The stratigraphy and structure of the syncline of stainmore

H. G. Reading

THE STRATIGRAPHY AND STRUCTURE

OF THE

SYNCLINE OF STAINMORE

BY

H. G. READING, B.A., F.G.S.

The Stainmore Area is a topographical and geological depression lying between the two upstanding block areas of the Northern Pennines. The succession includes beds of Yoredale facies of the Middle and Upper Limestone Groups, overlain by "Millstone Grit", the total time range extending from late P_2 age, probably to late E_2.

Detailed mapping of marine horizons has enabled the establishment of correlations between the successions of the Alston Block to the north and the Askrigg Block to the south. They show that marine conditions were more persistent to the south and east of the Stainmore Area. Millstone Grit facies enters at a lower horizon in the east and west of the Stainmore Area than it does in the centre. The grits on the flanks correspond to the Tanhill Grits of N.W. Swaledale and are considered to pass laterally into the Coalcleugh Transgression Beds in the centre. This is demonstrated by equating the Upper Felltop Limestone of Alston with the Hearne Beck Limestone of Upper Swaledale. An upper horizon of grit facies is subjacent to the Botany Limestone and is considered to be the equivalent of the First Millstone Grit of Durham and the Water Crag Grit of Upper Swaledale, the Botany Limestone corresponding to the

Shunner Fell Limestone.

The structure consists of an asymmetrical syncline, pitching gently to the east, with two small elongated domes to the south. The fault pattern on the east is similar to that of the Alston Block; on the west a semi-radial pattern is apparent. Joint directions are varied.

The area has been affected by both the Stainmore and Teesdale glaciers, the former being dominant only at first, and showing evidence of a minor readvance and second retreat.

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Being an account of the work carried out at the Geology Department, Durham University (Durham Division) during the period 1951-1954 under the direction of Professor Dunham, D.Sc., Ph.D., S.D., M. Inst. M.M.

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I INTRODUCTION.

(a) Geography.

(i) Situation. Physiographically the Northern Pennines extend from the Tyne Gap in the north to the Aire Gap in the south though geologically the southern boundary is usually taken to be the Craven District. They consist of high moorland intersected by narrow dales. West of the northern half is the Lake District which is separated from the Pennines in the north by the Vale of Eden but which is connected further south by Shap Fell. The steep scarp of the western Pennines contrasts with a more gentle slope on the east, the dales running down in the latter direction towards the Durham Coal-field and Vale of York.

Across the middle of the Northern Pennines lies the Stainmore Pass. Strictly speaking this is the narrow shoulder at the head of the river Greta through which the main road and railway now run from Bowes but in geological literature, particularly on glaciology, the Stainmore gap is taken to be that area of relatively low lying ground between Lune Forest and Stainmore Forest. This area is roughly 100 square miles in extent and in this account is known as the Stainmore Area.

(ii) Relief. The geographical importance of the Stainmore Area does not lie in the fact that its altitude is particularly low. The pass at the head of Wensleydale into the River Eden is under 1200' O.D. while the Stainmore Pass is just 1400' O.D. It is however the 'waist' of the Northern Pennines and the low ground is not confined to one narrow valley but extends for nearly 8 miles in a north-south direction.

In the west a steep scarp overlooks the head of the Vale of Eden into which run short steep streams, the most important of which are Swindale Beck, Borrowdale Beck and Yard Sike. The greatest altitude in the area is reached at the top of the scarp, from which the ground slopes away gently towards the east. There is a thin strip of country over 1500' O.D. from the scarp to just beyond the County Boundary, broken only by the Stainmore Pass itself and by the pass between Birkbeck Gill, a tributary of Borrowdale Beck, and Black Beck. The two highest points are Iron Band at 1843' O.D. in the north and Great Knipe at 1689' O.D. on the southern extremity of the high ground. Since they are both formed from the same stratum, they reflect the synclinal nature of the rock structure.

East of the watershed the streams run in a direction just north of east into the Middle Tees. The two most powerful are the River Lune and River Greta, the former draining the Lune Forest on the north of the Stainmore Area, and the latter draining the Stainmore Forest on the south. In the centre there are two main valleys, Baldersdale and Deepdale. The former is now the more important for it has captured Hunder Beck which in pre-glacial times made a third stream probably larger than either of the other two.

Between these valleys there are ridges which also slope gently towards the east. The highest is the ridge between Lunedale and Baldersdale, known to geologists as the Botany Ridge (Carruthers 1938). It maintains an altitude of over 1250' O.D. to within two miles of the Tees and then drops rapidly. The other ridges fall more gradually from about 1500' O.D. at the County Boundary towards the River Tees which at Barnard Castle is just under 450' O.D.

<u>(iii) Climate.</u> The Stainmore Area shows considerable variations of climate, particularly of rainfall. The average annual precipitation at Barnard Castle is about 30 ins. and it increases towards the west until it is over 55 ins. Cloud cover also increases in the same direction particularly with a westerly wind and as the increase corresponds with a rise in altitude there are substantial changes in the vegetation of the area.

<u>(iv) Vegetation.</u> In Teesdale the land is mainly enclosed as permanent grassland, though a few fields may be ploughed for crops of potatoes or oats. Cultivation extends up all the valleys and there may even be enclosed fields on the tops of the ridges between. In general however above the cultivation line in the east, Fescue grassland is dominant, particularly between Baldersdale and Deepdale. Patches of heather-moor also occur as far east as Lamb Hill, but they become more frequent towards the west until the centre of the area is almost entirely covered by it. Further west the rainfall becomes too high for heather-moor and bog vegetation replaces it with its characteristic cotton sedge.

Although the type of vegetation is mainly governed by altitude and rainfall, artificial considerations are important. Grouse are reared and sheep are grazed. The heather is burnt and the bogs are drained, both operations tending to increase the range of heather-moor beyond its natural range of moderate rainfall, between 35 ins. and 45 ins. (Pearsall, 1950). An example of this is along the County Boundary west of the Lunehead Mines. Heather on the Yorkshire side ceases suddenly when the boundary is reached, though there has been no fence along the boundary for some years. The reason is that in the past grouse shooting and the consequent encouragement of heather growth has been greater in Yorkshire and its effects are still apparent today. More recently the encouragement of draining hill pastures has reduced the area of bog vegetation considerably, particularly in those patches where it is due to local topography rather than rainfall.

(b) People.

Since the days of the "Beaker People" about 1800 B.C. the Stainmore Pass has been used by man as a means of communication between east and west England (Fleure 1951). However, though there are four tumuli of unknown origin near Bowes, nothing definite is known of the history of the area prior to the Romans.

The Romans built a major fort at Bowes (Lavatrae) which has been partially excavated, a smaller one at Maiden Castle overlooking the Vale of Eden, and there is also a rhombus shaped camp on the summit of the Stainmore Pass, just east of the County Boundary. These were to guard the Roman Road which followed the direction of the present main road except that a detour with a more gradual gradient has recently been built round Maiden Castle. It is apparently this detour which is the most frequently blocked part of the road after a heavy snowfall. The old Roman Road, being more exposed, usually remains clear of snow.

Beside the road, at the summit and within the Roman Camp, is the Rey Cross which was put up in the 10th century by King Edmund to mark the boundary between England and Scottish Cumberland. Its name was employed by the old geological surveyors for a limestone which outcrops at that point. This has now been shown to be the Little Limestone.

The Norman castle at Bowes exemplifies the importance of the Stainmore route during the Middle Ages and during the 12th century a mediaeval hospital was founded at the spot where a farm called the Old Spital now stands. The name Coach and Horses to a farm half-way across the moor also illustrates the use of the road during coaching days. However the coming of the railway did temporarily eclipse the road, for during the 19th century it reverted to a grass track, and it was not till the present century that it was revived to become one of the country's most important trunk routes.

It is not possible to say when the Stainmore Area was first inhabited, but the sprinkling of Norse place-names in Lunedale (Ramsden 1947, p.90) may be significant. Certainly castles in Teesdale were built in the 12th century at Barnard Castle and a little later at Cotherstone, but it was probably the 18th century before the outlying districts, away from the villages, were enclosed (Raistrick 1946) though no doubt summer pasturing had already been carried on for some time.

Today it is apparent that the population is declining. Quite apart from the closure of the Lunehead Mines, farms have recently been abandoned, such as Soulgill House in Lunedale, Water Knott in Baldersdale and Levy Pool in Deepdale. The maximum altitude for habitation varies in the different valleys depending as much on the presence of alluvial flats for hay growing and on communications as on altitude. Old Spital at 1350' O.D. is the highest in the Yorkshire part of the area but Windmore End, in Westmorland, lies at 1400' O.D. On the other hand in Lunedale no farm is over 1250' O.D. and in Baldersdale 1150' O.D. is the highest point of habitation, though Botany Farm in the east of the area is situated just below the top of the Botany Ridge at 1250' O.D.

Railways only fringe the Stainmore Area; the one crossing the Stainmore Pass was completed in 1861 while the one up Teesdale to Middleton was opened in 1868. In those days there were many tracks across the area suitable for horse carts but many of these have since fallen into disuse. For instance, one is clearly marked on the map from God's Bridge in the River Greta to Race Yate, between Deepdale and Baldersdale, and it is part of the present 'Pennine Way', but on the ground not even a footpath can be found. On the other hand a track from north Baldersdale to Wham in Westmorland can still be traced quite easily and could be traversed by a jeep.

There are two main roads, one going from Middleton-in-Teesdale to Brough in the north, and the other from Bowes to Brough in the south. These make the form of a U open to the east since they are joined at the base of the U by a minor road running from North Stainmore. The open side of the U is closed by a road from Bowes which meets the main Teesdale road at Cotherstone. Following the valleys into the area from Teesdale are minor roads up the south side of Lunedale and up both sides of Baldersdale. Thus no part of the area is more than three miles from a road.

(c) Geology.

<u>(i) General</u>. The Stainmore Area is a physiographic and geological depression lying between the two upstanding halves of the Northern Pennines. The area was mapped geologically on a scale of 6 inches to 1 mile, the limits being taken, where possible, at the base of the Four Fathom Limestone. At the places where such low strata did not reach the surface the boundary was drawn in the north at the Lunedale Fault and in the south at approximately the line of the Stainmore Summit Fault. No natural boundary offered itself in the east so precise mapping was concluded at the National Grid line 400. An arbitrary boundary also had to be drawn in the N.W. corner of the map at a convenient line just west of Swindale Head.

The strata included in the survey range from the base of the Four Fathom Limestone to the top of the Botany Limestone; that is, they include, in lithological terminology, the top of the Middle Limestone Group, the whole of the Upper Limestone Group, and part of the Millstone Grit. The Middle and Upper Limestone Groups are separated at the base of the Great Limestone, though there is no agreement in their position in relation to coral-brachiopod zones (Dunham 1948, pp.10-11). The base of the Millstone Grit however is not well defined and in fact varies in horizon throughout the Stainmore Area. Nevertheless, with the lack of precision of coral-brachiopod zones and the lack of information on goniatite zones, it is essential to use the lithological divisions.

Thus the term 'Yoredales' is employed for strata of the Middle and Upper Limestone Groups which show alternations of limestone, shale and sandstone. The term 'Millstone Grit' is used for strata with a similar cyclic deposition but with substantial and persistent grit (as defined below p. 13) in place of the sandstone. No precise line can be drawn between these two facies and they do grade into one another.

In the goniatite scale the range of strata extends from the top of P_2, probably to the top of E_2, though there is no direct evidence from within the Stainmore Area.

The stratigraphy has been divided into cyclothems or units of rhythmic deposition, the bases of which were taken to be the bottom of the marine members. Only those marine horizons have been used which it was considered extended with certainty throughout the Stainmore Area, so that many of the cyclothems include minor marine bands and are in effect composite cyclothems. The names of the basal members have been employed to designate each cyclothem.

The nomenclature of the beds in the Stainmore Area presented a problem. The north of the area coincided with the work of Carruthers (1938) and Dunham (1948), both of whom have used successions from the Alston Block. The south of the area, though not actually in contact, was adjacent to areas covered by the authors of the Mallerstang Memoir (1891), Hudson (1924, 1925, 1941) and Chubb and Hudson (1925), all of whom used the nomenclature of the Askrigg Block. In addition Turner (1935) covered the western edge of the Stainmore Area using a mixture of Alston and Askrigg Block terminology. Finally, the primary geological survey employed different names for the same strata in different parts of the area.

As Turner's map is the only one since the primary survey to overlap with the present account, his nomenclature is used wherever possible for the primary names of each stratum, though for his 'Felltop Limestone' the suggestion of Hudson (1941) that they should be renamed 'Stonesdale Limestones' to avoid ambiguity has been accepted. Secondary names for each stratum are also used on the map and in the description. For instance, in Lunedale, Alston Block terminology is used exclusively and around Bowes the names in use in North West Swaledale are employed. The principle was to name strata after those known beds with which correlations were most definite.

Turner's map ceased at his 'Millstone Grit' (the Transgression Beds Grit of the present survey) and so the beds above have either been given new names, where no names existed before, or else have followed the Alston Block terminology. The only stratum which previously had a name exclusive to the Stainmore Area is that of the Botany Limestone.

Each cyclothem is illustrated in one or more figures containing vertical sections, which are lettered, their position being shown on an accompanying key map. The letters are occasionally employed in the text to refer to a particular section. The numbers in the text, when three figures or less, designate rock specimen numbers; six figure numbers are National Grid Reference Numbers, the lines of which are shown on all the major maps. As far as possible all place names are taken from the 2½ inch map, though the name Rowton Sike is used at the Lunehead Mines for the continuation of Dowcrag Sike, and an unnamed stream flowing from the south into the Grassholme Reservoir just below the bridge is called No Name Beck.

The six-inch maps used were Yorkshire, North Riding, 3 N.E., 4 N.W., 4 N.E., 5 N.W., 3 S.W., 3 S.E., 4 S.W., 4 S.E., 5 S.W., 10 N.E., 11 N.W., 11 N.E., 12 N.W., 11 S.W., 11 S.E., 12 S.W., 22 N.W., 22 N.E., and Westmorland 16 N.E., 17 N.W., 16 S.W., 17 S.W., 17 S.E., 24 N.W., 24 N.E. The geological boundaries were later transferred to the scale of 1 : 25,000 or approximately 2½ inches to 1 mile, using parts of Sheets 35/82, 35/92, 35/81, 35/91. These sheets were the basis of the final copy of the geological map.

(ii) Symbols, Abbreviations and Colours: The symbols and abbreviations on the 6 inch maps are as follows:-

Geological boundary, certain	Black line, continuous.
" " conjectured	" " discontinuous.
Fault, certain	Red line, continuous.
" conjectured	" " discontinuous.
Mineral Vein	Orange line.
Base of feature	Blue line, arrow towards base.
Boundary of glacial drift	Continuous black line, with ticks towards drift.

Dips are shown by the continental type of strike line; an arrow indicates the direction of the depositional dip.

Limestone	Lst.
Sandstone	Sst.
Shale	Sh.
Chert	Ch.
Grit	Gr.
Ganister	Ga.
Seatearth	Seat.
Siltstone	Silt.
Mudstone	Mud.
Coal	C.
Ironstone	Ir.
Conglomerate	Congl.
Flags	Fls.
Boulder Clay	B.C.
Carbonaceous	Carb,C.

Sandy	Sa, S.
Shaly	Sh.
Fossiliferous	Foss, F.
Nodular	Nod, N.
Flaggy	Fl.
Compact	Co.
Muddy	M.
Argillaceous	Arg.
Siliceous	Sil.
Calcareous	Ca.
Pebbly	P.
Hard	Hd.
Very	V.
Broken	Br.
Loose	L.
Black	Bl.
Weathered	W.
Specimen no. or Notebook reference	(345)
Swallow Holes	S.H.S.

The colours used on the 6-inch and 2½ inch maps are as follows:-

Superficial:	Alluvium	Brown Ochre, pale.
	River Terrace	" " dark.
Solid:	Limestone	Prussian Blue.
	Chert	Violet.
	Sandstone	Chrome Yellow, pale.
	Grit	" " dark.
	Ironstone	Orange.
	Shale and unknown	Blank.

(iii) Grit. The retention of the term 'grit' needs some apology. Originally the coarse sandstones which dominate the strata between the Carboniferous Limestone and the Coal Measures were called 'grits' and thus gave the name Millstone Grit to that series of strata. Westgarth Forster, for instance, (p.54) uses the term Millstone Grit to designate a stratum which had a coarser grain than freestone. The old geological surveyors also used the term 'grit' to describe a similar rock.

On the other hand, modern petrographical custom is to restrict the name 'grit' to a sandstone composed of angular grains and on the whole the larger the grain size of the sandstones the more rounded the grains become. However in the Cambrian of the Harlech Dome, for example, 'grit' is used to describe sediments containing detrital fragments ranging from 0.2 mm. to 20 mm. in size with a shape that varies from angular to rounded (Matley and Stacey Wilson, 1946). In the Jurassic the 'calcareous grits' are only slightly arenaceous, the 'grittiness' being due to quartz grains or shell fragments which stand out on the surface when the calcareous cement has been weathered away.

Furthermore, Gilligan (1919) in his classic account of the petrology of the Millstone Grit uses the term grit for the coarser sediments. He does not give a precise definition of grit or sandstone but after distinguishing three grades of grit with their largest pebbles (1) over ½-inch, (2) less than ½-inch and (3) less than ¼-inch in diameter, he mentions sandstone with the largest pebbles less than ⅛-inch (c. 3 mm.) in diameter, though the average grain size must be considerably smaller.

Thus it appears that while the petrographer has a restricted definition of the word 'grit', the stratigrapher uses it in a much broader sense to embrace many types of rock whose only common factor is a certain 'roughness of feel'. In this sense the term 'grit' may be employed for the coarse sandstone of the Yoredales and Millstone Grit, and there is also a classical precedent for its use.

It does not imply the same exactitude as one of the standard dimensional classifications. These are of little use to the field mapper who cannot give a precise definition to an exposure several square yards in extent.

In this account the term sandstone has been used for rocks with a grain size of roughly between 0.05 mm. and 0.25 mm. and the term grit for rocks with a grain size above 0.25 mm., i.e. with grains that can be clearly seen with the naked eye. Where it is difficult to decide to which division an exposure or specimen should belong, it has been mapped or recorded as a coarse sandstone. Some grits contain pebbles which are distinctly larger than the average grain size and may be several centimetres in diameter. These rocks are called pebbly grits.

(d) History of Research.

(i) Stratigraphy. Although the lead miners of the Northern Pennines had undoubtedly already recognised and named many individual beds (Dunham 1948, p.8) the geological succession of Alston Moor was first published in Westgarth Forster's 'Treatise on a Section of the Strata from Newcastle-upon-Tyne to Cross Fell' (1809, 1821). The earliest geological map was due to Winch (1817) who described the general geology of Northumberland and Durham. A few years later Phillips published his 'Illustrations of the Geology of Yorkshire, Part II, the Mountain Limestone' (1836) in which he showed that the Yoredale Beds and Millstone Grit of Wensleydale and Swaledale could be followed into Teesdale.

The next phase of research was the primary six-inch geological survey which started in the Northern Pennines about 1865 and included the Stainmore Area. The Yorkshire portion of the area was mapped, mainly by W. Gunn, in considerable detail, with particular emphasis on the obvious lithological horizons of limestone, sandstone, grit and coal. Parts of Westmorland were not covered on the six-inch scale and those that were have been mapped with very little care. However the one-inch published maps (Old Series 102 S.E. and 103 S.W.) which include the Stainmore Area are extremely accurate for Westmorland and even in Yorkshire show some information not present on the six-inch map (p. 82).

No memoir was issued for these sheets or for any neighbouring sheets except to the west and south-west. The western sheet (Old Series 102 S.W.) is described in the Appleby Memoir (1897), but since the Carboniferous rocks it describes are some distance from the Stainmore Area and are mainly of a lower horizon, it is of very little use for the present survey. The description of the south western sheet however (Old Series 97 N.W.) in the Mallerstang Memoir (1891) is invaluable, particularly the detailed sections of lithological successions.

