limestone near Eweclose Farm, Plumbland. The bitumen is not accompanied by any other introduced minerals. It does however resemble closely bitumens recently found in mineralised fault and joint veins in First Limestone at Park Head Quarry, Caldbeck [340 407] and Tendley Hill Quarry, Eaglesfield [088 288] and like these occurrences may have been introduced during a mineralising episode.

Dickite. Small pockets and veinlets of the clay mineral dickite ($Al_2Si_2O_5(OH)_4$) occur in the Fifth Limestone east of Wardhall Common [1462 3748] and near the base of the Fourth Limestone south of Moota Quarry [1468 3561]. In the latter occurrence the limestone also exhibits veinlets of baryte. The dickite has probably been introduced during the mineralising process.

APPENDIX 6. Summary logs of boreholes mentioned in the text.

	Thickness	Depth
BIRKBY MILL BOREHOLE [0520 3695] (NY 03 NE 5)*		
Superficial deposits	4.50	4.50
Hensingham Group		
Mudstone and sandstone	2.20	6.70
Ironstone	0.92	7.62
Mudstone and sandstone	17.21	24.83
Coal	0.17	25.00
Mudstone and sandstone with several coal seams	283.00	308.00

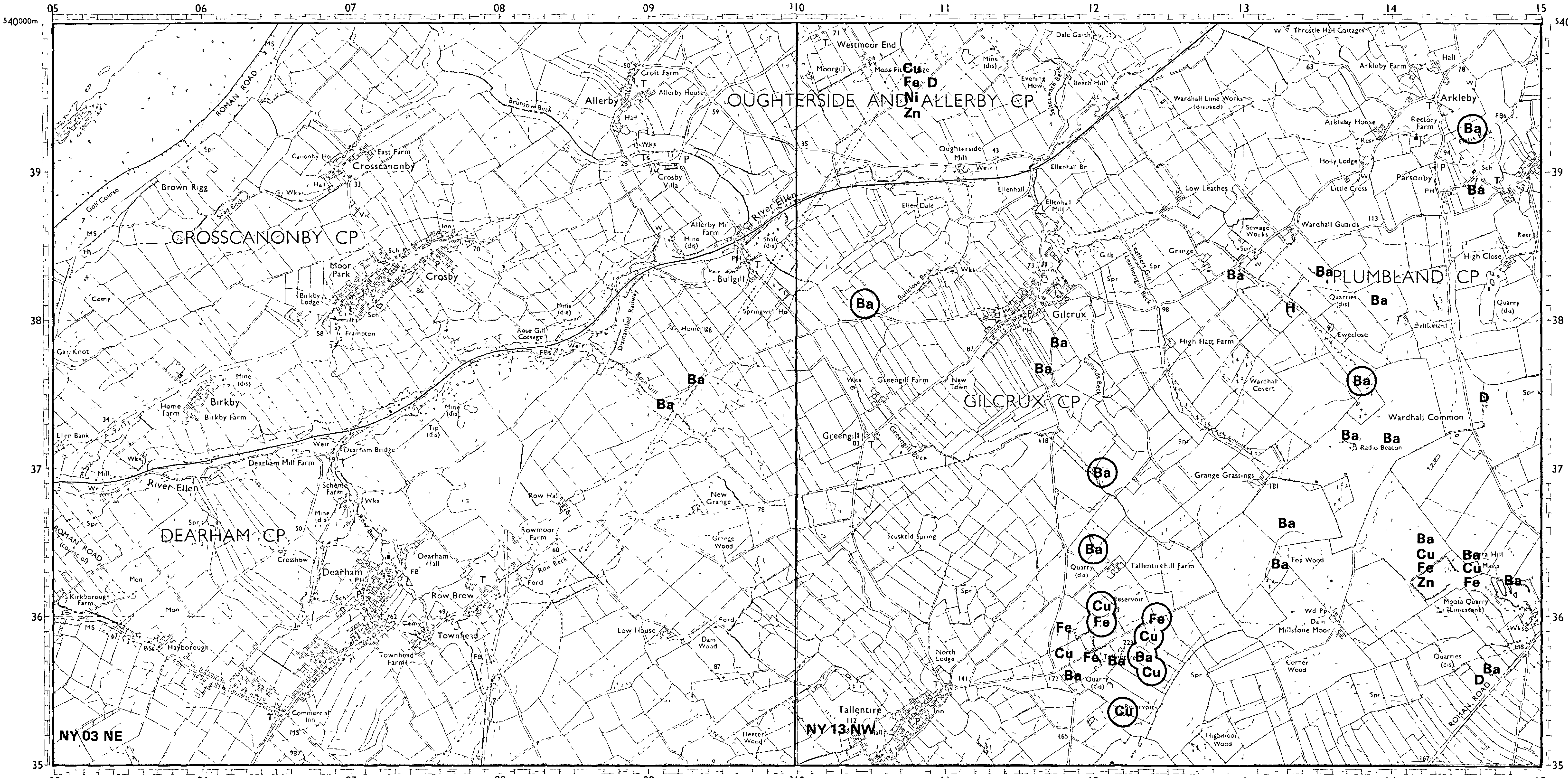
*Numbers shown thus are the registration numbers of boreholes in the BGS field records collection.