With the completion of the primary survey little more was done or in fact could be done to the solid geology until palaeontological research had established a system of life zones. Meanwhile Tiddeman (1872) and Dakyns (1872) had initiated work on the glaciology of the Northern Pennines. Goodchild (1875) showed that the ice from the Vale of Eden had pushed over into the Yorkshire Dales, the detailed effects of which were described by Dwerryhouse (1902). The latter deals with the glaciation of Teesdale, Weardale and the Tyne Valley in a general sense, though Lunedale and Teesdale above Middleton are considered quite thoroughly. More recently the southern margin of the Stainmore Area is reached in Raistrick's (1926) description of the glaciation of Wensleydale and Swaledale, but he only mentions the Rivers Greta and Tees indirectly. The superficial features of the Stainmore Area are described by Fawcett in 'The Middle Tees and its Tributaries' (1916). He had some interesting observations to make on the development of the river system of Stainmore but he dismisses the effect of glaciation very briefly, being of the opinion that it had little influence on the present drainage pattern. His conclusion that many of the river directions, such as the River Tees both above and below Barnard Castle and the River Greta at Brignall Banks, are governed by fault lines seems quite unwarranted.

A fresh stimulus was given to the study of the Carboniferous System by Vaughan (1905) whose zonal work in the Bristol area was applied to the North West Province by Garwood (1907, 1912). Garwood's coral-brachiopod zones enabled correlations to be carried much further afield than had previously been possible with lithological mapping, but they had their limitations. Firstly the zones were not fine enough for detailed correlations, and secondly higher up the succession with thinner limestones, they were found to be of little value owing to the scarcity of fossils and the slow rate of change of those which did exist.

In 1924 it appeared that this difficulty might be overcome for Bisat produced, in that year, his influential paper on goniatite zones. Goniatites had the merit of rapid evolution and they occurred in a shale rather than a calcareous facies, becoming common where corals and brachiopods were scarce. In the Southern Pennines they have been invaluable, but in the Northern Pennines, for some obscure reason, the conditions were unfavourable for their existence and though the rare goniatite finds are very useful for distant correlations, they are too few to be used for detailed work, which was still dependent on lithology. For strata of the Lower and Middle Limestone Groups this was not serious, as persistent thick limestones were frequent and corals and brachiopods were stratigraphically useful.

Turner (1927) for instance, extended the use of Garwood's zones in Westmorland and shows a map based entirely on faunal zones, with little attention to the lithology. In his second major structural paper (1935), which on the whole deals with higher strata than the earlier work, he employs an essentially lithological concept of the stratigraphy. The contrast in stratigraphical methods in these two papers exemplifies the limitations of the coral-brachiopod zones above a certain horizon.

For the Upper Limestone Group and Millstone Grit of part of the Askrigg Black Chubb and Hudson (1925) were able to establish successions and correlations based on the lithology and the mapping of some faunal horizons. A little later Trotter and Hollingworth (1927, 1932) described in detail the north west corner of the Alston Block making great use of 'coal-calcareous' horizons for comparative purposes in the higher beds of that area, though when it came to correlating southwards with the Alston sequence they used sandstones, considering them to be more persistent than the limestones (1932, p.71).

The full importance of the marine bands in the Upper Limestone Group and Millstone Grit was finally recognized by Carruthers (1938). He attempted to correlate the strata between the Great Limestone and Millstone Grit from the Tyne to North West Swaledale crossing the Stainmore Area and using horizons which contained marine fossils.

The result of his correlations was to show that the lower part of the Millstone Grit of Yorkshire was equivalent to the upper part of the Upper Limestone Group of Durham. He traced southwards the 'Transgression Beds' of Weardale and Teesdale into the Tanhill Grits of North West Swaledale, both of which lay unconformably on the beds beneath them. He called this unconformity the Tanhill Transgression, demonstrating how, on parts of the Alston Block, it cuts out the Lower Felltop Limestone which, he considered, reappeared in the Stainmore Area as the Botany Limestone. Whilst agreeing with the Carruther's general view, the present survey disagrees strongly with many of his detailed correlations, particularly as regards the position of the Botany Limestone.

Carruthers pointed out that it was the marine fossils which were important, irrespective of the lithology in which they were found, though the associated strata must also be taken into consideration when identifying a marine band. He examined a great number of of isolated stream sections, sometimes many miles apart, and from these drew his conclusions as to the correlations between the Alston and Askrigg Blocks. However he did no mapping and so failed to realise the significance of structure on his stream sections. In addition, as he did not cover all the ground he missed a great deal of pertinent information, particularly regarding non-marine strata, which would have showed that some marine bands are more persistent than others and which would have enabled him to correct any mistake made in his correlations of sections, for, in the kind of cross country traverse that he employed, a small initial error becomes cumulative.

On the Alston Block at Coalcleugh, however, Carruther's initial succession is correct for Dunham (1948) in giving further stratigraphical details of the northern area, shows a general agreement with Carruthers. This is the latest account of the succession on the Alston Block and has been used as a standard reference comparable to the Mallerstang Memoir (1891) and Chubb and Hudson's paper (1925) for the Askrigg Block. Hudson (1941) has also given further information on the strata adjacent to the Mirk Fell Ironstones and he attempts to correlate the Alston (Coalcleugh) succession with North West Swaledale. In spite of using the marine horizons the distances were too great for his attempt to be any more than an intelligent guess and some of the details are incorrect.

Thus it appears that while marine horizons must form the basis of correlations in the Upper Limestone Group and Millstone Grit in these areas, the distance these correlations can be carried is limited. Detailed mapping, area by area, following each marine horizon is the present method of research, using the occasional goniatite finds as checks from one area to another. This was the purpose behind the present survey, which it was hoped would form a link between the successions on the neighbouring areas of the Alston and Askrigg Blocks.

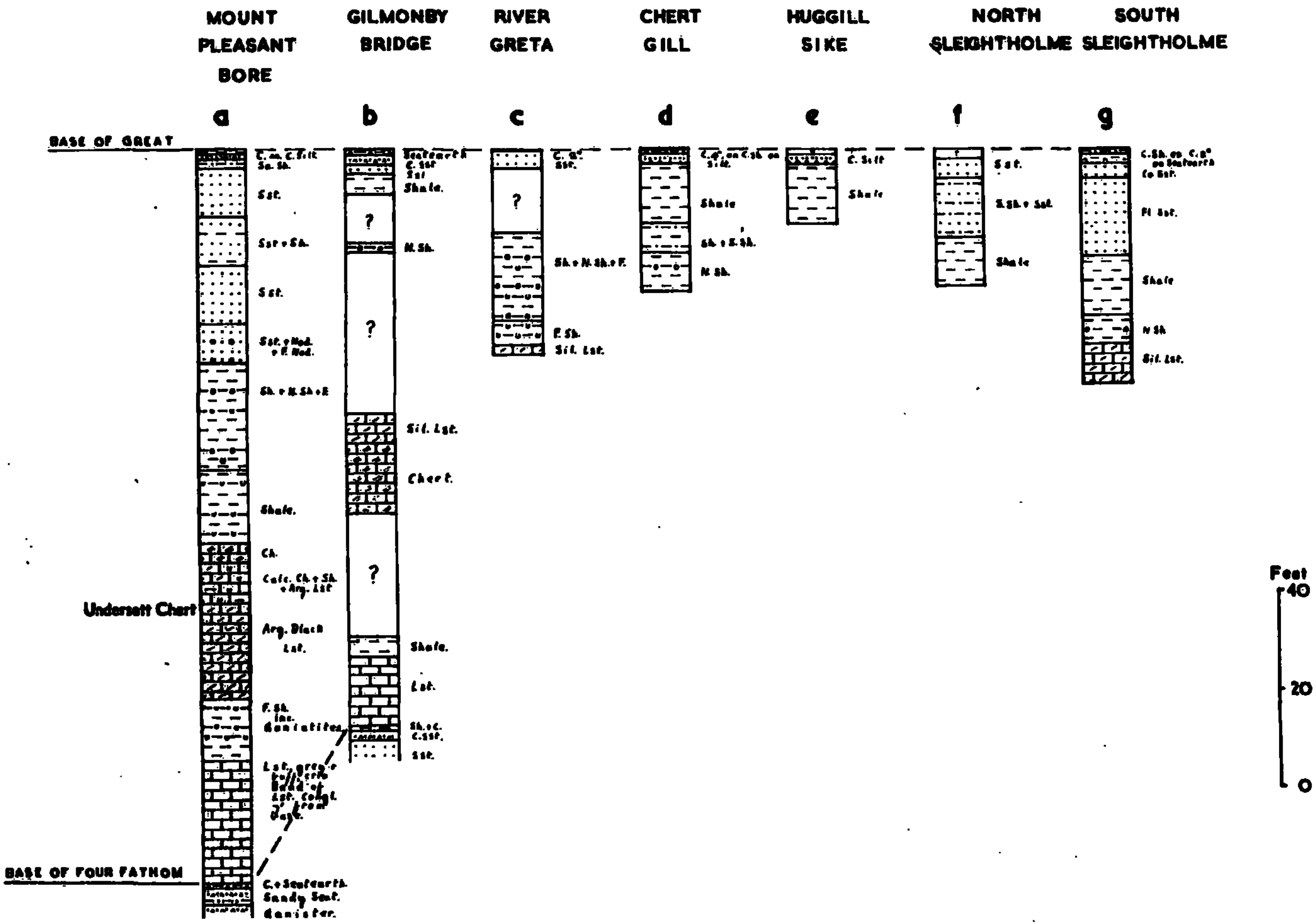
Previous detailed work on the Stainmore Area, apart from the primary geological survey, is inconsiderable. Garwood (1912) gives details of the Botany Beds and their fauna. Turner (1935) overlaps in his map and description onto part of the Westmorland scarp. In his traverse across the area Carruthers (1938) includes several stream sections from within it and Dunham (1948) gives detailed descriptions of the mineral deposits of Lunehead and Closehouse. The Stainmore Area, however, has never been considered as a whole and the conception of it as a structural unit is of recent origin.

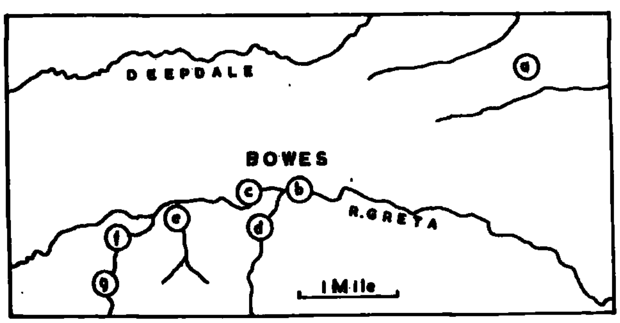
(ii) Structure. The structure of the Northern Pennines received little attention before Marr (1921) introduced the conception of the rigidity of North West Yorkshire. Trotter and Hollingworth (1928) gave the name of Alston Block to that part lying north of the Stainmore Syncline and described in detail its north Western corner. Dunham (1933) gave the first complete account of the Alston Block and its structural history in relation to outside areas. Meanwhile Turner (1927, 1935) was working on the western margin of the Rigid Block and had suggested (1927) that in early Permian times the Rigid Block was a depressed rather than an uplifted area, as conceived by Kendal (1902) and Versey (1927), the present elevation being due to Tertiary movements. This view has been confirmed by later research, particularly by Shotton (1935) who described the tectonics of the Cross Fell Inlier.

The first to specifically call attention to a syncline in the middle of the Stainmore Area was Versey (1927), though Phillips (1836, p.54) mentions a depression of strata in the River Tees between Eggleston Bridge and Eggleston Abbey and Kendall and Wroote (1924) state that the northern limb of the Howgills-Middleton Tyas anticline forms the southern limb of a syncline in the River Tees above Barnard Castle. Versey in his description of the 'Northumbrian Fault Block' says that a syncline "trends east-north-east across Cotherstone Moor and will be called the Cotherstone Syncline".

This is a very accurate description of the syncline. A glance at any topographical map of the area will show that Cotherstone Moor and the village of Cotherstone are only slightly south of the synclinal trough and that therefore the name is more applicable than that of the Stainmore Syncline, since Stainmore, as marked on a map, is limited to the neighbourhood of the Stainmore Pass. The name Cotherstone Syncline persisted for some time, Turner (1935) still employing that name.

However Trotter and Hollingworth (1928) had meanwhile written about the "Stainmore depression" which "divides the Northumbrian Fault Block into two both physiographically and structurally" and Trotter (1929) refers to "the synclinal depression of Stainmore". This name has persisted and in all recent literature (Dunham 1948, Rayner 1952) the name Stainmore Syncline is used. Provided Stainmore is taken to be the whole depression west of the Tees between Lune Forest and Stainmore Forest as it has long been considered by glaciologists (Goodchild 1875, Dwerryhouse 1902) it seems better to keep the better known name, though on grounds of priority and strict accuracy the name Cotherstone or Cotherstone Moor Syncline would be more correct.



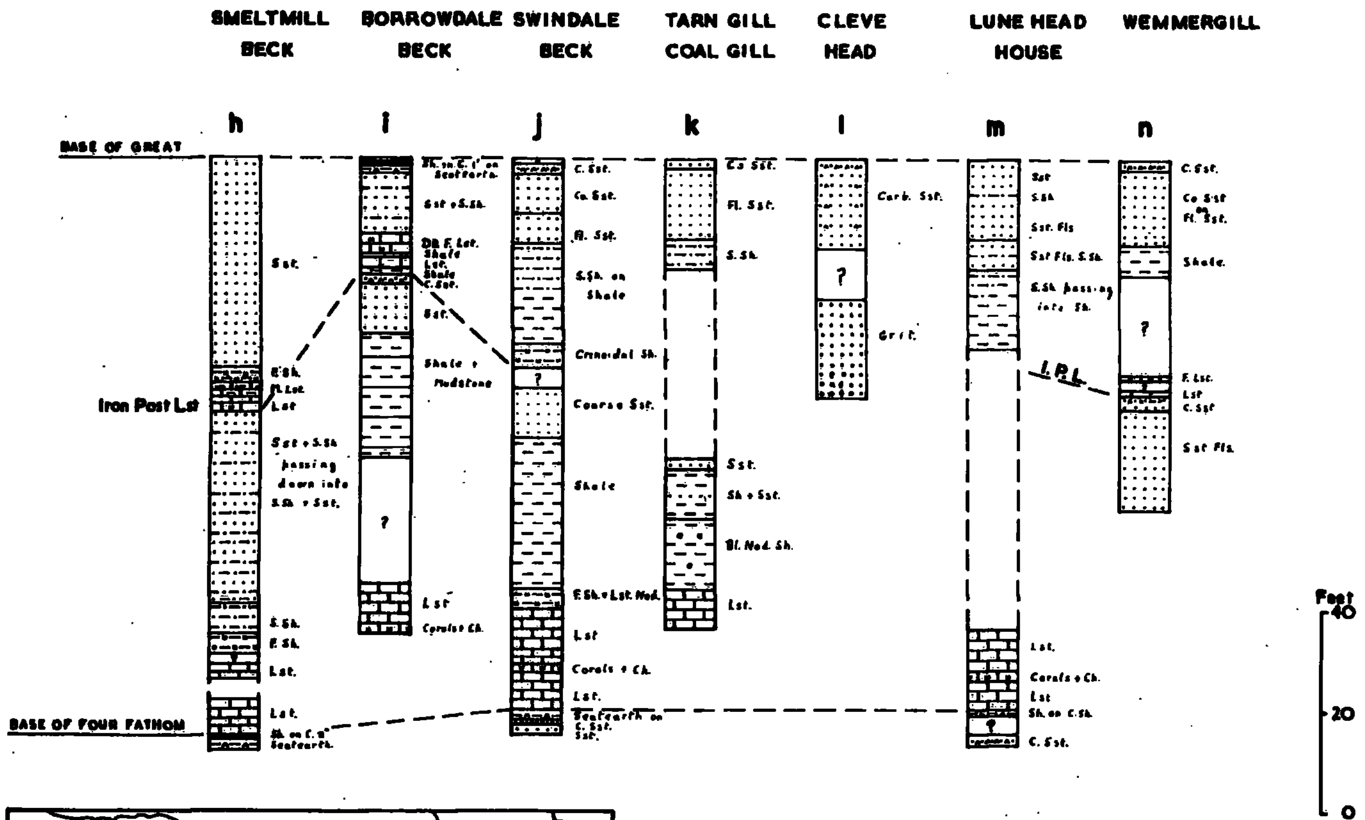


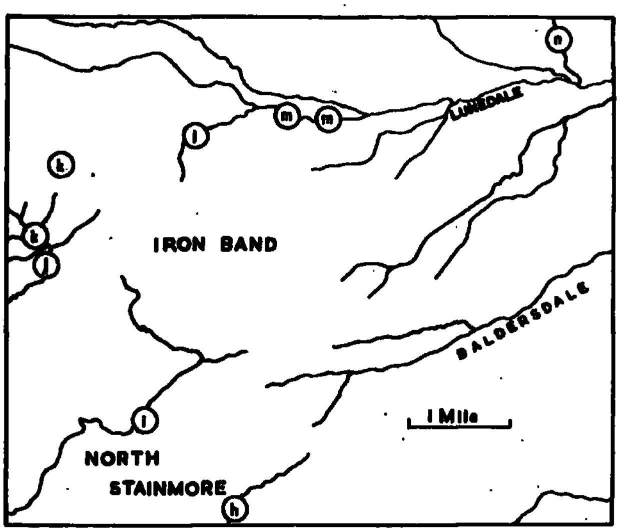
COMPARATIVE SECTIONS

OF

THE FOUR FATHOM CYCLOTHEM

FIGURE 1





COMPARATIVE SECTIONS

OF

THE FOUR FATHOM CYCLOTHEM

FIGURE 2

II. STRATIGRAPHY.

(a) Four Fathom and Iron Post Cyclothems.

(i) General. These two cyclothems are taken together, since although over much of the ground two can be distinguished only one cyclothem occurs in the Bowes area. There does not appear to be any justification for considering the Iron Post Limestone to be any more significant than some of the other minor marine bands, especially the Faraday House Marine Band which has a more widespread outcrop. In Swaledale and around Bowes (Geological Survey Map Old Series 103 S.W.) the limestone and chert are known as the Undersett. This term was also used in the Mallerstang (1891) and Appleby (1897) Memoirs. However in the Alston area and on the Old Series Sheet 102 S.E. Westgarth Forster's (1809) term Four Fathom Limestone was employed and this name was also used by Turner (1935) for the Westmorland part of the Stainmore Area.

In the Bowes area the strata are very well exposed at the surface. In addition they are recorded from the Mount Pleasant Bore. The limestone and chert are well seen at Gilmonby Bridge and in the River Greta, just to the west. North of the River Greta they disappear under drift in an easterly direction, but the outcrop can be easily followed in a S.S.E. direction as the strata rise up the hill towards Whorlands. Westwards from the weir below Bull Bank the beds of the River Greta and of Sleightholme Beck are formed from the siliceous limestone. Thus the base of the Great Limestone and the underlying rocks are fairly well seen in the river banks, and in the tributaries of the River Greta, Huggill Sike and Chert Gill.

Apart from a tiny inlier in the River Greta, just below God's Bridge, nothing more is seen of the rocks underlying the Great

Limestone until Westmorland is reached. Then, at first, only the base of the Great Limestone is exposed, in Yardstone Beck below Summit Cottages and in Yard Sike at Palliard Scar. Eventually the Four Fathom Limestone itself outcrops on the downthrow side of the Stainmore Summit Fault, at a distance of more than 8 miles from Gilmonby Bridge. Along the scarp from Slapestone to Cabbish Mine exposures of the Four Fathom Cyclothem are quite good, and a more or less continuous section is seen in Smeltmill Beck above Light Trees. From the point where the outcrop crosses the main road, north westwards, drifts and shafts, dug to mine the Bordale Coal (underlying the Four Fathom Limestone) are almost continuous until the strata disappear under drift N.W. of Windmore End Quarry. Exposures of the limestone are good, as is the feature formed by a massive sandstone a few feet below it. Thus, the limestone can be mapped with confidence across a number of E.-W. and E.N.E. faults. The beds between the Four Fathom Limestone and the Great Limestone are exposed in Borrowdale Beck and occasionally can be traced along the intervening feature.

Beyond Windmore End Quarry everything below the Tuft Sandstone is obscured by drift until Swindale Beck is reached. Just below the footbridge the Four Fathom Limestone forms a waterfall. About 80' above its top is the base of the Great Limestone. However the intervening beds are not well exposed, though an approximate section can be obtained and a very crinoidal shale appears at Swindale Head, about 30' below the Great Limestone.

At Coal Gill Head the shale above the limestone is seen, and a coarse sandstone to the west may be the Quarry Hazle, but its true stratigraphical position is difficult to ascertain. Around the north of Ley Seat exposures of limestone and swallow holes enable the Four Fathom Limestone to be mapped accurately, but nothing of the intervening beds are seen until Cleve Beck is reached. Here the limestone, a grit, and the Tuft Sandstone are well exposed, but nothing is seen between them. At Lune Head House the limestone is again seen, as are the beds below the Great Limestone, between Renny Gill and Lune Head House, but about 30'-40' are concealed above the Four Fathom Limestone, and, as in Cleve Beck, no marine rocks can be found.

Apart from a few swallow holes, in one of which limestone is found, nothing more is seen of the cyclothem till Wemmergill is reached. Here quite a good succession is obtained from the Quarry Hazle to the Great Limestone. To the north of Sleight Edge exposure of limestone is almost continuous as far as Low Wythes, but, apart from the Tuft Sandstone the intervening beds are not exposed. Eastwards, drift obscures all the solid geology, but, in Carl Beck are exposed sandstones which are believed to underlie the Four Fathom Limestone, since the Three Yard Limestone appears below them. To the east of Grassholme Reservoir scraps of limestone are seen, and there is one exposure of the base of the Great Limestone. Otherwise drift obscures the cyclothem. At Eggleston Bridge, however, the Four Fathom Limestone is fully exposed north of the Lunedale Fault.

(ii) Underlying Beds. Throughout the area carbonaceous beds occur below the Four Fathom Limestone. At Eggleston Bridge the actual base is not seen, but about 4' below it there are 6' of carbonaceous shales and siltstones containing many plant remains. These overlie 12' of flaggy sandstones. In Swindale Beck, 2' of ganister underlie the limestone.

Elsewhere, a coal occurs wherever the base is seen. This is only 2" thick in the Greta River below Gilmonby Bridge, and it is rather shaly. Below it are at least 2' of carbonaceous sandstones passing down into flaggy sandstones at least 30'-40' thick, which, in the Mount Pleasant Bore, are 86' thick with shales and sandstones above. Near Lune Head House there is also coal below the limestone. This cannot now be seen, but the Survey Map reports a thickness of 1'6". It is, however, along the Pennine scarp, above North Stainmore, that the coal reaches its full development. Here it is known as the Bordale coal and was worked until recently, but, owing to the N.E. dip of the rocks, water drainage became too expensive and the workings were closed down. The coal was up to 2' thick (Smith 1912) and was worked for a distance of 2 miles along the scarp, between Banks Gate and Windmore End Quarry. South eastwards it thins to 6" at Light Trees. In the same area the flaggy sandstones below the coal pass down into a compact sandstone, in places very coarse and even approaching a grit. This coarse development of the sandstone is also seen near Coalgill Head.

<u>(iii) Four Fathom and Undersett Limestones.</u> This is a typical Yoredale Limestone, dark, fine-grained, with numerous fossil fragments, mainly crinoid ossicles. Its thickness varies from about 12'-25', these two extremes both occurring in the Bowes area. In the Mount Pleasant Bore there are recorded 25' of grey and buff crinoidal limestone lying above 3" of hard, dark, very fossiliferous shale. The limestone has a high proportion of darker cement towards the top, and a 9" band of limestone conglomerate 7' above the base (Johnson, personal communication). In the River Greta only 12' of limestone

can be seen and, though this may not be the full thickness, it is undoubtedly much less than in the Mount Pleasant Bore only 2½ miles away. No chert and no coral band can be seen.

Throughout the remainder of the area there is a coral band a few feet from the base of the limestone. This is recorded by Miller and Turner (1931) from the Dent Line District, the Shap District, and from near Brough. They state that it is about 2' above the base of the limestone. In this area it is usually some 6' above the base and is about 2' thick. It consists of rolled clisiophillid corals which stand out on a weathered surface. Chert nodules are usually associated with the band. As the limestone is followed eastwards down Lunedale the band becomes thinner. It persists substantially as far as Low Wythes where there are both corals and chert nodules. No trace of either can be found east of the Grassholme Reservoir, though admittedly exposure is very poor. At Eggleston Bridge, however, there is a 6" band with scattered corals, but no chert, 5' above the base.

(iv) Shale. In the Mount Pleasant Bore there are 13' of fossiliferous shale between the limestone and chert.

The details are as follows:

	Ft.	Ins.
Black, fine grained, slightly calcareous shales, rather tough irregular fracture. Extensive scattered fauna, large gastropods, lamellibranchs and brachiopods, with orthocone nautiloids and fish fragments	1	0

	Ft.	Ins.
Black, fine grained, non-calcareous shales. Tough, difficult to cleave. Scattered fauna and some richer bands, gastropods, especially *Dentalium*; Lamellibranchs, brachiopods and orthocone nautiloids	1	6
Tough, black shale with pyrite and scattered small ironstone nodules. Scattered fauna, lamellibranchs and gastropods with brachiopods. One band contains many orthocone nautiloids and molluscs	3	0
Tough black mudstone shale with much pyrite in nodules and markings on the shale. Many *Euphemites*, orthocone nautiloids, with lamellibranchs and gastropods, few Productids, few specimens of *Posidonia membranacea* (M'Coy) and 8 goniatites. Determination has been confirmed by Dr. Stubblefield and Mr. Bisat as *Girtyoceras? costatum* Ruprecht and other goniatites referable to *Girtyoceras* indicating a high P_2 age (Rayner 1953)	3	6
Black, unfossiliferous shale with ironstone. Ironstone at the top with black shale mudstone and a few scattered shells	2	6
Broken masses of black shale, very weathered; many shell remains including brachiopods, lamellibranchs and gastropods. One fish tooth	1	6

Unfortunately these beds are not exposed at the surface in the Bowes area. In the bank of the River Greta above Gilmonby Bridge there are about 5' of shale above the limestone. Though the shale was searched thoroughly no lamellibranchs or goniatites were found. The shale is dark grey with a few ironstone nodules and contains no pyrite. If the goniatite horizon exists here, it must be just above. However, the rocks above are completely obscured by debris from a cliff of chert and siliceous limestone 20 yards back from the river.

In Westmorland a slightly fossiliferous shale passing up into unfossiliferous sandy shale is seen in Smeltmill Beck, and in Swindale Beck there is a very fossiliferous shale, full of crinoid stems and brachiopods, above the limestone. At Coalgill Head there are over 15' of black shale with nodules above the limestone, very slightly fossiliferous at the base. The shale becomes sandy higher up and passes into sandy shale with sandstone ribs. The shale is again seen at Low Wythes and at Eggleston Bridge, but in none of these shale exposures can anything comparable with the goniatite horizon be found.

(v) Undersett Chert. In the Bowes area the Undersett Chert is well developed. Elsewhere no chert occurs and, as was seen above, the fossiliferous shale passes up into non-marine strata which become gradually coarser in grain size.

The chert is at least 14' thick in the cliff above the River Greta, but the base is hidden and it may be thicker. It is a dark chert, rather fossiliferous and often very calcareous. There are bands of purer chert among the more calcareous layers. Above it are 6' of siliceous limestone with thin interbedded shales and these are overlain by fossiliferous shales from 5' - 10' thick. These beds vary laterally, with passages from one lithology to another. A comparison with the Mount Pleasant Bore, where the chert appears towards the top, shows this very well. Consequently these members are all mapped together as the Undersett Chert.

There is no very clear demarcation between the fossiliferous shales of the Undersett Chert and the non-marine beds above. A cliff section in the River Greta (988132) shows 18' of nodular shale with occasional marine fossils only about 15' below the base of the Great Limestone. In the Mount Pleasant Bore marine fossils are proved in a sandstone with shale bands and ironstone concretions 35' below the base of the Great Limestone. Thus if the whole of this were included as the Undersett Chert, the thickness would be about 75'. The top of the Chert has therefore been taken for mapping purposes at the horizon at which the last of the harder siliceous limestone and very fossiliferous shales occur.

(vi) Quarry Hazle. Exposures of the sandstone and of its marker, the Iron Post Limestone, are most unsatisfactory. Consequently it is neither mapped nor discussed with ease. Except in the Bowes area where there are no comparable strata, there seems to be a constant arenaceous member of the succession. This is very variable in grain size. In Smeltmill Beck there are 38' of alternating sandstones and sandy shale bands, becoming coarser towards the top. In Borrowdale Beck 25' of mudstone are overlain by 12' of sandstone. In both of these becks, the Iron Post Limestone can be used as a check.

A grit occurs in both Swindale Beck and Cleve Beck at about 30' - 40' below the base of the Great Limestone. This is at least

15' and may possibly be more than 20' thick in Cleve Beck. While it may occur west of Coal Gill Head (p.23), it possibly is absent, and is certainly not exposed anywhere round the north of Ley Seat. At Lune Head House, in addition, nothing is seen of it and it is possible that the coarse development is very local. By Wemmergill, there is only a sandstone 20' - 25' thick, carbonaceous at the top, exposed in the beck and in the bank to the east. Elsewhere in Lunedale nothing is seen of the Quarry Hazle, though scraps of sandstone occur at approximately the same horizon at Low Withes.

(vii) Iron Post Limestone. This is a very fossiliferous limestone and shale horizon about 5' - 9' thick. As a separate band, it is absent in the Bowes area. It occurs in Smeltmill Beck where a limestone with a few corals at the base is followed by a muddy limestone with trilobites and lamellibranchs. Above this is a very crinoidal fossiliferous shale. There is another outcrop of limestone in the scarp just to the N.W. It appears again, possibly, in the beck north of Cabbish Mine (838158). In Borrowdale Beck two bands of limestone have a thin shale parting between. A small exposure occurs in the scarp (822169). This shows the rather creamy colouring of the weathered rock. The fresh surface is the usual dark fine grained Yoredale Limestone, relatively unfossiliferous except for crinoid plates.

In Swindale Beck the crinoidal shale mentioned above (p.23) is undoubtedly the equivalent of the Iron Post. It is about 5' thick and contains large crinoid stems 6" or more in length and up to 1" in diameter. The base is not seen, and it presumably represents the crinoidal shale of Smeltmill Beck and may possibly be the equivalent of some of the limestone. No more is seen of the Iron Post except in Wemmergill where two 1' bands of limestone occur, one of which is very fossiliferous.

(viii) Shale. As was mentioned above (p. 29) this non-marine shale is not easily distinguished from the fossiliferous shale in the Bowes area. In the Mount Pleasant Bore none occurs at all, and in the stream exposures no more than 12' is ever seen. It may continue up to 4' below the Great Limestone. Elsewhere this shale is very rarely exposed. In Smeltmill Beck and Borrowdale Beck the Iron Post fossiliferous shale is followed by sandstone in the former and sandstone with shale partings in the latter. In Swindale Beck there are about 10' of dark unfossiliferous shale grading up through sandy shale into sandstone. A total of 28' of shale, with one sandstone and sandy shale band, are seen near Lune Head House, and the Iron Post Limestone is at an unknown depth below it. In Wemmergill there are probably at least 25' of shale, though only 6' are seen. Thus it seems that the shale thickens to the north east.

(ix) Tuft Sandstone. In the Bowes area this sandstone is very poorly developed, though its thickness increases to the north, and to the south, away from the River Greta. The Mount Pleasant Bore proves 32' of sandstone, with occasional shale partings, above the highest true marine beds. At two horizons, fish scales are found. The sandstone is frequently carbonaceous and at the top is a sandy micaceous seggar overlain by a thin layer of patchy coal with good cleat.

Along the banks of the River Greta the sandstone is only about

4' thick, with rootlets and carbonaceous matter at the top. In Chert Gill and Huggill Sike there are just 2' of carbonaceous siltstone, but westwards sandstone increases in thickness until in Sleightholme there are about 20' of sandstone, compact at the top. Throughout the Bowes area a coal is found below the limestone, with its associated seat earth and overlying carbonaceous shale. This coal is from 2" - 4" thick and continues at least as far as the inlier east of God's Bridge.

In Westmorland the Tuft Sandstone is much more substantial, becoming a grit in places. The Smeltmill Beck section shows a thickness of 42'. No grit is seen here, but in a south easterly direction along the scarp a grit appears. Owing to the absence of any exposure of the Iron Post Limestone its exact stratigraphical position is difficult to determine. It is possible that some of the lower exposures of grit are the Quarry Hazle. If, however, a line of springs along the escarpment marks the position of the Iron Post Limestone, it can be seen to pass below the lowest exposure of grit above Borrenthwaite. It is also unlikely that a grit would develop at the same place on two horizons. Therefore the grit and sandstone above Borrenthwaite must be the Tuft Sandstone, and it is over 60' thick. Near Ledderhowe (840153) 4' of grit form a good feature, but it does not extend very far, since in the stream (838157) no sandstone or grit is revealed, and in Borrowdale Beck only 12' of sandstone and shale appear to represent the Tuft Sandstone and its underlying shale.

A coal seam 1' thick occurs in Borrowdale Beck, with a seat-earth below and shale above. This is the only exposure of coal beneath the Great Limestone along the Westmorland escarpment. South eastwards this may be due to the difficulty with which the limestone base is seen, but in a north westerly direction the top of the Tuft Sandstone frequently outcrops along the lengthy face of Windmore End Quarry and at one point (819171) the following section is exposed beneath the Great Limestone:-

	Ft.	Ins.
Dark limestone and fossil fragments	2	0
Fine-grained, black, slightly cherty limestone		2
Carbonaceous mica-sandstone with rootlets.	1	6
Massive sandstone with flaggy ribs	8	0

The sandstone reaches a thickness of at least 11' in Windmore End Quarry and it can be followed along to Swindale Beck where a compact sandstone with carbonaceous top overlies several feet of sandstone flags.

According to the 1-inch Old Series Sheet 102 S.E., along Ley Seat Edge a coal seam 1' - 1'6" was once worked. Nothing can now be seen of the coal, though the Tuft Sandstone is well exposed along Cleve Beck and Lune Head Beck. It is probably 18' thick in Cleve Beck (Dunham 1948, p.317) rather coarse, micaceous and carbonaceous. The sandstone can be traced down Lunedale with little variation. It does become a little coarser east of Grassholme (155) but, generally, it is a 10' - 20' flaggy sandstone becoming compact and carbonaceous towards the top, and with no development of coal.

(x) Discussion. The most noticeable feature of these cyclothems is the contrast between the Bowes area and those areas to the north and west. From Bowes there is a gap to the west of 8 miles and to the north of 6 miles, in exposures of equivalent strata, and, in the absence of any marker horizon between the Four Fathom Limestone and the Great Limestone, comparison of the sections must be a matter of conjecture.

The Undersett Limestone, in Swaledale, contains Miller and Turner's coral band, and though this marker is absent at Bowes, there is no doubt about the equivalence of the Undersett to the Four Fathom Limestone. The coral band must represent a period of widespread shallow water deposition when corals flourished in abundance and were subjected to strong currents. The limestone conglomerate in the Mount Pleasant Bore represents a small break in deposition, with strong current action, and may be at the same horizon.

The Iron Post Limestone is rarely exposed. This must be due to one of three reasons:-

(i) Erosion by the overlying Tuft Sandstone, as happens at Stanhopeburn Mine (Dunham 1948). In Smeltmill Beck the Tuft is 42' thick, considerably thicker than anywhere in the Stainmore Area except just along the escarpment to the S.E. Yet the Iron Post Limestone and shale are 9' thick, the greatest known thickness; thus there is no connection between the absence of the Iron Post and development of the Tuft;

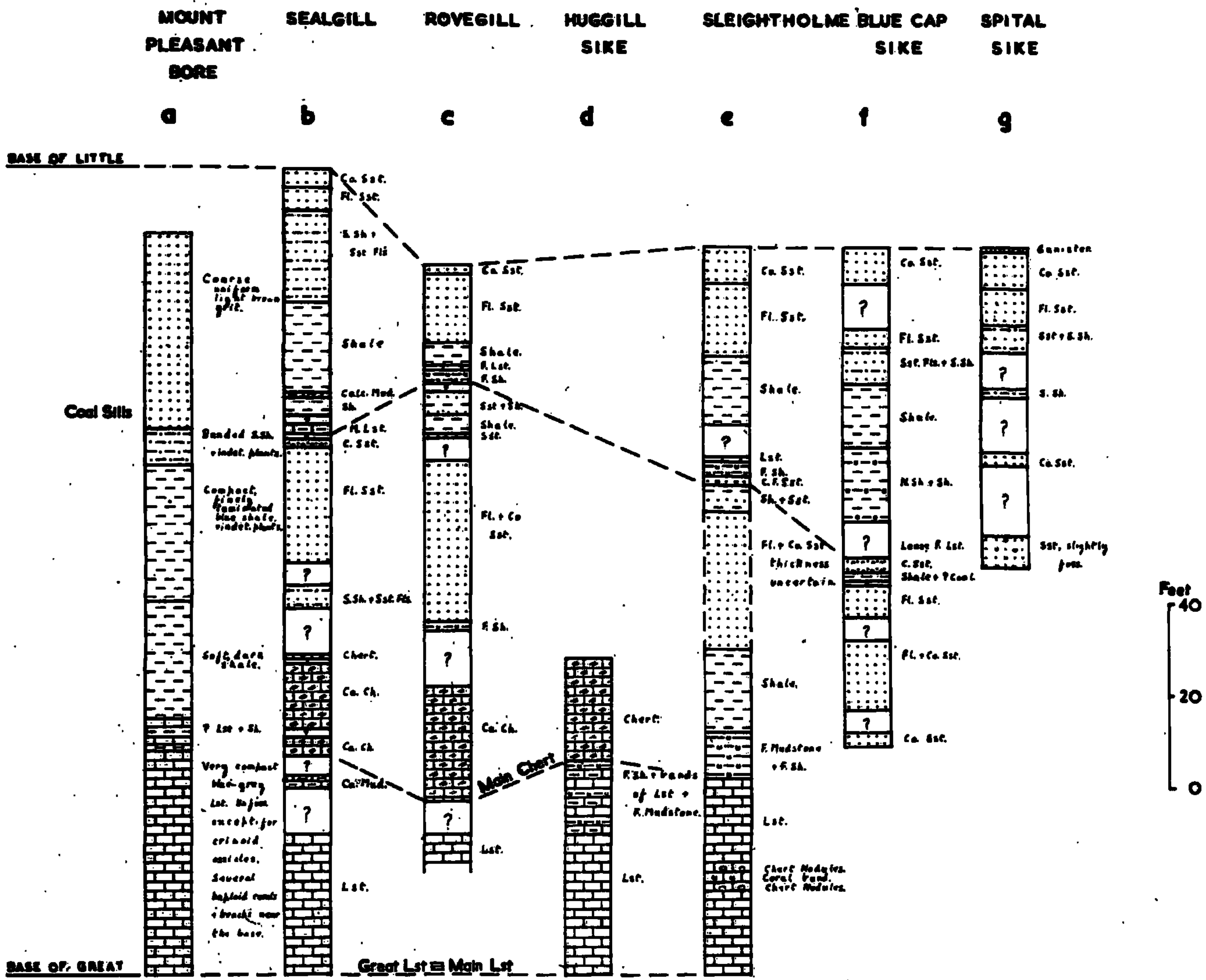
(ii) The Iron Post may not have been deposited over the whole area, and certainly in the Bowes Area it is absent as a separate marine horizon. However, if this is so, its deposition must have been very sporadic, as exposure of it occurs at points far apart;

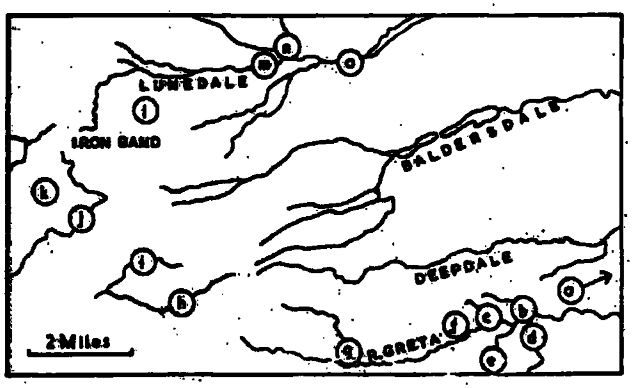
(iii) Its apparent absence may be due to its thinness. This is the most likely explanation, as, at no point can its absence be proved and exposure of its expected horizon is invariably very poor. However, it has not been mapped as a continuous band as the evidence for its presence over the whole area is negative.