	Thickness	Depth
HAYBOROUGH BOREHOLE [0589 3600] (NY 03 NE 4)		
Superficial deposits	10.82	10.82
Hensingham Group		
Mudstone, sandstone and siltstone	41.14	51.96
Coal	0.07	52.03
Sandstone, mudstone and siltstone	30.41	82.44
Sandstone and siltstone with three limestone bands	48.62	131.06
Limestone	4.26	135.32
Sandstone and siltstone	1.84	137.16
BANKEND BOREHOLE [0512 3845] (NY 03 NE 3)		
Superficial deposits	10.36	10.36
St Bees Sandstone	75.64	86.00
St Bees Shales, with basal breccia	81.00	167.00
Coal Measures		
Mudstone, sandstones, coal seams	135.00	302.00
Hensingham Group		
Mudstones and sandstones with thin coal seams. A thin fossiliferous limestone at 433.60 m	511.00	813.00
CROSBY BOREHOLE [0824 3961] (NY 03 NE 32)		
Superficial deposits	2.74	2.74
St Bees Sandstone	50.30	53.04
St Bees Shales	49.98	103.02
Coal Measures		
Mainly mudstone with coal seams	58.52	161.54
Hensingham Group		
Mainly mudstone and sandstone	157.59	319.13
First Limestone	10.05	329.18

	Thickness	Depth
CROSBY NORTH DRIFT [0412 3859] (NY 03 NE 28) (inclined drift starting at Little Main seam in No 1 or Crosby Pit)		
Lower Coal Measures		
Mainly mudstones and sandstones with coal seams below horizon of Little Main seam	109.73	109.73
Hensingham Group		
Mainly sandstone and mudstone	20.43	130.16
Coal	0.30	130.46
Sandstone and mudstone with several beds recorded as "coarse or bastard limestone". Section terminates at fault (Maryport Fault or a branch thereof). Colliery debris at surface was recognised by T Eastwood as identical in appearance with Hensingham Grit, and First Limestone and both of these beds are presumed to have been cut near the termination of the drift.	135.20	265.66
BLUEDIAL BOREHOLE [0724 4066] (NY 04 SE 1)		
Superficial Deposits	12.34	12.34
St Bees Sandstone	138.53	150.87
St Bees Shales, with basal breccia	65.84	216.71
Lower Coal Measures		
Mainly mudstone and sandstone with thin coal seams. Stained red in upper	250.85	467.56
Hensingham Group		
Mudstone and sandstone	254.14	721.70

MINERALISATION

SHEETS NY 03 NE & NY 13 NW



MINERALISATION SEEN IN SITU

Ba	Baryte
Cu	Copper minerals
D	Dickite and Kaolinite
Fe	Iron minerals
H	Hydrocarbon
Ni	Nickel minerals
Zn	Zinc minerals

MINERALISATION NOT SEEN IN SITU e.g IN SOIL BRASH OR LOOSE BLOCKS SHOWN THUS - (Ba)

This map should be read in conjunction with the accompanying geological report The Geology of the Dearham and Gilcrux area, Cumbria (Young,B and Armstrong,M 1987)

Any enquires regarding this map should be directed to -

British Geological Survey,
Windsor Court,
Windsor Terrace,
Newcastle upon Tyne, NE2 4HB

SCALE 1 25 000

0 1 2

kilometres

THIS MAP IS TO BE USED ONLY FOR PRELIMINARY STUDIES AND IS NOT INTENDED AS A SUBSTITUTE FOR ON-SITE INVESTIGATION

THIS MAP GIVES AN INTERPRETATION OF DATA AVAILABLE AT THE LAST DATE OF SURVEY. ADDITIONAL INFORMATION IS AVAILABLE IN BGS FILES

STRUCTURE CONTOURS

SHEETS NY 03 NE & NY 13 NW

Area contoured in Little Main Seam

Area contoured in Harrington Four Foot Seam

Area contoured on base of First Limestone

Area contoured on base of Fourth Limestone

Area contoured on base of Fifth Limestone

Coal Outcrop

Fault at outcrop, crossmark indicates downthrow side. Many minor faults omitted.