The Mallerstang Memoir (pp.83-4, and p.133) mentions a limestone occurring between the Main and Undersett Limestones, which may be very cherty. In the Appleby Memoir (p.51) it is assumed that the Lower and Upper Undersetts of Yorkshire are the equivalent on Alston of the Four Fathom and a limestone above the Quarry Hazle respectively. Furthermore a comparison of the Bowes section with one in Westmorland or Lunedale, shows that the increase of marine beds at Bowes is considerable. In the River Greta and in the Mount Pleasant Bore there are about 100' of marine strata above the base of the Undersett Limestone, while in Westmorland the total thickness of the two cyclothems is only about 100'. The proportions of marine beds are shown in the following table:-

Section, Figs. 1 and 2.	a	b	h	i	j
4 Non-marine	35'	20'	42'	14'6"	32'
3 Marine (Iron Post)			9'	6'6"	5'+
2 Non-marine			44'	53'6"	40'
I Marine (Four Fathom or Undersett)	113'	77'	20'	c.20'	23'6"
Total 1 - 3	113'	77'	73'	80'	68'6"
Total 1 - 4	148'	97'	115'	94'6"	100'6"

It can be seen that, apart from an increase in total thickness in the Mount Pleasant Bore, the thickness of the marine beds in the Bowes area compares favourably with the total thickness of the beds between the base of the Four Fathom, and the top of the Iron Post Limestone elsewhere. Probably, therefore, the assumption in the Appleby Memoir is correct, and the Iron Post is the equivalent of part of the Undersett Chert or the marine beds above it. Thus while continuous marine deposition was taking place at Bowes, to the north, west and south west a normal Yoredale cyclothem, with non-marine shale and sandstone was being laid down.



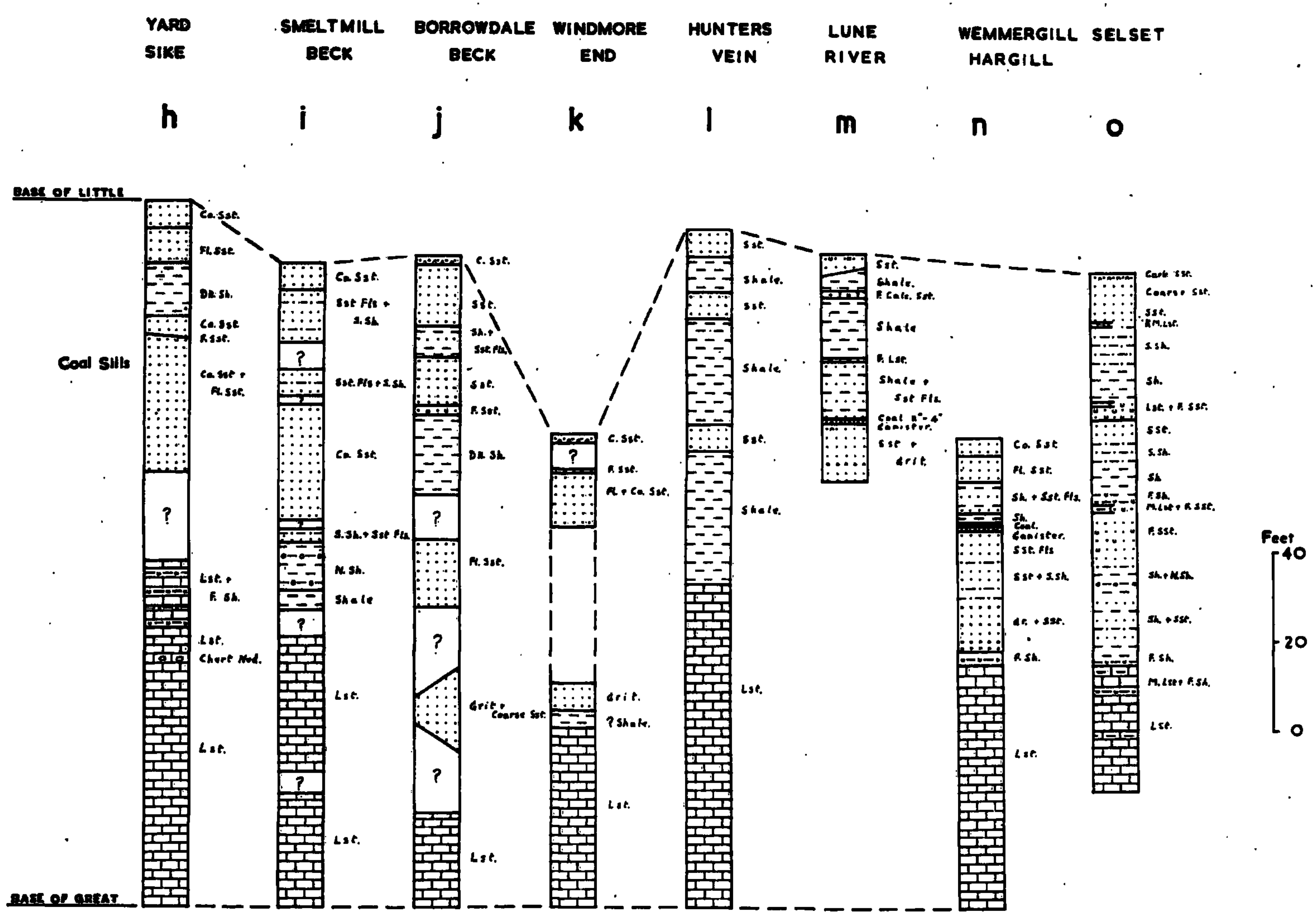


COMPARATIVE SECTIONS

OF

THE GREAT CYCLOTHEM

FIGURE 3



COMPARATIVE SECTIONS

OF

THE GREAT CYCLOTHEM

FIGURE 4

(b) Great Limestone and Coal Sills Group.

(i) General. This limestone is by far the thickest of those considered in this thesis. Consequently, it is easily recognised in the field and the exposure of it, and the overlying Coal Sills, is very good. Around Bowes, and on the Askrigg Block it is known as the Main Limestone. However on the Alston Block, on the Old Geological Survey Map 102 S.E., and in Turner (1935) it is called the Great. Nevertheless the term 'Main Chert' must still be used as the chert is confined to the Bowes area.

The nomenclature of the shales and sandstones of the cyclothem must be somewhat arbitrary. On the Alston Block the name White Hazle has been given to the topmost sandstone, while the two lower sandstones, where present, are known as the High and Low Coal Sills respectively (Dunham 1948). In most of the literature, however, all these sandstones are simply known collectively as the Coal Sills (Mallerstang Memoir 1891) (Turner 1935) (Carruthers 1938), and it seems more convenient to refer to them as such, while the term Coal Sills Group will be used to include all the strata between the Great and Little Limestones. When two sandstones occur they will be known as the Upper and Lower Coal Sills, and the third one, where present, will be called the Middle Coal Sill. They are undoubtedly lenticular bodies which are not equivalent over the whole area, and the terms are merely convenient aids which have no exact time significance. So far as is known, no name has been given to the marine bands within the Coal Sills Group.

Two bore holes penetrate the cyclothem near Bowes. In the Mount Pleasant bore there is recorded 160' of solid rock above the base of the Great Limestone. The Bowes Bore, put down by the R.A.F. during the 1939-45 war, is most unsatisfactory. It is within 75 yards of an outcrop of the Little Limestone and Upper Coal Sill which form a distinct feature. Less than a mile away a clear section of the Coal Sills is seen in Seal Gill. Yet there is so much limestone in the record that it is not even possible to ascertain the position of the Great Limestone in the bore, though its base may be about 150' below the surface.

The limestone is exposed almost continuously in the banks of the Greta River around Bowes. The northern arm of the V disappears for a mile under drift, before appearing again just off the map at Hulands Quarries. The southern arm rises up the valley side and bends round in a south easterly direction. The base of the limestone can be mapped accurately, but towards the top limestone gives place to interbedded siliceous limestones and shales, the Tumbler Beds, which are not so clearly seen. However, in comparison with the rest of the area, they are well exposed, and consequently have been mapped as a band separate from the massive limestone below them.

Moving westwards up the River Greta, the limestone is seen to form the stream bed for a considerable distance, and for about ½ mile the river flows underneath the limestone, which is only covered during rainy periods. Further upstream the Tumbler Beds are exposed, until cut off by the Northern branch of the Stainmore Summit Fault. Outcrop of the Main Chert is good, but it is of limited extent.

Though not particularly well exposed on the hill slopes, the Coal Sills can be clearly seen in the small tributary becks to the north, and, off the map, in Sleightholme Beck to the south. The Upper Coal Sill, underlying the Little Limestone, however, is a very continuous mappable horizon for the top of the cyclothem. Like the underlying beds, it disappears under drift north of Bowes. Westwards, however, it can be traced more or less along the main road which from Blue Gap has been built along the top of its feature. This continues right into Westmorland, after which the road drops down from the feature top.

Before the county boundary is reached, the remaining Coal Sills and the Great Limestone have reappeared. The limestone is much faulted and, though substantial features are formed by the Coal Sills, good stream sections are absent between Spital Sike and Yard Sike. Beyond Yard Sike, the limestone, occasionally broken by faults, forms the top of an escarpment almost as far as Swindale Beck. Above it the Coal Sills produce good step features, and they are well exposed in the streams. On either side of Smeltmill Beck however, the Lower Coal Sill feature disappears. The same happens to the Middle Coal Sill S.E. of Borrowdale Beck. This is taken to be due to the lenticularity of the sandstone bands.

The strata are lost under drift until the mineralized area, either side of the County Boundary, at Lune Head, is reached. Here there are very good exposures of the Great Limestone, but little can be learnt about the Coal Sills. A shaft on Hunter's Vein (853198) penetrates the whole sequence, and there are loose blocks of coarse sandstone over much of the ground, but no stream exposure exists. In Rowton Sike, where one would expect a section, Wensley Vein cuts out all the strata between the Great Limestone and siliceous limestones at the top of the Little.

Eastwards from the Lunehead Mines, the Great Limestone crosses the River Lune to form a text book dip feature north of the road. This runs for 4 miles, as far as Nettlepot. The Coal Sills, however, are covered by peat and glacial drift which spreads over most of the lower valley slopes. Nevertheless, west of Low Wemmergill, Hargill and the River Lune have cut down far enough through the drift to expose the Coal Sills Group from the Great to the Little. These exposures were described by Carruthers (1938).

Further down the valley in spite of the Selset Bores and occasional outcrops of sandstone, it is not possible to map so variable a sequence as the Coal Sills, though the limestone can be followed fairly accurately. The limestone forms an almost continuous feature as it outcrops south east of the Grassholme Reservoir, and some sandstone can be seen near Shields Beck and in Easter Beck, but the remaining beds are not exposed. Finally the whole cyclothem disappears, probably thrown down by the Teesdale Fault, but drift obscures the evidence.

(ii) Great and Main Limestones. This is the highest Yoredale limestone to form a constantly thick, pure limestone throughout the North of England. Under various names it is known from Upper Wharfedale to Scotland and so, in this area, it was taken as a datum line for mapping. In spite of the regular appearance of the limestone, it shows considerable variation in thickness and lithology within the present area.

The Mount Pleasant Bore proves 48' of compact limestone lying above 2" of soft shale, full of crushed fossils, and overlain by 7' of Tumbler Beds. No coral band was recorded, and the limestone was not split up into posts. This massive nature of the pure limestone is characteristic of the Bowes area, though, in the exposures in the Greta Valley, the massive limestone becomes thinner, with a complementary thickening of the overlying Tumbler Beds. These are a series of alternating siliceous and muddy limestones with fossiliferous shaly bands. In Huggill Sike the limestone has thinned to 30', but has 16' of Tumbler Beds above it.

In Sleightholme there is, in the middle of the Great Limestone, a 2' band of corals, mainly of clisiophyllid type, and small brachiopods. The limestone at this horizon contains many chert nodules, and, as with the Four Fathom Limestone coral bands, there seems to be an association between the two. The only other place around Bowes where this coral band can be seen is in the Greta River (965128) where, for some distance, the band forms a limestone pavement in which are beautifully polished coral sections. The massive limestone in Sleightholme has expanded to 42', with about 10' of fossiliferous mudstone and shale, with no limestone bands above. In the absence of the Main Chert (see p. 45) this is probably its equivalent horizon and so it appears that, as in the Mount Pleasant Bore, the massive limestone facies has, at the top, taken the place of the Tumbler Beds. Elsewhere, in the River Greta a great deal of limestone is exposed, but complete sections cannot be obtained as the upper boundary of the limestone is never clearly defined. The thickness seems, nevertheless, to be of the order of 25' - 30', but it may well be more. To the west, as one goes up the stream, the limestone becomes more muddy and siliceous and it is clear that the Tumbler Beds form the river bed.

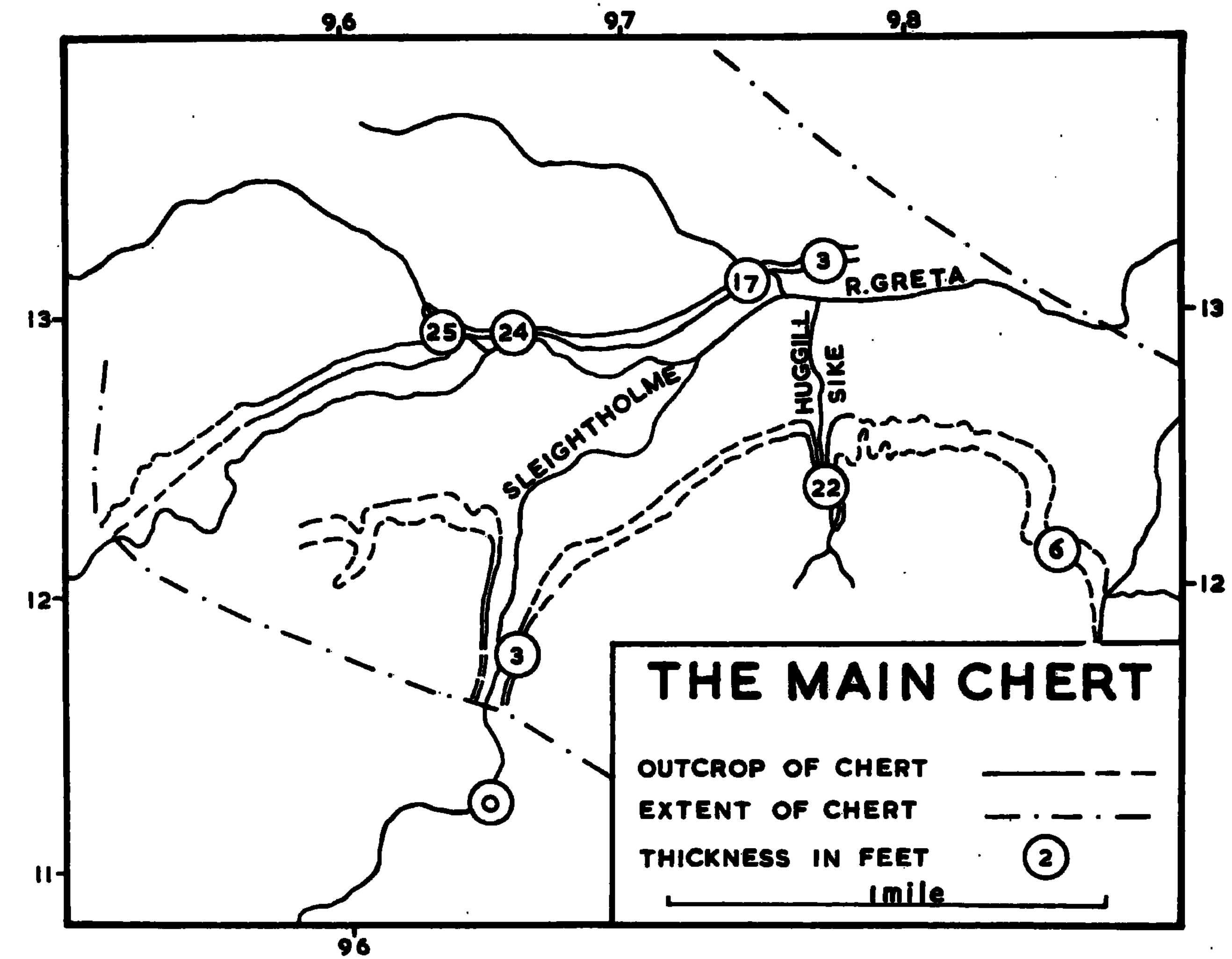
West of Aygill Cottages a thick limestone outcrops along the north side of the Greta River. It is probably at least 35' thick and while most of it is typical of the normal compact Great Limestone, near the top are 10' of a very pale, extremely crystalline limestone, containing masses of crinoid ossicles of all sizes. Nothing quite like it is seen elsewhere in the present area in the Great Limestone, but it cannot be any other horizon having regard to its thickness, the lithology of the lower part, and its relation in the field to the overlying Coal Sills and Little Limestone.

Though the Great Limestone outcrops extensively in Westmorland it is not easy to measure its thickness accurately, partly because of the absence of any exposure of the overlying beds, but also because it forms wide pavements which make vertical sections almost unobtainable. At the S.E. end of the escarpment quite a lot can be seen of the Tumbler Beds with their fossiliferous calcareous shales and impure limestones, but here the base of the limestone is seldom exposed. Yard Sike however does give about 60' of limestone with a band of chert nodules near the top, overlain by 15' of Tumbler Beds. Much the same thickness of limestone occurs in Smeltmill Beck, but the top disappears under peat and nothing can be seen of the Tumbler Beds. The same thing happens throughout the rest of the Westmorland area, and, assuming it is not just due to the concealment of these beds by peat, which is most unlikely considering their exposure elsewhere, must be due to the fact that they are not developed, though (p. 50) there is evidence that the Lower Coal Sill is transgressive, and may have cut out the Tumbler Beds.

In Borrowdale Beck the thickness of limestone seen is 21', and though this is certainly less than the true thickness, it is not a lot less. Along Windmore End Quarries about 40' of limestone appear, and towards Swindale Head the thickness seems to increase to 50'. Finally in the Lunehead Mines 72' is recorded in the section on Hunter's Vein and 102' in the main level by the London Lead Company

(Dunham 1948, p.26). Thus variations in thickness may be very local, but nevertheless there is undoubtedly a tendency for the Great Limestone to be at its thinnest in Borrowdale Beck while it increases in thickness to the N.W. and S.E. There is nothing noteworthy about the lithology of the beds. The step features within the limestone along the escarpment give the impression that there may be a number of posts, separated by shale, but the stream sections do not confirm this. In a few places, such as the top of the waterfall in Borrowdale Beck, and just below the road in Smeltmill Beck, the limestone becomes slightly more fossiliferous than usual, but there is no band comparable to the coral band seen further to the east.

The next complete exposure of the limestone is in Wemmergill Beck where 55' of massive limestone are overlain by a maximum of 5' of fossiliferous shales. No trace of a coral band occurs here, but across the Grassholme Reservoir, in the old quarries (953226) the first sign of the Frosterly Marble horizon appears. In the western quarry a 2" band of brachiopods is seen 13' from the quarry base. This, in the eastern quarry, has expanded to a band nearly 3' thick, composed mainly of brachiopods, but with a few rolled clisiophyllid corals towards the top. It is 20' above the base of the limestone which here probably totals 35' - 40' with intercalations of shale bands in the upper portion. In Banklands quarry beside the former L.N.E.R. railway line the coral band has become more definite with masses of corals and large brachiopods. In addition, the Tumbler Beds have become better developed, giving about 30' of limestone and shale partings, above at least 32' of compact limestone:-



9,6
9,7
9,8
13
12
11
96
R.GRETA
HUGGILL
SIKE
SLEIGHTHOLME
25
24
17
3
22
6
3
0
THE MAIN CHERT
OUTCROP OF CHERT
EXTENT OF CHERT
THICKNESS IN FEET
2
1mile

FIGURE 5

	Ft.	Ins.
Limestone	2	0
Fossiliferous Shale	5	0
? Limestone and Shale partings	4	0
Limestone and Shale partings	18	0
Compact limestone	16	0
Band of large Brachiopods and corals	2	6
Compact limestone	14	0

(iii) Main Chert. The exposure of the Main Chert is limited to the Bowes area where the boundaries of chert development can be traced. This is shown on the accompanying map (Figure 5).

Sargent (1929) has studied the Yoredale cherts, including the Main Chert, of Swaledale. He found that the cherts were original contemporaneous deposits, whose silica was mainly of inorganic origin, the occasional siliceous organisms found in the chert being the result and not the cause of the silica. Locally there may have been some silicification of limestone and calcareous fossils within the chert, but there was no general metasomatism. The deposits were believed to have been formed in a shallow sea bordered by a peneplaned land surface whose decomposition produced abundant silica carried in solution, and precipitated on the sea floor as a gel.

The evidence on the whole supports Sargent's view. The chert is mainly a banded type (198), rather calcareous, in fact containing some thin bands of limestone, though most of the banding is probably simply due to the segregation of impurities. Under the microscope rhombs of dolomite are seen in a matrix of cryptocrystalline silica. Sargent considers that this is clear evidence against metasomatism, though the possibility of two separate processes taking place must not be overlooked.

The field relations of the chert are as follows. In the banks of the Greta River (967129), and in Rovegill, the chert reaches its greatest measured thickness. In Huggill Sike it is 22' thick, yet in Sleightholme, only a mile to the S.W., it has disappeared completely. A comparison of the two complete sections from the limestone base upwards seems to show that the limestone and Tumbler Beds of Huggill Sike pass into massive limestone in Sleightholme. Certainly, the overlying fossiliferous shales and mudstones of Sleightholme cannot be found in Huggill Sike. They must therefore by the equivalents of the Main Chert. Thus in a distance of about a mile 22' of chert have passed into 10' of fine grained, banded siliceous mudstones and fossiliferous shales, with some of the mudstone bands packed with Lingula (582). Admittedly no passage can be seen but unless one invokes a period of non-deposition in the Sleightholme succession while the chert was being laid down, for which there is no evidence, there is no other explanation. Both the chert and the fossiliferous mudstone pass up into non-marine shales which admittedly are not clearly exposed in Huggill Sike, but there can be no doubt that no chert occurs above the fossiliferous mudstone of Sleightholme.

Thus, Sargent's peneplaned land surface, from which silica was decomposed to be washed down into the shallow chert sea did not exist in the Sleightholme area. Possibly this in fact was the margin of the sea, where too much mud was deposited for chert to be formed, the lingula bands indicating brackish water condition. The silica solutions, however, were either carried further into the basin, or, more likely, came from another direction, to be precipitated in a clear sea, free from terrigenous matter.

(iv) Coal Sills Group and Marine Bands. The strata between the Great and Little Limestones must be considered as one item, as, though marine bands occur within them, these cannot be traced over the entire area and so the series cannot be subdivided with any satisfaction.

In the Bowes area there are two Coal Sills with a marine band overlying the lower one. This marine band is a fossiliferous dark muddy limestone, weathering orange brown. It varies, however, as it may become rather micaceous as in Sealgill (286) or it may be almost deficient of clastic matter as in Sleightholme (581). Exposure of it is good in the streams of Sleightholme, Sealgill and Rovegill, and some loose pieces occur in Blue Cap Sike. The limestone seen in Burnt Gill between branches of the Stainmore Summit Fault (932115) is probably the same band.

Below the marine band, but not necessarily immediately beneath it, is the Lower Coal Sill. This is a substantial sandstone, the base of which is not very far above the Main Limestone or Chert. In fact the shale is only really seen in Sleightholme and even there the cliff section is partially hidden by debris. Expansion of the sandstone seems greatest along a north-south line through Rovegill and Sleightholme, in both of which it may reach over 35' but estimation is difficult owing to the false bedded nature of the rock.

The boring record at Mount Pleasant, where 42' of grit overlie 63' of shale, shows a striking contrast with the surface exposures. It is 3½ miles away from the nearest stream exposure and it seems that the Lower Coal Sill and marine band have been replaced entirely by shale, though the possibility of considerable thickening of the Coal Sills Group must not be overlooked. A section was drawn up in the Tees, N.W. of Abbey Bridge (063152) but this does not help very much, except that it is noteworthy that the Lower Coal Sill is there formed of coarse sandstone. A fairly rapid survey of the ground unfortunately failed to reveal any marine band, though this may still be present above the Lower Coal Sill. Lacking a marine horizon above the Great Limestone, correlation of the Mount Pleasant Bore with the Bowes and Tees exposures must be somewhat speculative, but it does illustrate very well the variable nature of the Coal Sills.

Above the marine band are shales, which become more sandy higher up, until, underlying the Little Limestone, are 20' of sandstone, massive at the top. These massive sandstones contain marine fossils in their upper portions and often appear to pass imperceptibly through a fossiliferous, calcareous sandstone into a sandy limestone. Frequently no clear boundary can be discerned, as the crumbly and weathered nature of the rock makes a detailed examination difficult. In the bank of the Tees near Abbey Bridge it is possible to distinguish a pale grey sandstone with carbonaceous streaks from a coarser sandstone which is slightly calcareous and fossiliferous, but in the Bowes area, while a sandy limestone may be distinct from the fossiliferous sandstone below, this cannot be separated from the underlying unfossiliferous sandstone.

No coal has been found anywhere in the Coal Sills Group of the Bowes area, but on the Old Series Geological map two thin bands of coal, 2" - 3" thick, are marked in Blue Cap Sike towards the top of the Lower Coal Sill.

For the next two miles west of Blue Cap Sike, not much of the Coal Sills appears through the drift and the marine band is completely lost. Occasional sandstone exposures, however, enable the two sills to be mapped. The Upper Coal Sill maintains its lithology all the way, but in Spital Sike a ganister has come in under the fossiliferous sandstone. By this point the marine band, as it was known before, has gone. There is no longer any calcareous band either immediately above or in the shale close above the Lower Coal Sill. Instead a slightly fossiliferous crumbly micaceous sandstone appears near the top of a series of flaggy sandstones, but it is extremely difficult to fix its precise horizon, for fossil fragments can be found disseminated through several feet of sandstone. Above this fossil sandstone, and separated from it by perhaps 10' - 15' of unexposed strata, is a compact white coarse sandstone. This is certainly distinct from the Upper Coal Sill, and, in Spital Sike, may be distinct from the fossil sandstone, but the evidence to the west implies that this is all one sandstone, with a broad band containing fragmental fossils running through the middle.

The coarse sandstone continues westwards as far as Maiden Castle and for much of the way the fossil sandstone, which is frequently quite coarse and almost a grit, can be traced. There are some exposures in the streams in the valley bottom, but these are broken by faults and not easy to make out. On the valley side, on the other hand, there are masses of loose boulders marking the feature, but very little sandstone in place and nothing whatever of the finer grained members of the succession. However, the scraps of evidence available do show that the fossil fragments may persist through about 20' of sandstone as in the beck S.W. of Black Riggs (872125) and that they are overlain by unfossiliferous coarse sandstone and grit.

Comparing the two sequences described above, two possibilities emerge. Either the Lower Coal Sill in each sequence is the same, in which case the marine bands have come in at different horizons, or the marine bands are the same and the arenaceous members of the succession have entered at different times. In favour of the first suggestion is the contrast in the marine horizons, which normally keep their lithological peculiarities over quite a wide area, and the evidence from Lunedale of more than one marine band. In favour of the second possibility are the following facts.

In Sleightholme the complete marine band is as follows:-

	Ft.
Pure dark Limestone (581)	1
Fossiliferous shale	8
Carbonaceous micaceous sandstone with fragmental fossils	2
Shale and sandstone bands	6

There is no sign here of any sandstone or grit, but the fossiliferous sandstone is very like that seen in Spital Sike. In addition there is no similarity between the rather flaggy sandstone of Rovegill and the coarse massive sandstone to the west, and on the ground there is a definite gap of about a mile, east of Spital Sike, where no sandstone can be found in place. In view of the uncertainty the marine band has been mapped as a discontinuous horizon, while the sandstones, which undoubtedly pass into each other, even though they may not be entirely contemporaneous, have been mapped as a continuous band.

Along the Westmorland scarp and in the stream sections there is further evidence of the variability of the Coal Sills. Most of the way they form very good features, but these disappear at some points, and, as there is no drift cover, this appears to be due to their lenticularity. The Upper Coal Sill persists, as it does everywhere, though its thickness as a truly arenaceous member of the succession may change.

In Yard Sike, the fossil sandstone appears to thin out due to a transgression at the base of the sandstone above. This transgression has increased so markedly by Smeltmill Beck that no marine horizon can be found at all. A thick massive sandstone has cut right down until it has coalesced with the Lower Coal Sill. This facies is of very local extent, however, as half a mile on either side of the beck the feature which the sandstone forms has disappeared. Borrowdale Beck shows yet a different section. Here, the fossil sandstone occurs at the base of a sandstone band with dark shale beneath it. Meanwhile a strong grit has come in, not far from the top of the Great Limestone. This is first seen near Cumpstone House and it increases in a north westerly direction. With its associated sandstones, it becomes 30' thick by Spurrig End and can be traced as far as Windmore End Quarry. It has a transgressive base and probably cuts into the top of the Great Limestone. In a swallow hole (823173) grit can be seen lying almost on top of the limestone, with only 3' - 4' of shale between. Above Windmore End Farm the fossil sandstone lies on top of the Middle Coal Sill, here a massive sandstone, at least 15' thick, but this also deteriorates until it is represented by about 6' of flaggy sandstone in Slateshill Beck (823174).

As already stated, surface exposures of the Coal Sills Group around Lunehead are non-existent. Loose boulders of grit and sandstone nevertheless show that there is yet another development of the coarse facies. Its proximity to the Great Limestone suggests that it might be the Lower Coal Sill, but it may equally well be the massive development of the Middle Coal Sill, once again joined to the sandstone beneath. The only mine section, in Hunter's Vein, does not help, as it shows three sandstones, separated by shale, with no marine beds recorded.

The constant nature of the Upper Coal Sill throughout the area contrasts strikingly with the beds below it. It can be followed over much of the ground even where it is drift-covered, and it is picked up again in the River Lune above Blake House.

Two marine bands are seen in the River Lune below Black House and an additional one has been found in the Selset Bores. Holes Nos. 1, 2 and 3 penetrate the entire thickness of the Coal Sills Group, and Holes Nos. 5, 12, 13 and 14 reveal some part of them.

At Selset the boreholes show that though the bottom 30' are extremely variable lithologically there is usually a coarse sandstone some 10' above the top of the limestone. In Hole No. 14, at Wemmergill, a grit lies directly on fossiliferous shale. This can also be seen in Hargill where there is a faint suggestion of transgression at the base of the grit. Above this grit and coarse sandstone are sandy shales which may become true shales, sometimes nodular, at Selset. These change into sandstone which, in the Selset boreholes contain marine fossils, and are capped by a limestone with very fossiliferous shale above it.

This marine band does not occur on the surface although equivalent rocks are exposed in Hargill. In this stream the sandstone is overlain by a 1' coal seam followed by shales and another sandstone. Nothing marine is found here at all. In the River Lune the lowest sandstone is roughly at the horizon of this marine band, but no fossils have been seen. Hole No. 14 proves 40' of solid rock with no marine fossils above the top of the Great Limestone, though, in the bores at Selset, the entire marine band occurs within 40' of the limestone. It is probable that the marine band has died out, as there is no evidence of transgression above it.

Another coal appears in the Lune above the coarse sandstone and this is overlain by shales and lenticular sandstones well exposed in the river bank (893213). There are then two marine bands separated by shale. The lower one is a muddy limestone, packed with fossils, mainly Productids and their spines. It is only 6" thick in the River Lune, but the boreholes show that the sandstone below also contains some marine fossils. The higher marine band is a calcareous sandstone composed mainly of quartz grains of sand grade, cemented by calcite, but containing a few larger grains. The calcite is partly dolomitized; fossil fragments occur, but they are not abundant. This marine band has been recovered from only one borehole, though four of them penetrate it. The cause of its absence is not certain, but as recovery of the cores was only about 50% non-recovery could be the explanation as well as transgression or non-deposition. In the River Lune there is a slight transgression at the base of the Upper Coal Sill, as noted by Carruthers (1938), and a coarse sandstone rests directly on the marine band in the borehole, so it is quite probable that the Upper Coal Sill, which undoubtedly has thickened at Selset, does cut out the top marine band.

East of Grassholme the only exposure of interest is in Easter Beck where sandstone about 30' thick appears some 6' above the top of the Great Limestone. One or two pieces of loose fossil sandstone were found here and they may represent the lowest marine band of the Selset Bores. Nothing else marine is seen this side of the reservoir though there are exposures of sandstone at the bottom of Shields Beck.

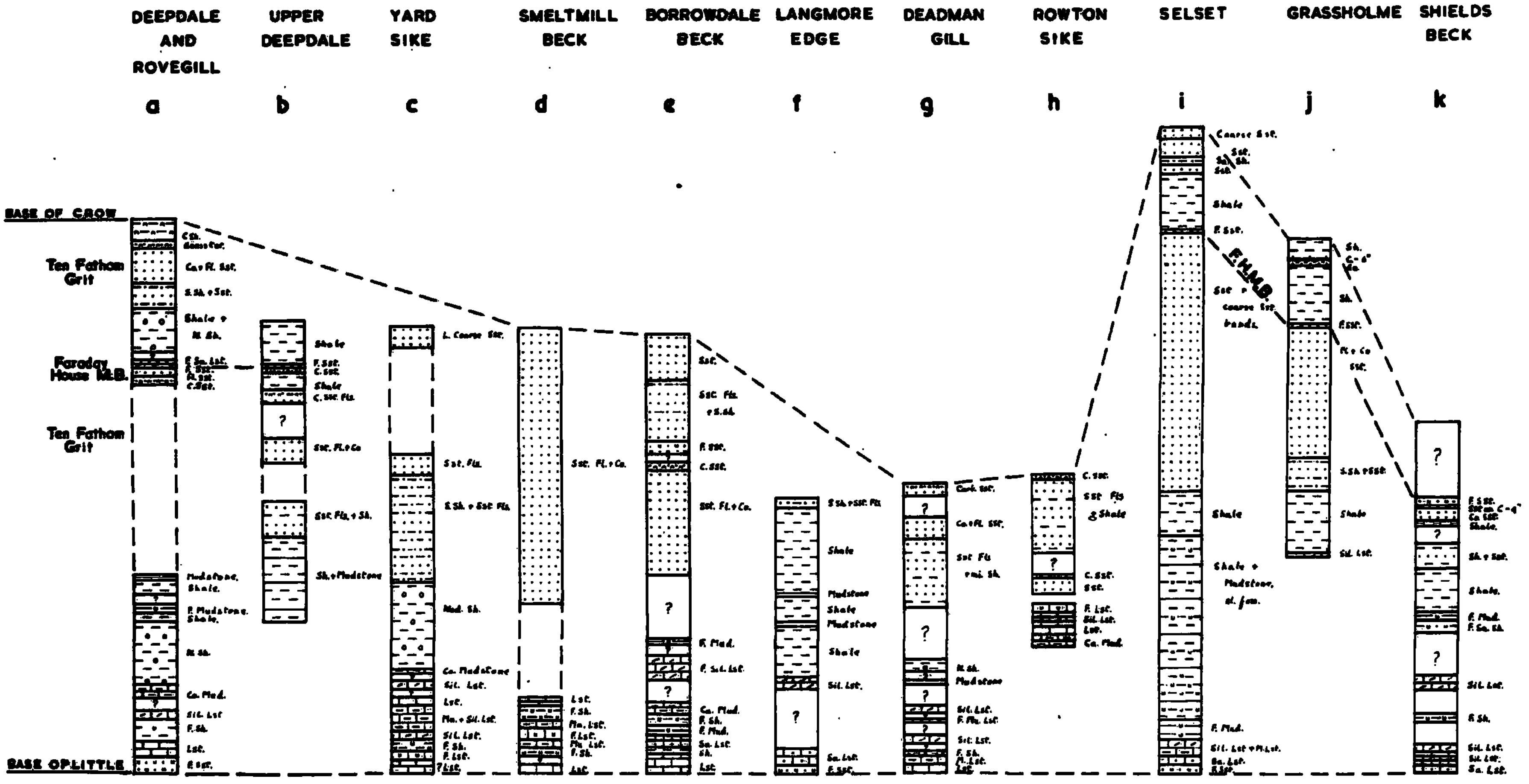
The lack of actual coals in the Coal Sills Group is noteable. The only ones found are those in Lunedale, though there are also the thin seams reported from Blue Cap Sike. No coal is ever seen under the Little Limestone, though there may be a ganister as in Borrowdale Beck. This is very different from some other areas where the Little Limestone Coal is the best developed of all the Yoredale coals.

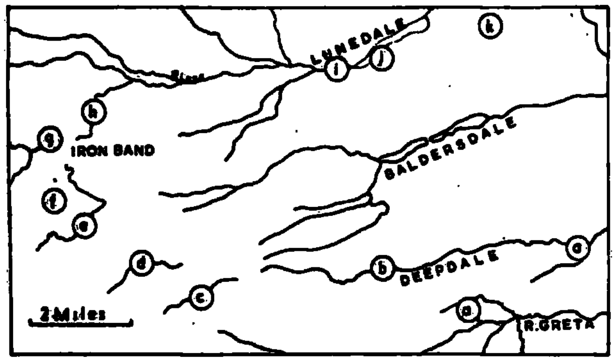
(v) Discussion. In the north eastern corner of the area the coral band is undoubtedly the Frosterly Marble of Weardale. It has the same large brachiopods and clisiophyllid corals and is at about the same horizon in the limestone. A cursory examination of the Great Limestone in Teesdale to the north seems to show that the band can be traced down the valley. To the west, however, it dies out. Does it extend southwards, joining up with the coral band seen in the River Greta? This coral band is of very limited extent near Bowes, though its continuation in a northerly direction is possible. It definitely does not extend eastwards, as shown by the Mount Pleasant Bore and the exposures in the Tees. In addition, the corals are not associated with large brachiopods, and, in spite of its position at roughly the same horizon there is no justification for correlating the two coral bands without evidence of their continuation under the syncline.