Contours in seam or on base of formation

Broken lines denote uncertainty

SCALE 1:25 000

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kilometres

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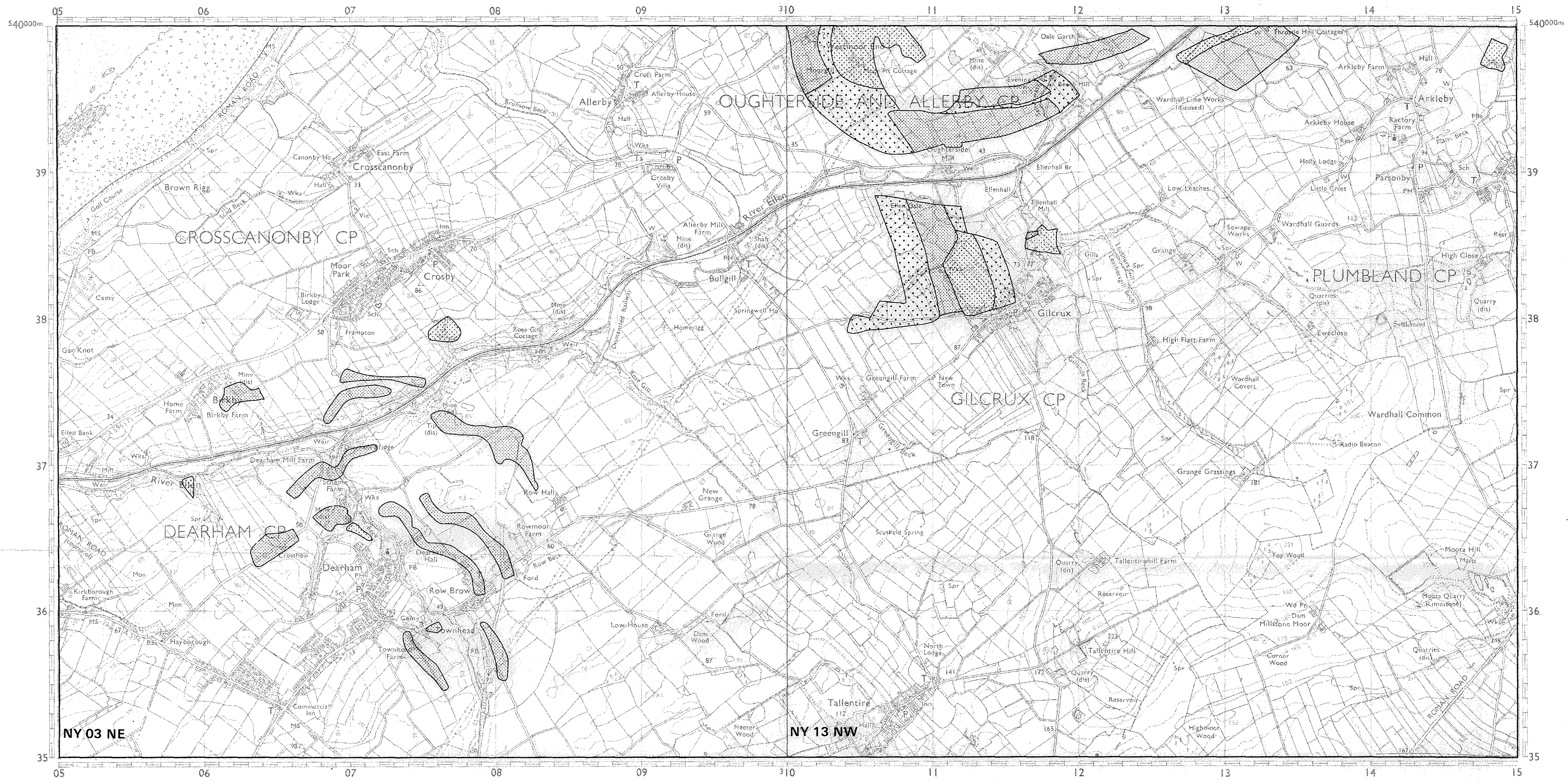
SHALLOW COAL WORKINGS

SHEETS NY 03 NE & NY 13 NW



MINE WORKINGS WITHIN 30 METRES OF GROUND SURFACE

- Workings recorded on plans
- Some evidence for mining from surface features or borehole data, no plans available
- Local workings possible
- Workings absent within 30 metres of surface (includes areas where old workings have been removed during opencast excavations)

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