It is a pity that the Tumbler Beds are not well exposed, but it has been shown that on the whole they reach their greatest development in the north east and south east of the area. As, however, in the same regions they pass laterally into massive limestone in a very short distance (as has been shown south west of Bowes), this is probably only a generalization. A complication is introduced by the transgressive nature of the Lower Coal Sill which may in some places be the cause of the absence of the Tumbler Beds rather than non-deposition.

Dunham (1948) shows how the High Coal Sill of Alston may coalesce with the Low Coal Sill in a washout channel in the latter to form a single sandstone. Nothing quite so clear can be demonstrated in this area except in Smeltmill Beck where the marine band is definitely cut out by the Middle Coal Sill. The same thing however may well occur just to the west of the Lunehead Mines. The Upper Coal Sill is probably transgressive in Lunedale and so is the Lower Coal Sill both there and above Windmore End Quarry. These transgressions, however, are only of minor importance.

Correlation of the marine bands over the area as a whole is not profitable as they are all limited in extent. The Selset Beres show that there may be at least three horizons of marine deposition, but that they do not necessarily extend far laterally. In this respect the marine bands of the Coal Sills Group contrast with the others in the Upper Limestone Group. It seems then that though the Coal Sills Group is dominantly non-marine, the sea was never very far away and that at frequent but irregular intervals the sea covered part of the area. In view of the supposed equivalence of the marine Red and Black Beds of Swaledale with the Coal Sills (Hudson 1941, p.266) this evidence of proximity of the sea is not surprising.



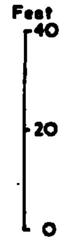


COMPARATIVE SECTIONS

OF

THE LITTLE CYCLOTHEM

FIGURE 6



(c) Little Limestone and Ten Fathom Grit.

(i) General. This cyclothem is the last whose mapping is straightforward. The Little Limestone at the base is well exposed and easily recognized, and, higher up, the Faraday House Marine Band possesses a characteristic lithology which makes it readily identifiable.

Throughout much of the North of England the limestone is known as the Little, or more specifically, the Upper Little, to distinguish it from another limestone of the same name low down in the Middle Limestone Group. Around Richmond, however, the name Red Beds Limestone has been used for the supposedequivalent horizon, and on the original 6-inch map, Yorkshire N.E. II, it was called the Rey Cross Limestone because of its outcrop at the Roman Camp on the Bowes-Brough road.

The Ten Fathom Grit occurs over much of the country to the south between the Little and Crow Limestones and includes fine grained strata as well as grits. The equivalent rocks to the north are less easily named. Dunham (1948, pp.31-32) discusses the uses of the terms Pattinson, White (High Pattinson) and Firestone Sills on the Alston Block. In Lunedale there are, at the most, two sandstone bodies separated by a marine band and for convenience they will be called the Pattinson and Firestone Sills, though it is quite possible that the lower sandstone is the equivalent of the White Sill of Alston Moor rather than the Pattinson. The marine band has been called the Faraday House Limestone by Turner and Rowell (personal communication) after a locality to the south of the present area. As it is seldom a true limestone here, in the text and figures it will be referred to as the Faraday House Marine Band, though on the map it is called the Faraday House Limestone.

The beds of this cyclothem have a very broad outcrop along the southern flank of the area. Horizontal or very gently dipping strata cover most of the ground between the Bowes-Brough road and Deepdale. It is however thickly covered by drift and peat. This makes it impossible to obtain a complete section and the middle beds are never properly seen. Nevertheless, the Little Limestone itself is often exposed here on the feature formed by the Upper Coal Sill, appearing also to the north in Red Bogs Sike, on Sandy Hill and W.S.W. of North Ings, where it forms an extensive limestone pavement, though only 3'- 4' thick. The Faraday House Marine Band is also frequently exposed in Deepdale and is a good guide to the higher beds of the cyclothem, better, in fact, than the overlying Crow Limestone which is very rarely seen. South of Deepdale occasional exposures of sandstone and grit and the many features covered by loose rock show the approximate position of the Ten Fathom Grit, but its relation to the Faraday House Marine Band is obscure.

In Westmorland the Little Limestone is the best mapping line available, until it disappears under drift east of Swindale Beck. Above it the only guide is the Ten Fathom Grit which is here the sole substantial arenaceous band between the Little Limestone and the Millstone Grit. The Faraday House Marine Band is not seen at all except in Borrowdale Beck, and so, while mapping is quite straightforward, the true relationships of the strata are not so easily discerned.

Much the same is true of the Lunehead Mines area where the Little Limestone is exposed, but the sandstones have thinned and the Faraday House Marine Band cannot be found. The whole of the Little Limestone outcrops in Deadman Gill, and in the River Lune above Blake House. In addition the upper part of it can be found in Rowton Sike, but this stream section is badly faulted, and it is quite possible that the apparent thinning of the cyclothem here is due to minor faulting cutting out most of the shales.

Occasional exposures in the Lune valley enable the beds to be traced along to the south east of the Grassholme Reservoir, where in the reservoir band and in the unnamed beck east of Grassholme Bridge there are excellent exposures from the Little Limestone upwards which can be compared with the Selset Bores. The sandstone forms a feature eastwards and can be followed along to the stream below Swarthy Mere and on to Shields Beck. The Faraday House Marine Band is seen in many of these becks, but the Little Limestone is only exposed in Shields Beck.

(ii) Little Limestone. The Little Limestone is best regarded as a marine series 20' - 30' thick, with either sandy or pure limestone at the base. The difficulty of separating the marine rock from the rock without marine fossils below has already been mentioned (p. 47). In some places, for example in Borrowdale Beck, the ganister top of the Upper Coal Sill makes the distinction quite clear. Here the pure limestone reaches a thickness of 5' but normally the basal limestone is rather sandy, in Lunedale there being about 50% quartz, with calcite and some organic material forming the cement. Around Bowes the same is true, and in fact the rock is really a calcareous sandstone. One thing is constant about the lower members of the Little Limestone series: they are free from muddy sediment. This comes in above the basal limestone and produces a very variable sequence of muddy and siliceous limestone interbedded with pure or sandy limestone and fossiliferous shales.

It is not easy to draw an upper boundary to the marine beds of the Little Limestone series. The typical fossiliferous shales and impure limestone pass up into unfossiliferous shales and mudstones. These may contain fossiliferous nodules as in Rovegill (80) and they may be capped by fossiliferous siliceous limestones. These resemble the 'lime plate' of Carruthers (1938) and in Lunedale may continue up to 40' above the base of the series with occasional fossils in even higher shales. These gradually become unfossiliferous, siliceous mudstones so well exposed in Deepdale, with non-marine shale separating the mudstone bands. At the Lunehead Mines, the shale appears to have thinned, but, as mentioned above (p. 57) this may be more apparent than real. The total thickness of the limestone is not clear here. Rowton Sike proves at least 20' of impure limestone with calcareous mudstone at the bottom, and the Hunter's Vein shaft section gives 7' of limestone above the Coal Sills Group. This means a minimum of 27', exclusive of shales above, and the true thickness may be greater still.

There are two outcrops on Bowes Moor whose stratigraphical position is a little doubtful. The first is in Glasgow Gill which is a deep overflow channel cut in a feature formed by a coarse sandstone, loose boulders of which are seen on Glasgow How and on Grey Scar. In the Gill are about 6' - 7' of massive limestone dipping very gently southwards. The rock contains bands of both pure and siliceous limestones, and it is all rather fossiliferous. No solid rock can be found either above or below the massive limestone. Either it is near the top of the Great Limestone and the coarse sandstone above is the Lower Coal Sill here showing the facies seen in Spital Sike, or it is the Little Limestone with the Ten Fathom Grit above.

Lithologically the former is more likely. The limestone could well be a rather thick post of the Tumbler Beds, while the Little Limestone has not been found to possess quite such a thickness of limestone without shale bands. On the other hand, if it were, the E.N.E. fault to the south would have to have a very much greater throw, and another fault would have to be introduced north of the outcrop in order to throw down the Little Limestone seen in Black Beck. On structural grounds therefore the latter is preferred.

In a small quarry N.W. of Clint House (982143) there is a rather calcareous chert. About 6' are exposed altogether, dipping at 8° to the N.N.W. Nothing is seen of the beds above or below, and there are no other exposures of identifiable solid rock between Deepdale to the north and the Clint Quarries to the south. The rock is a pale fossiliferous cherty limestone, rather banded, with lumps of pure dark chert forming lenticles about 12" long and 6" high. Nothing quite like it has been seen anywhere else. It is definitely not the Main Chert which is a dark, unfossiliferous and much more banded rock. The Crow Limestone, well exposed in Deepdale less than a mile to the North, does not contain any chert. It must therefore be the Little Limestone chert facies. It is not seen elsewhere in the neighbourhood as the nearest full exposure of the Little Limestone is in Sealgill, a mile to the south west. Eastwards, there are no exposures at all apart from some siliceous limestone in Thornberry Quarry just north of the Barnard Castle-Bowes road, until the Tees is reached, where no true chert was found.

The dip to the N.N.W. in the Quarry might imply that the chert is stratigraphically far above the Little Limestone of Clint Quarries, but at the latter place the beds are almost horizontal and so there is no structural reason for thinking the chert lies very far above the limestone. It is suggested therefore that this might be an extension of the chert facies of Swaledale northwards, the boundaries of which lie somewhere between this outcrop and Sealgill to the West and the Tees to the east.

(iii) Ten Fathom Grit and Faraday House Marine Band. In Swaledale the Ten Fathom Grit consists of sandstones, often coarse, and shales, in two divisions, with a thin limestone between them (Mallerstang Memoir 1891, p.10). In this area it is very similar.

On Ravock, the grit reaches its coarsest development. There are over 15' of compact and current bedded grits with depositional dip to the W.S.W. Much loose grit can also be found, sometimes forming low features appearing through the peat to the east and west of Ravock, and there are outcrops of grit in Deepdale just to the north.

The position of the Faraday House Marine Band within the grit facies is not certain. Above the Ravock grit there is a little siliceous limestone, lying in place. This appears to be more like the Crow Limestone than the Faraday House Marine Band, yet in Deepdale itself (949148) a sandy, fossiliferous limestone similar to the Faraday House Marine Band lies on top of grit. The old surveyors considered this limestone to be the Rey Cross (Little), repeated by a conjectured fault a little downstream. There is no sign of the limestone downstream, though there is some grit. The conclusion drawn is that there is a grit facies both above and below the Faraday House Marine Band.

Eastwards, below Crag Bridge in Deepdale, the section shows a complete cyclothem above the Faraday House Marine Band. No grit is seen here below the Crow Limestone, which actually lies on carbonaceous shale, and not on ganister. Not a great thickness of rock is seen below the Faraday House Marine Band in this section, but if the strata were coarse they would surely outcrop somewhere in the neighbourhood.

In Deepdale, above Green How, an E.-W. fault lets down the Faraday House Marine Band and the beds below it. These are obviously not very coarse, and, though the fault prevents a continuous succession from being obtained here right down to the Little, it is quite clear that there is no grit facies. Thus the grit facies of Ravock dies out to the N.E. and N.N.W., though in a westerly direction it probably extends as far as the two outliers either side of Glasgow Gill.

The Faraday House Marine Band is a band of very shelly sandstone or sandy limestone. The constant feature of the band is the occurrence of masses of well-preserved brachiopods, usually just their casts in the sandy type of rock, but the complete shells in the purer limestone. The brachiopods are mainly Spirifers and Rhynchonellids, with some Productids. In Deepdale, below Crag Bridge the limestone is almost pure (543), but in the higher reaches of Deepdale close to the county boundary it becomes a rather gritty sandstone (352). In the beck here its exposure is extensive, and just to the N.W. the Crow outcrops. Nothing can be found of the intervening rocks, so presumably the finer grained facies extends as far as this point.

Beyond the county boundary, however, the coarser rocks begin to show themselves again about the Old Quarry (876138) and just beyond Yard Sike. In this beck quite a thickness of non-marine shales passing up into sandstone flags can be measured, but the exposure is not continuous up into the coarser sandstones; nor can any sign of the Faraday House Marine Band be found. For ¾-mile along the escarpment only flaggy sandstones outcrop, but, south of Great Moss a strong feature appears through the peat. This is High Crag, which near Smeltmill Beck has become a huge cliff revealing about 65' of flaggy and compact sandstone extending down to within 20' of the top of the Little. A thorough search was made for the Faraday House Marine Band, but without success. Less than 300 yards N.W. of Smeltmill Beck this thick sandstone has gone, and sandy shales and flaggy sandstones represent the Ten Fathom Grit as far as Longcrag House.

It is suggested that this is a sandstone-filled washout. The channel was formed after deposition of the Faraday House Marine Band which is here cut out. The thick sandstone, representing the upper part of the Ten Fathom Grit, then filled up the eroded channel. The Faraday House Marine Band may not have been deposited, but this is most unlikely considering its persistence in Borrowdale Beck, Deepdale, and in Argill Beck 1½ miles to the south west (Rowell, personal communication).

North of Long Crag the sandstone becomes more compact again, but the outcrop in Borrowdale Beck of the Faraday House Marine Band shows that no washout of the same magnitude occurred. In fact, the thickness of sandstones is greater below the marine band than above and this suggests that much of the sandstone at High Crag is the lower part of the Ten Fathom Grit, the transgression occurring perhaps only half way down the section. The beds immediately below the Crow are exposed again further up, at the foot of Crook Beck, by a fault but the throw is not sufficient to show the Faraday House

Marine Band. North westwards there are many exposures of sandstone flags and some of the underlying shales and mudstones which may be 30' thick. Nothing very definite is seen of any overlying marine band until Deadman Gill is reached. This is the beginning of the Lunehead Mine area, and a change of nomenclature for the sandstones is necessary.

<u>(iv) Pattinson and Firestone Sills.</u> In the becks on either side of the county boundary the Firestone Sill and Crag Limestone are often exposed, but their identification is seldom quite certain as the sections are never complete and there are undoubtedly more faults than are shown on the map. The possibility of strata being cut out in Rowton Sike has already been mentioned (p. 57), especially as 60' of beds, mainly hidden, occur between the top of the Little and the Crag Limestone in Clove Sike. Two sandstones are seen here. One, the Firestone, is at least 8' thick, comprising carbonaceous sandstone lying on top of flags. The other is some 20' below this and is at least 4' thick; presumably it is the Pattinson Sill. The intervening beds are not revealed.

In Rowton Sike two sandstone members are seen. One lies immediately below the Crag Limestone and so must be the Firestone Sill. It is a flaggy sandstone with shale bands, and below this is a thin carbonaceous sandstone lying on a siliceous sandstone. Much the same is found in Deadman Gill where the Crew Limestone is only recognised by a few loose pieces, and so its exact horizon cannot be placed. It is believed that in both these streams the Faraday House Marine Band should occur above the lower sandstone, but it has not been found. Two sandstones can be distinguished, even if the absence of the marker horizon makes their exact position difficult to prove. The complete sequence can be ascertained from the Selset Bores, though no single hole goes from the Crag to the Little Limestone. There is a tremendous increase in thickness compared with the Lunehead Mine area and it is unfortunate that nothing is exposed between the two. The Pattinson Sill has expanded to nearly 60' of sandstone, often coarse. Its thickness diminishes eastwards but it is well exposed near Grassholme Bridge and in numerous quarries and streams south and east of the reservoir, forming a continuous sandstone band.

The fossil sandstone occurs above the Sill in the bores, and in the surface exposures. It has the typical lithology of the Faraday House Marine Band, being very sandy and full of brachiopod casts. The beds between this and the Crag Limestone are almost entirely shale though a coal and ganister can be seen at Grassholme Bridge, and there is some sandstone at Selset. Thus the Firestone Sill has here been replaced almost entirely by shale and for a distance of 3 miles east of Grassholme Bridge only shale is seen between the Faraday House Marine band and the Crag Limestone.

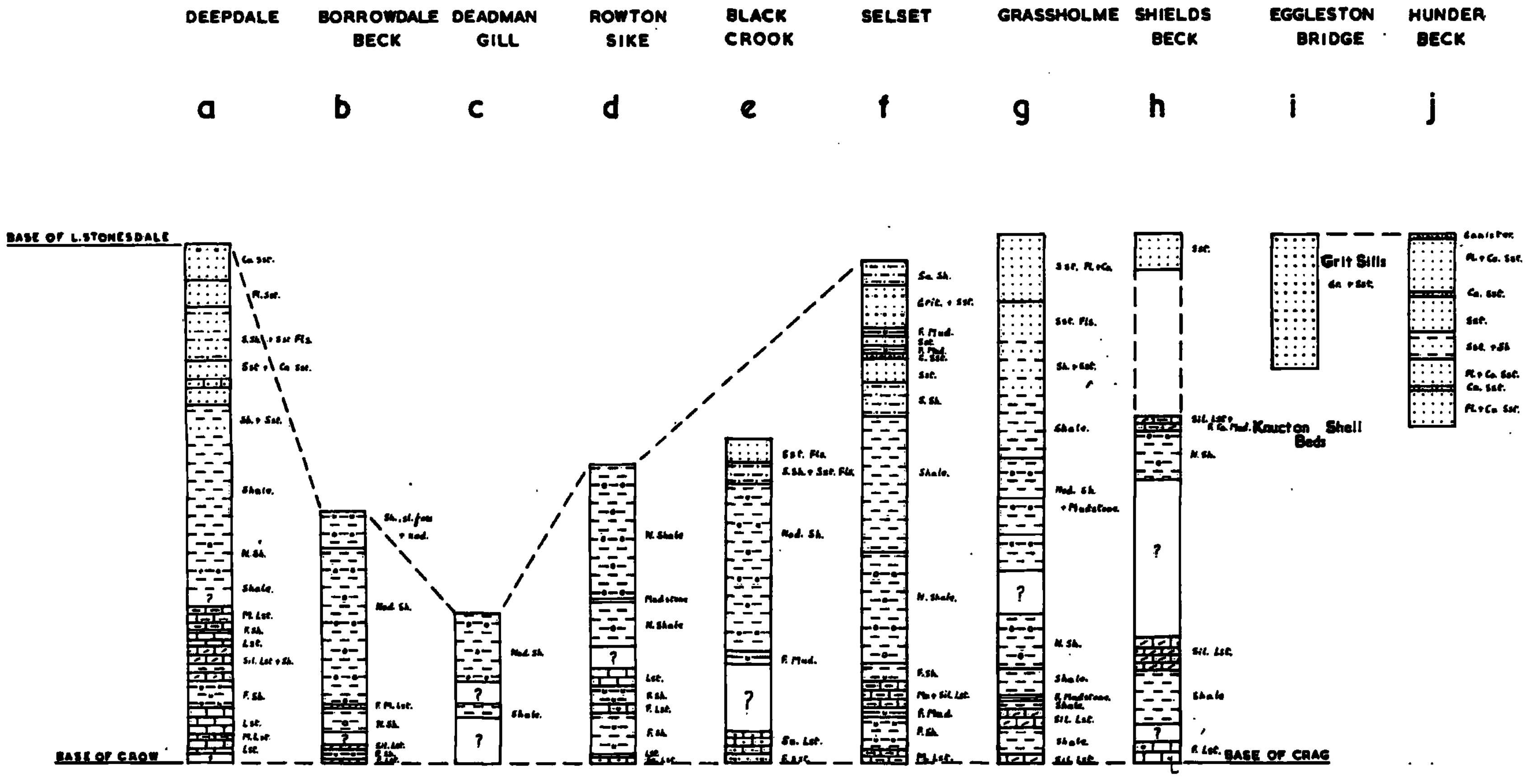
(v) Discussion. Once again, the transgressive nature of the sandstones in the Upper Limestone Group has been shown. In addition to the washout proved at High Crag, there may be others in the Stainmore Area. At Ravock one would expect to find some exposure of the Faraday House Marine Band round the southern flank of the hill or at least in Duckett Sike. As it is, the only exposure, outside the Deepdale ones already mentioned is just to the east of Ravock (963146) where some loose fossiliferous sandstone was found.

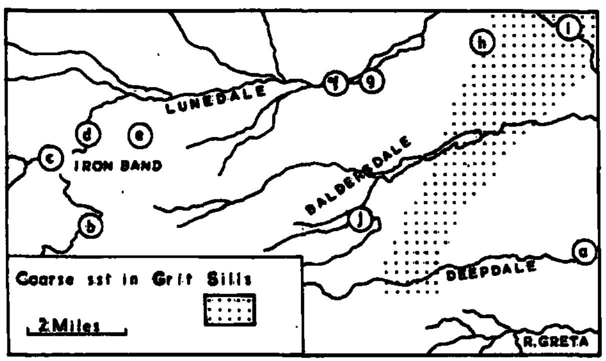
Nothing else is seen even of loose pieces, in spite of the presence of many grit boulders. Here, there is probably another washout, less than a mile across. Similar evidence from the Tees just below Barnard Castle Bridge shows much the same thing. A great thickness of sandstone is seen in the river bed, but there is no sign of the Faraday House Marine Band.

Marine bands have been reported at at least two horizons between the Little and Crag limestones on the Alston Block (Dunham 1948, pp. 31-32). It is not clear to which one the Faraday House Marine Band corresponds, but it is certain that it can be followed across the Tees into North Teesdale as it has been found 40' above the Little Limestone in Eggleston Burn at the road bridge (989249). It is the usual shelly sandstone and has shale above and below it. The only arenaceous rock is a grit, presumably the Firestone Sill, about 18' above it, but the Crag Limestone could not be found. Identification of the Faraday House Marine Band with one of the Alston Block marine bands would enable sills below the Firestone to be correlated as well.

In the previous cyclothems there was considerable variation in lithology within each cyclothem, but the total thicknesses remained much the same throughout the area. In common with many of the succeeding cyclothems, the total thickness of this cyclothem varies a great deal from about 70' at the Lunehead Mines to 150' at Selset, and down to about 80' in Shields Beck. The thickness increases roughly with the proportion of sandstone and differential compaction may be partly the cause. However there are also changes of thickness in the marine beds of the Little Limestone and these can only be explained by differential subsidence during deposition.

Differential compaction could also be invoked to explain the absence of the Faraday House Marine Band in the places mentioned above. The thick sandstones at these places would then underlie its horizon and have stood up above the sea, so that the Faraday House Marine Band was not deposited. However, in the Selset Bores, where the Pattison Sill is at its thickest, the Faraday House Marine Band was definitely laid down, so that removal by transgression is the more likely explanation for its absence.





COMPARATIVE SECTIONS

OF

THE CROW CYCLOTHEM

FIGURE 7

(d) Crow Cyclothem.

(i) General. The beds of this cyclothem and the succeeding one are the least satisfactory of all the strata discussed in this thesis. Exposure of the marine beds is poor, and there are no definitely recognizable bands between the Faraday House Marine Band and the ~~Upper~~ Lower? Stonesdale. In addition the lack of arenaceous rocks over most of the area makes mapping difficult. Finally there is the loss of one marine band between the bottom of Lunedale and the remainder of the district so that correlation between isolated outcrops is always speculative.

The limestone has been known as the Crow over all the country to the south and west, in the Mallerstang Memoir (1891), on the Old Geological Survey Maps, and in Turner (1935). On the Alston Block the equivalent bed is the Crag Limestone, with the Knucton Shell Beds of Carruthers (1938) above it. To the south no strata have been named between the Crow Limestone and the Lower Stonesdale Limestone, but to the north there are a number of thick sandstones above the Knucton Shell Beds. These are Westgarth Forster's Slate Sills for which the Hunstanworth miner's term Grit Sills was used by Carruthers (1938). The latter term is also used here for sandstones and grits below the Rookhope Shell Beds.

No section of any value could be obtained from the Bowes area, so one was drawn up for Deepdale just beyond the eastern boundary of the map. A triple fault throwing north breaks the section, but as equivalent strata can be recognized on either side of the fault the section is fairly accurate. The Crow Limestone is well exposed in the river for some distance either side of Crag Bridge and there is a small outcrop on the north west side of Ravock (954146).

Between Ravock and an isolated outcrop of the limestone north east of Deepdale Head nothing is seen of the cyclothem except for a coarse sandstone in Backstone Beck and Knotts Sike at the horizon of the Grit Sills.

In Westmorland exposure is no better though there is a complete section in Borrowdale Beck repeated by the fault in Crook Beck. A few loose limestone boulders sometimes enable one to map the position of the Crow Limestone and there are small exposures above High Crag, and at Cow Howe, but they are all.

In Deadman Gill the upper part of the cyclothem is fairly clear but the lower part is doubtful since there is no limestone in place. A more complete section is seen in Rowton Sike with further exposures in Clove Sike and Black Crook. Then everything is lost under drift until the Selset Bores are reached. Holes Nos. 7a, 7 and 8 each penetrate part of the cyclothem but as correlation between the holes is not precise the section is only an approximate one. Good surface exposures can be found near Grassholme Bridge and in Shields Beck, but as the Rookhope Shell Beds are not seen in either case the tops of the sections are not exact. East of Grassholme the Grit Sills form a good mappable horizon, as good as the Pattinson Sill for purposes of correlation between the stream sections. These sandstones also outcrop in the River Tees and in Hunder Beck but apart from one exposure of what is probably the Crow Limestone in the Tees, the rocks below the Grit Sills are not seen.

(ii) Crow and Crag Limestone. The Crow Limestone of Deepdale is a thick, moderately pure limestone with muddy and siliceous bands, and some shale partings, but lateral changes are rapid. It is comparatively fossiliferous though the fossils are mainly fragments and crinoid ossicles. Some of the limestone is rather siliceous but no chert occurs. Eastwards the Crow Limestone maintains this thickness as can be seen below the castle at Barnard Castle, but westwards it must thin considerably for it is not exposed for more than 4 miles, and in spite of the drift this is most unlikely if its thickness was maintained.

Confirmation of thinning is obtained from a comparison of the outcrops in Borrowdale Beck and in Crook Beck which show how rapidly the lithology may change.

In general, however, there are three hard bands, separated by shale, the lowest one containing a slightly muddy limestone which weathers a deep orange brown. Boulders of this are sometimes seen lying around marking the position of the Crow. Otherwise, outside the streams, only a siliceous limestone is seen, typical of the lime plate of Carruthers. The three hard bands are again found in the streams near the Lunehead Mines, though the identification of the limestone in Black Crook is rather doubtful. The fossil sandstone and sandy limestone at the base resemble the Little Limestone, but a sandy limestone occurs in both Rowton Sike and Clove Sike at the base of the Crow and the overlying nodular shale suggest that it is probably this limestone.

The remaining three sections of the Crag Limestone show nothing very new except that there is a high proportion of interbedded shale and that the thickness at Shields Beck is approaching that of Deepdale. The outcrop in the Tees also shows a thickness of about 30'. Thus both the thickness and the proportion of pure limestone and siliceous limestone to shale increase to the east and south east.

(iii) Shale. Throughout the area the thickness of shale above the Crow Limestone is considerable. It usually contains bands of unfossiliferous chalybite-mudstone nodules and it may continue right up to the base of the overlying cyclothem without any sandstone.

(iv) Knucton Shell Beds. On the Alston Block these consist of two beds of shelly sandstone interbedded with shale which follow the Crag Limestone (Dunham 1948, p.35). In Snaisgill, north of Middleton-in-Teesdale, the two bands can be picked up, but the sandstone is rather micaceous and muddy. This is even more obvious in Shields Beck where the Knuctons are represented by a slightly calcareous sandy mudstone with some siliceous lime-stone. This marine horizon is not particularly fossiliferous, and only one band is seen, but the beds above it are obscured so that there may be two. This is the only surface outcrop, but in the Selset Bores two thin bands of fossiliferous mudstone were recorded in the Grit Sills which may be the equivalent of the Knuctons. Carruthers (1938) includes one Knucton Shell Bed in his section for Grassholme Bridge, but this is now shown to be the Faraday House Marine Band, the lithology of which is identical with the Knuctons of the Teesdale-Weardale watershed.

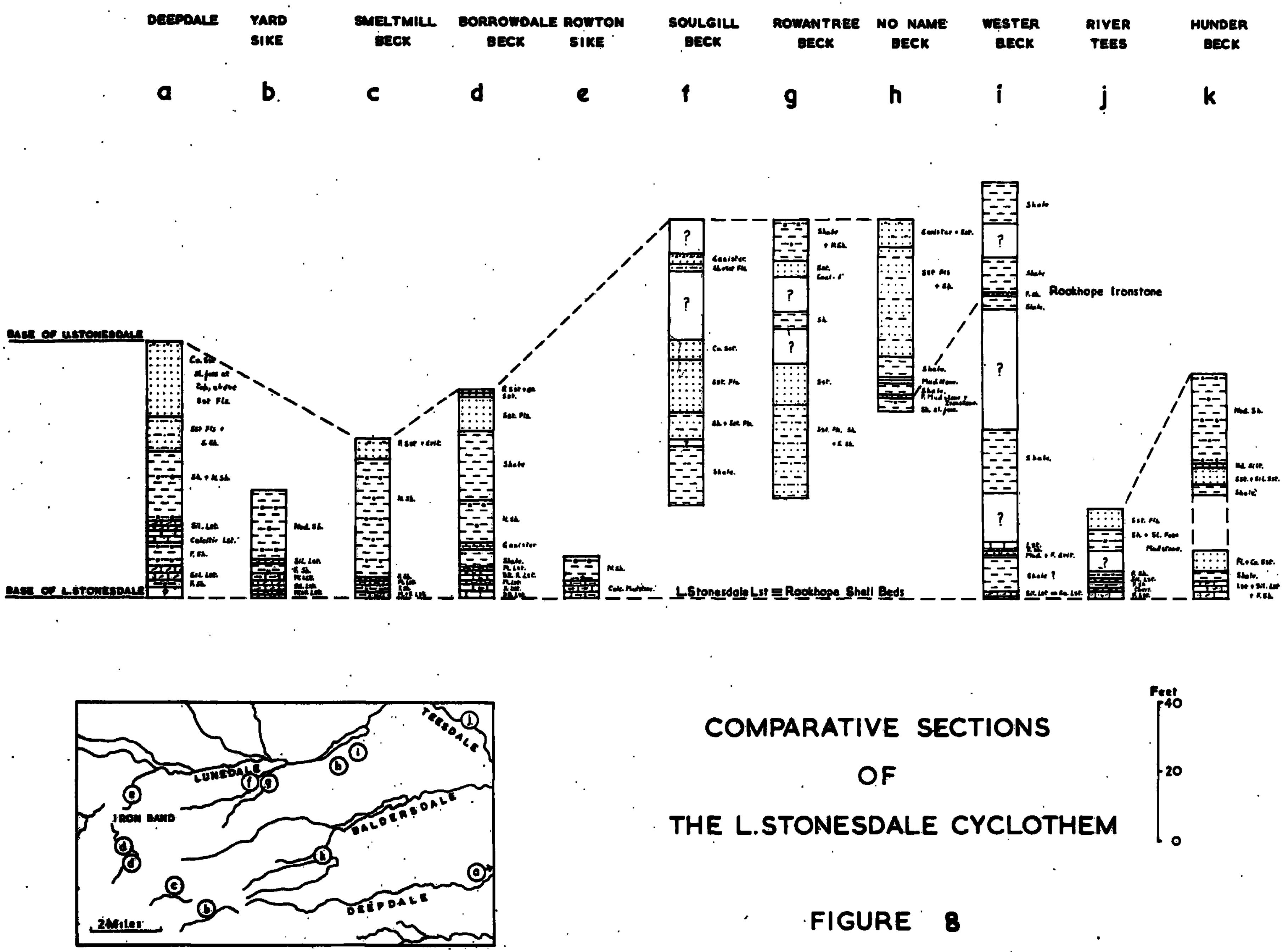
(v) Grit Sills. Over most of the eastern half of the area the top part of the cyclothem contains a sandstone up to about 40' thick which grades up from the shale below. In Deepdale and Hunder Beck this is a normal flaggy compact sandstone with occasional lenticular bands of calcareous sandstone. This calcareous sandstone is non-marine and contains no fossils, but is an extremely micaceous sandstone cemented by calcite. The western sections show no sandstone, though it begins to appear at Black Creek.

In addition there is another arenaceous facies, consisting of a coarse sandstone or grit which is partly seen at Selset and east of Grassholme. However it does not really develop until Bail Hill just east of Shields Beck is reached, where a grit lithologically comparable with the normal Millstone Grit appears. This it was thought to be by the old surveyors who inserted a north easterly fault east of Shields Beck. The fault, however, would cut across several mappable horizons, including the Little Limestone, the Faraday House Marine Band and the Transgression Beds Grits. Furthermore the Rookhope Shell Beds and Lower Felltop Limestone have been found above this grit, and, in the Tees the sandstones below these limestones are distinctly coarse and contain grit bands. This is therefore a continuation of the coarse facies above the Rogerley Transgression at the base of the Low Grit Sill on the Alston Block described by Dunham (1948). The base of the grit is never seen, so there is no positive evidence in this area for unconformity. Since the width of the Hunstanworth-Stanhope-Middleton washout is only 2 to 2½ miles it is possible that it exists here but that it is hidden by drift. On the south side of the syncline the coarse sandstone around Knotts Sike may be the Grit Sills, though its horizon is not absolutely certain. At any rate the true grit facies has died out and probably the wash-out has disappeared.

(vi) Discussion. As with the previous cyclothem the variations in thickness are very great, and the thinnest sections are found in the same part of the area, in the north west and also the west. Sandstone is completely absent from this part and this compares with the Askrigg Block where the Crow and the Lower Stonesdale marine horizons are quite close together, separated only by shale.

The disappearance of the Knucton Shell Beds is a problem. On the Alston Block Dunham has shown how they may be cut out by the Rogerley Transgression. This is not the cause of their disappearance here as their absence has no connection with the development of Grit Sills. Therefore either they die out or they combine with another marine band, or the correlations are wrong. A comparison of the sections shows that they are not likely to combine with another marine band. The possibility of incorrect correlations above the Crow Limestone is too big to be discussed in full here, but an examination of the Deepdale section shows that if the Knuctons are equivalent to the Lower Stonesdale Limestone then there is a thick sandstone beneath them, and this is contrary to anything seen on the Alston Block. Thus the probability is that the Knucton Shell Beds die out just west and south of the Grassholme Reservoir.

The Grit Sills almost certainly disappear south of the present area as there is no record of a sandstone below the Lower Stonesdale in the Mallerstang Memoir. This confirms the evidence of the area itself that the Grit Sills and Rogerley Transgression decrease in importance southwards.



COMPARATIVE SECTIONS

OF

THE L.STONESDALE CYCLOTHEM

FIGURE 8

(e) Lower Stonesdale Cyclothem and Rookhope Shell Beds.

(i) General. The name Stonesdale for the limestones of this cyclothem and the succeeding one was first used by Hudson (1941, p.264) as they are well exposed in the valley of that name. Previously they had been known as the Fell Top Limestones because they were considered by the authors of the Mallerstang Memoir (1891) to be the equivalent of the Fell Top Limestones of the Alston area. This correlation is now shown to be incorrect and as Westgarth Forster's term Fell Top is of earlier usage it will be confined to the limestones of that name on the Alston Block, where the strata considered to be equivalent to the Lower Stonesdale Limestone are the Rookhope Shell Beds, named by Carruthers (1938). They are usually in two bands and may have the Rookhope Ironstone above them.

On the south side of the syncline exposure is extremely poor but, once again, a section can be obtained from Deepdale just beyond the margin of the map. There are two outcrops of limestone in Knotts Sike and Knotts Gill with some sandstone above, but too much reliance should not be placed on the correct identification of any of the rocks along the north side of Deepdale as mapping is very much a question of guess work. Along the Westmorland scarp, however, exposure is better and the limestone outcrops in most of the small becks, often with an appreciable thickness of shale above it. In addition, the hard nature of the rock compared with the shale above and below it causes a strong feature to be found between the becks, often revealing solid rock exposures.

This continues through Deadman Gill to Rowton Sike, beyond which the entire cyclothem is hidden by drift until Soulgill Beck is reached. Good sections are obtained in both this and Rowantree

Beck of the upper part of the cyclothem, and there are further outcrops at Bink House and in the beck S.S.E. of Grassholme referred to as No Name Beck. Three of the Selset Bore Holes pierce part of the cyclothem but there is no precise correlation between the holes, and the top is not revealed. East of No Name Beck exposure is poor except for Wester Beck and little scraps in Shields Beck and Wadycarr Sike. In the River Tees the whole sequence can be seen and both the upper and lower parts occur in Hunder Beck, but they are separated by faults so that the full thickness cannot be ascertained.

(ii) Lower Stonesdale Limestone and Rookhope Shell Beds. The marine part of this cyclothem is extremely variable lithologically. In Westmorland it does form a good mappable horizon, but in the rest of the area it has no diagnostic characteristics and its recognition is based merely on the constant occurrence of a marine band between the Upper Stonesdale Limestone and the Grit Sills.

In Deepdale the marine series is over 20' thick, consisting mainly of fossiliferous shale with some hard bands of pure and siliceous limestone. The base is not quite clear because the underlying sandstone does contain some fossils, producing a problem similar to that of the Little Limestone. Eastwards the marine beds thin a little.

The old surveyors mapped a limestone in Hazelgill Beck (976160) but nothing can now be seen of it there. They did not attempt to link it up with any other limestone but it is almost certainly the Lower Stonesdale. The exposures in Knotts Sike and Knotts Gill are very poor but they show that the marine band is fairly thick and that it may be associated with a very hard quartz grit.

In Westmorland the Lower Stonesdale is not much more than 10' thick and it is mainly impure limestone with purer limestone at the base, packed with crinoids and other fossil fragments. In the streams the impure limestone bands appear to be fairly homogeneous, but when exposed to weathering on the grassy slopes they are seen to be the typical lime plate of Carruthers, the more calcareous portions weathering out and leaving the siliceous bands, thus giving a platy effect. This lime plate is called siliceous limestone, though in the streams it was at first thought to be calcareous mudstone as the two appearances of the rock are very different. This siliceous limestone can be followed right round to Rowton Sike where the Lower Stonesdale is only 5' thick and contains no pure limestone.

At Bink House about 4' of siliceous limestone are seen at the top of the marine series, but in the Selset Bores there is a great thickness of partly marine strata above the Grit Sills. Hole No. 8 gives the following section above the Grit Sills:-

	Ft.	Ins.
Dark fossiliferous limestone, with a gritty limestone at the base	3	
Slightly fossiliferous shale and mudstone ..	14	
Very hard, fossiliferous calcareous mudstone	3	6
Dark, slightly calcareous grit	1	6
Nodular shale	25	
Calcareous, fossiliferous mudstone and muddy limestone	4	
Siliceous limestone on sandy mica shale	6	

Either the upper part of this section corresponds to the Lower Felltop Limestone or the Rookhope Shell Beds extends over a vertical range of more than 50'. The first suggestion seems improbable if the Soulgill, Rowantree and No Name Beck sections are examined for details of the beds below the Lower Felltop, in all of which streams thick sandstones occur. In Wester Beck, where the nearest surface exposures of the Rookhope Shell Beds are seen, the thickness may be a lot more than the 16' shown, as neither the top nor the bottom are clearly defined. It seems therefore that the Rookhope Shell Beds are extremely thick here and this agrees with Carruthers' sections for Swinhope and North Teesdale in both of which the Shell Beds are 60' apart.

The outcrop in Wester Beck shows the mudstone and grit well. It is very fossiliferous and the grit occurs in bands in the mudstone, consisting of rounded grains of quartz 2 mm. across, cemented by calcite. This is the only outcrop with this lithology, though the one in Knotts Sike is similar.

In Hunder Beck there are only 5' of marine beds at the horizon which is taken to be the Rookhope Shell Beds. They are a very variable series of siliceous and pure limestones with a little shale, comparable to the lithology of the Lower Stonesdale of Westmorland. The rocks in the Tees are similar, though a little thicker.

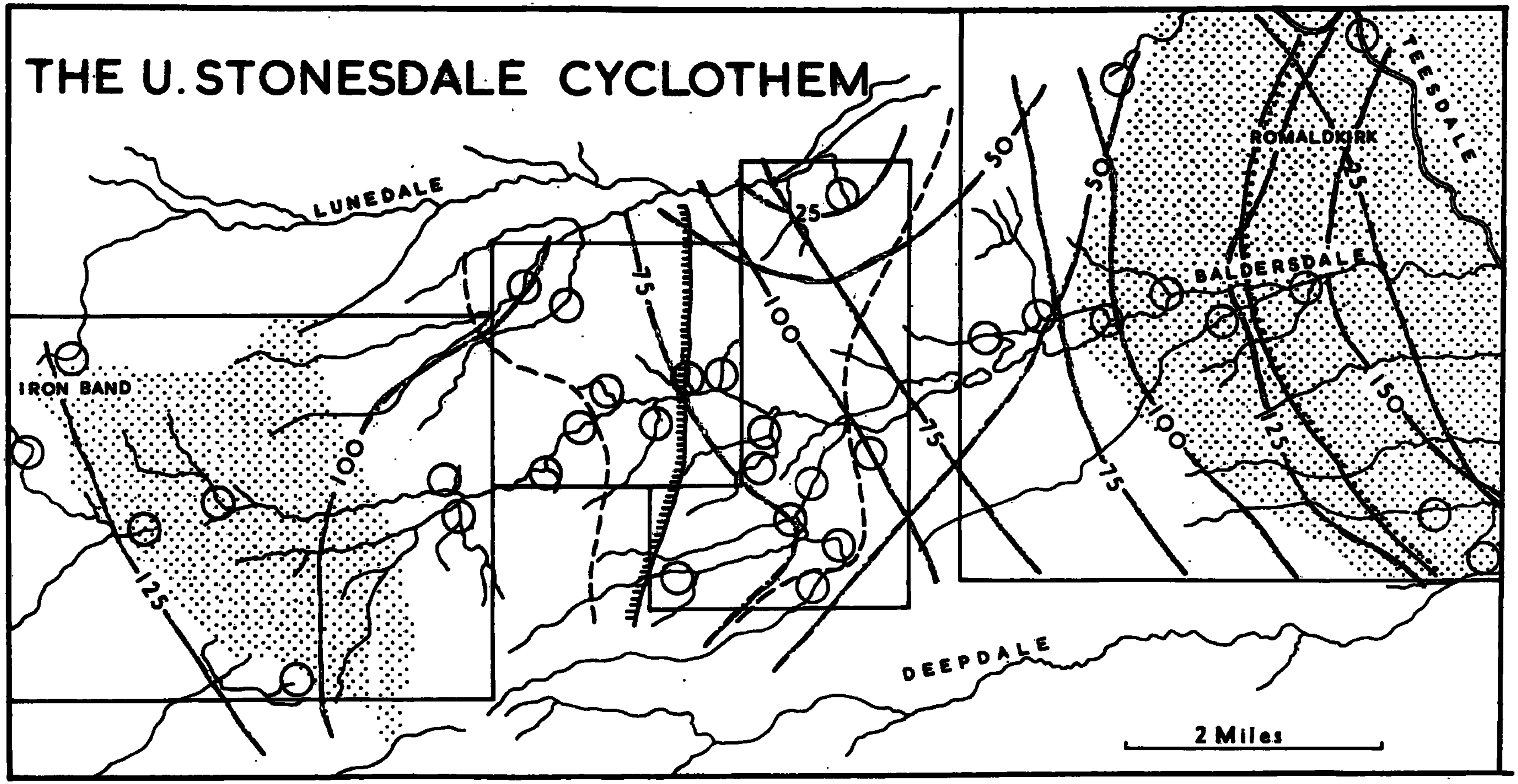
(iii) Shale, Sandstone and Rookhope Ironstone. The shale of this cyclothem cannot be separated from the sandstone as all the northern sections show considerable variation from normal cyclic deposition. It is true that in Deepdale and in Westmorland a shale, often nodular, is followed by a sandstone. This sandstone contains fossils and may become gritty at the top making a good marker band along the scarp and reaching its maximum thickness near Mickle Gill. However in Crook Beck, and below High Edge, another ganister or sandstone comes in a short way above the top of the Lower Stonesdale.

This is a precursor of the sandstones seen elsewhere. In Hunder Beck there is one just above the Rookhope Shell Beds and in Soulgill and Rowantree Becks there is a thick sandstone with shale above it and then more sandstone, while the cyclothem is topped by shale. On the other hand in Wester Beck there is a great thickness of shale, with no sandstone at all above the Rookhope Shell Beds. This is matched on the south side of the syncline, for the sandstone of Knotts Sike also dies out laterally to be replaced by 50' or more of nodular shale in Hazelgill Beck.

In No Name Beck there is, in the shale, a thin band of fossiliferous mudstone and ironstone, the latter showing good cone-in-cone structure. Nothing very definite can be found below it though there is a great deal of loose shale, suggesting a considerable thickness, and a broad shale feature can be traced eastwards to Wester Beck where there is a thin fossil band in the shale. These two marine outcrops have been correlated together, and it is suggested that they may represent the Rookhope Ironstone of the Alston Block. They are not found anywhere else in this area and are evidently restricted to where the cyclothem is thickest.

The beds beneath the Lower Felltop Limestone are not everywhere sandy, though in No Name Beck there is a thick sandstone which is partly carbonaceous and siliceous at the top of the cyclothem. This sandstone is not extensive as it cannot be found outside No Name Beck and undoubtedly in both Rowantree Beck and Hunder Beck a nodular shale underlies the Lower Felltop Limestone. By the time the Tees is reached there is only 6' of sandstone flags to represent the non-marine part of the cyclothem.

(iv) Discussion. The changes of thickness are greater than in any previous cyclothem. The position of maximum thickness is in the centre of the area where it is more than 120' with a reduction in the west to around 50'. To the east, however, the reduction is much greater and one might suspect that the correlations were wrong if it were not possible to trace the cyclothem down Deepdale to Barnard Castle, where only 6' of coaly shale and sandstone separate the Upper and Lower Stonesdales, as compared with 50' of non-marine beds two miles upstream. On the north side of the syncline the decrease in thickness is also very rapid and occurs near Shields Beck, for the reduction is almost certainly complete by Wadycarr Sike. Thus it appears that a line of maximum thickness could be drawn, running S.S.E. through the centre of the area, with a line of minimum thickness on the east and an intermediate one in the west, but without any definite information for the middle of the syncline this interpretation is probably too simplified and one is not justified in drawing isopachytes.



FIGURED SECTIONS

LIMIT OF MIRK FELL IRONSTONES

LIMIT OF PEBBLY GRIT

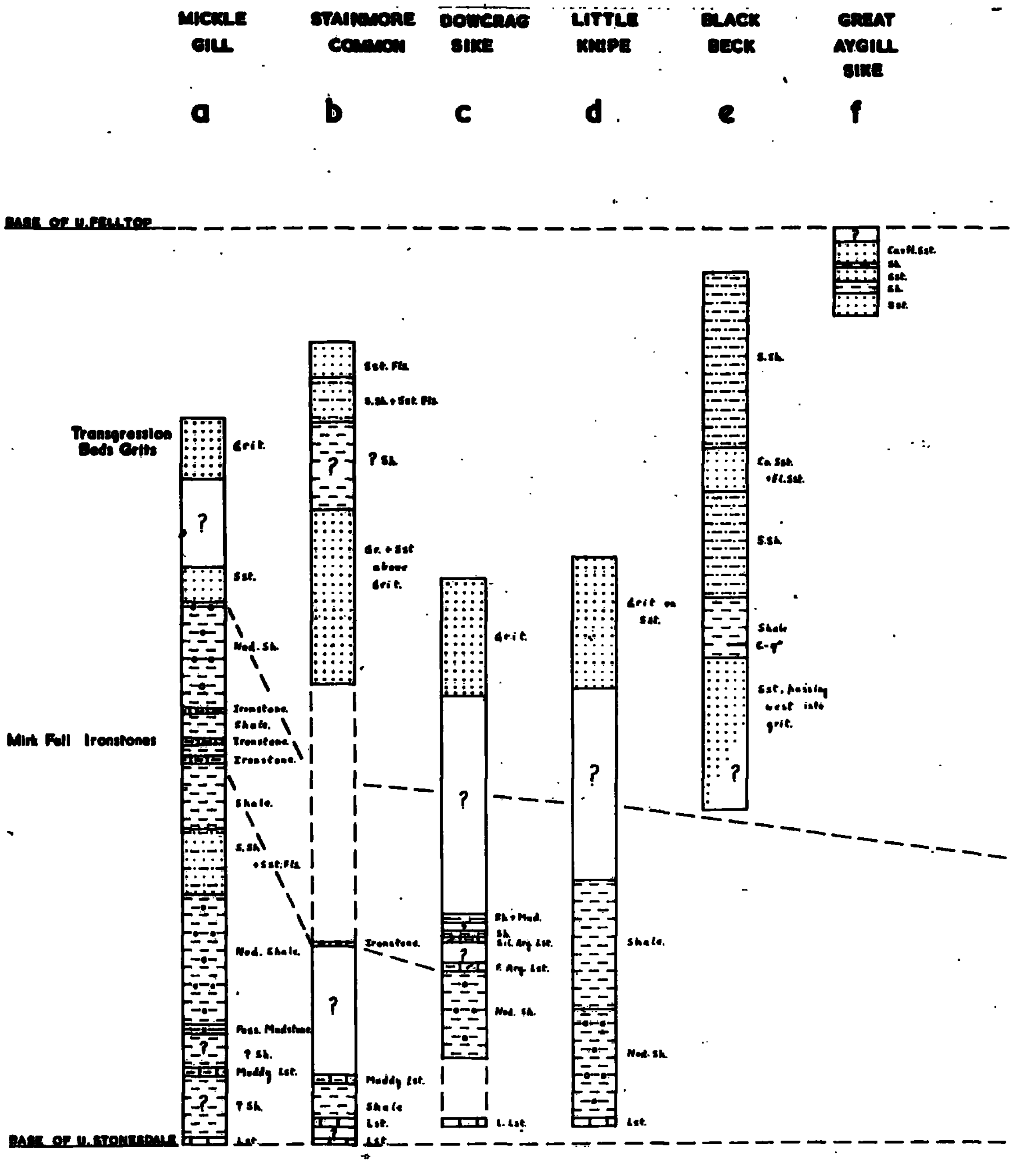
EXTENT OF TRANSGRESSION BEDS GRITS

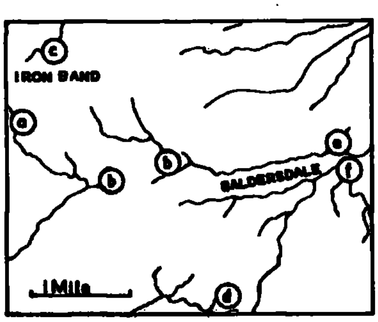
LIMIT OF COALCLEUGH MARINE BEDS

ISOPACHYTES IN FEET BELOW TRANSGRESSION —25—

ISOPACHYTES IN FEET ABOVE TRANSGRESSION —25—

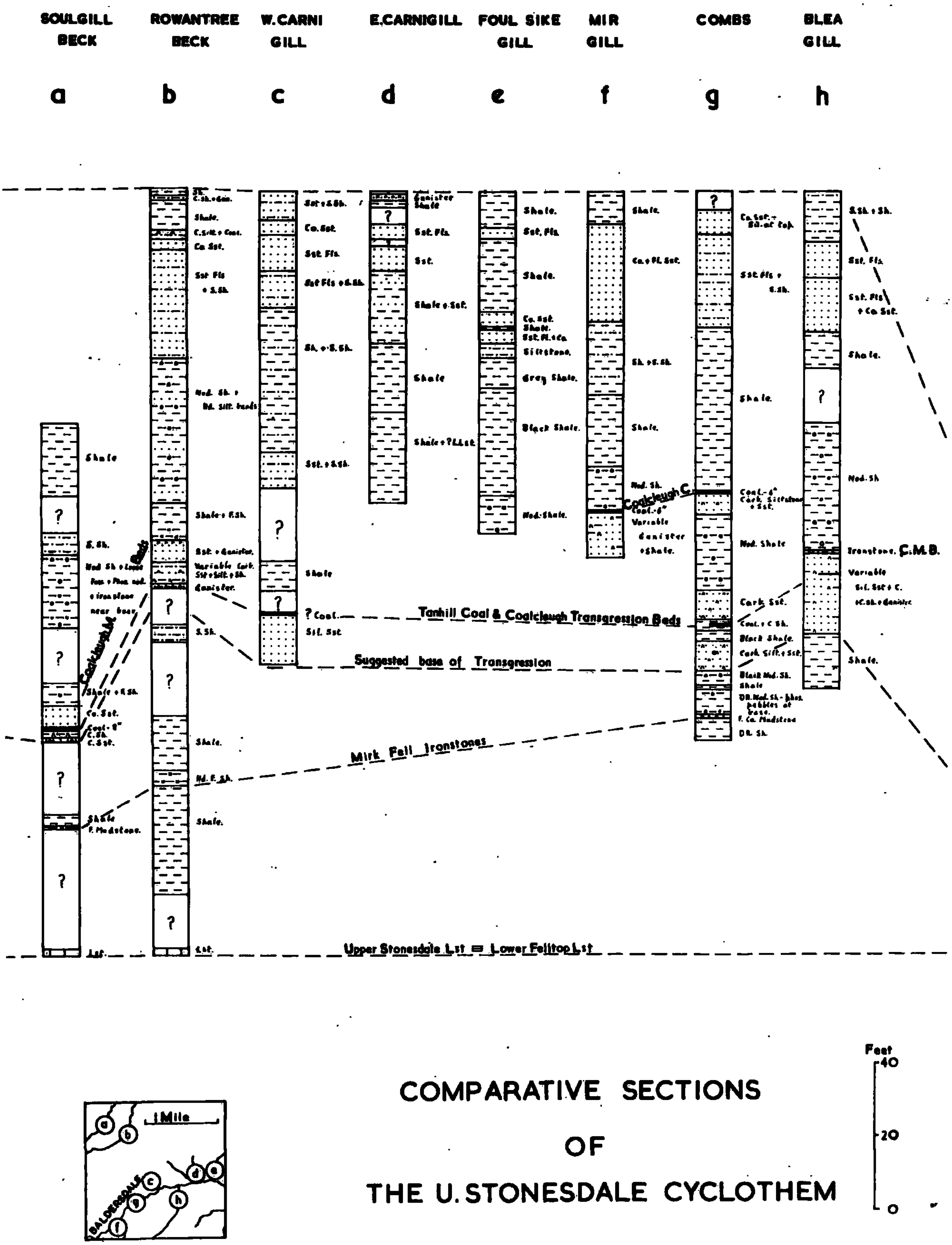
FIGURE 9





COMPARATIVE SECTIONS
OF
THE U.STONESDALE CYCLOTHEM

FIGURE 10

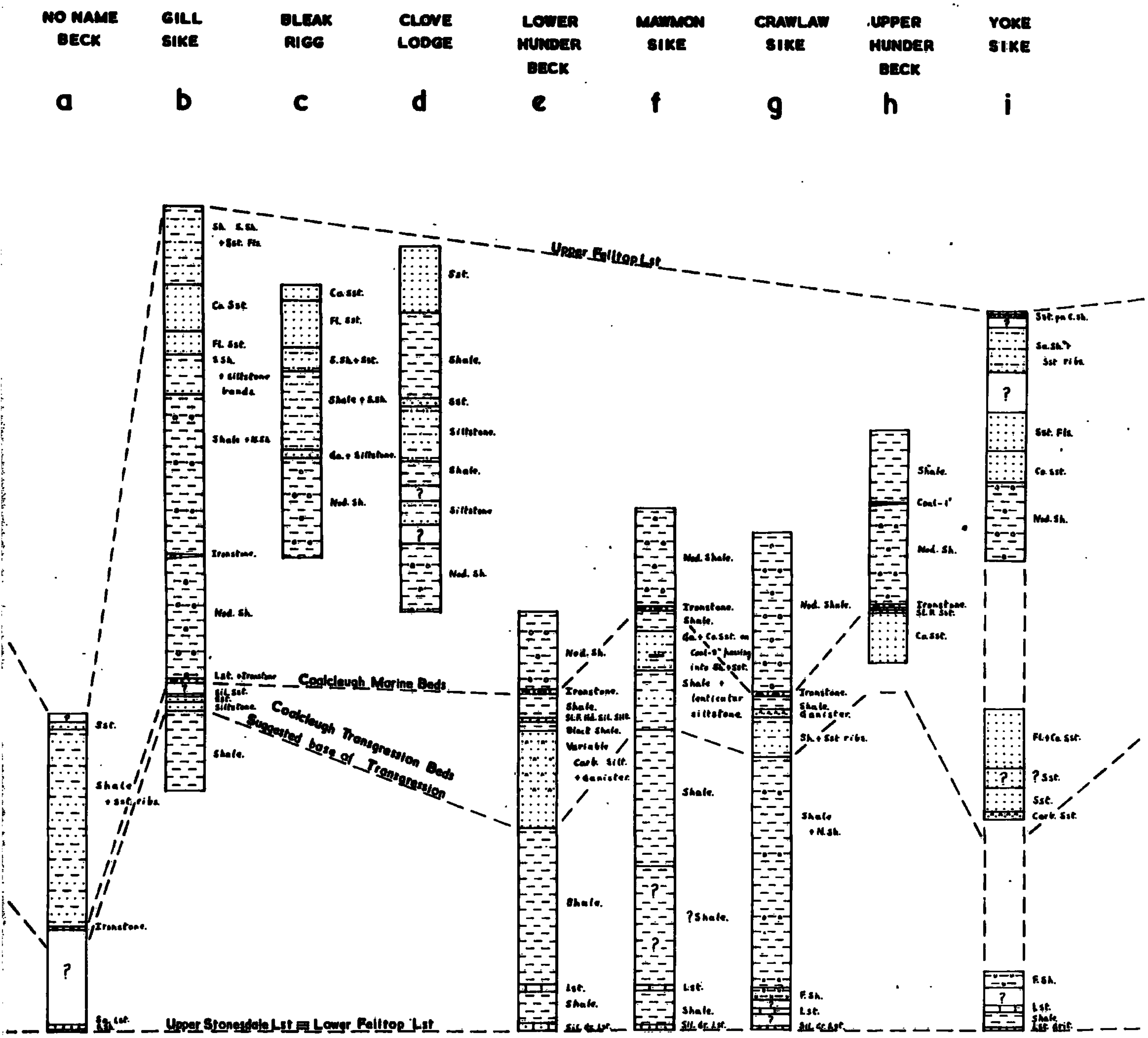


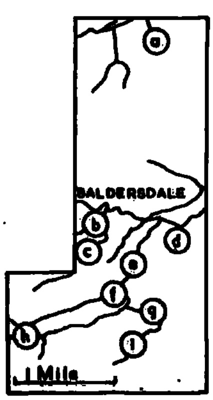
COMPARATIVE SECTIONS

OF

THE U. STONESDALE CYCLOTHEM

FIGURE 11





COMPARATIVE SECTIONS

OF

THE U.STONESDALE CYCLOTHEM

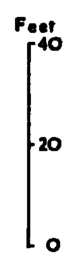
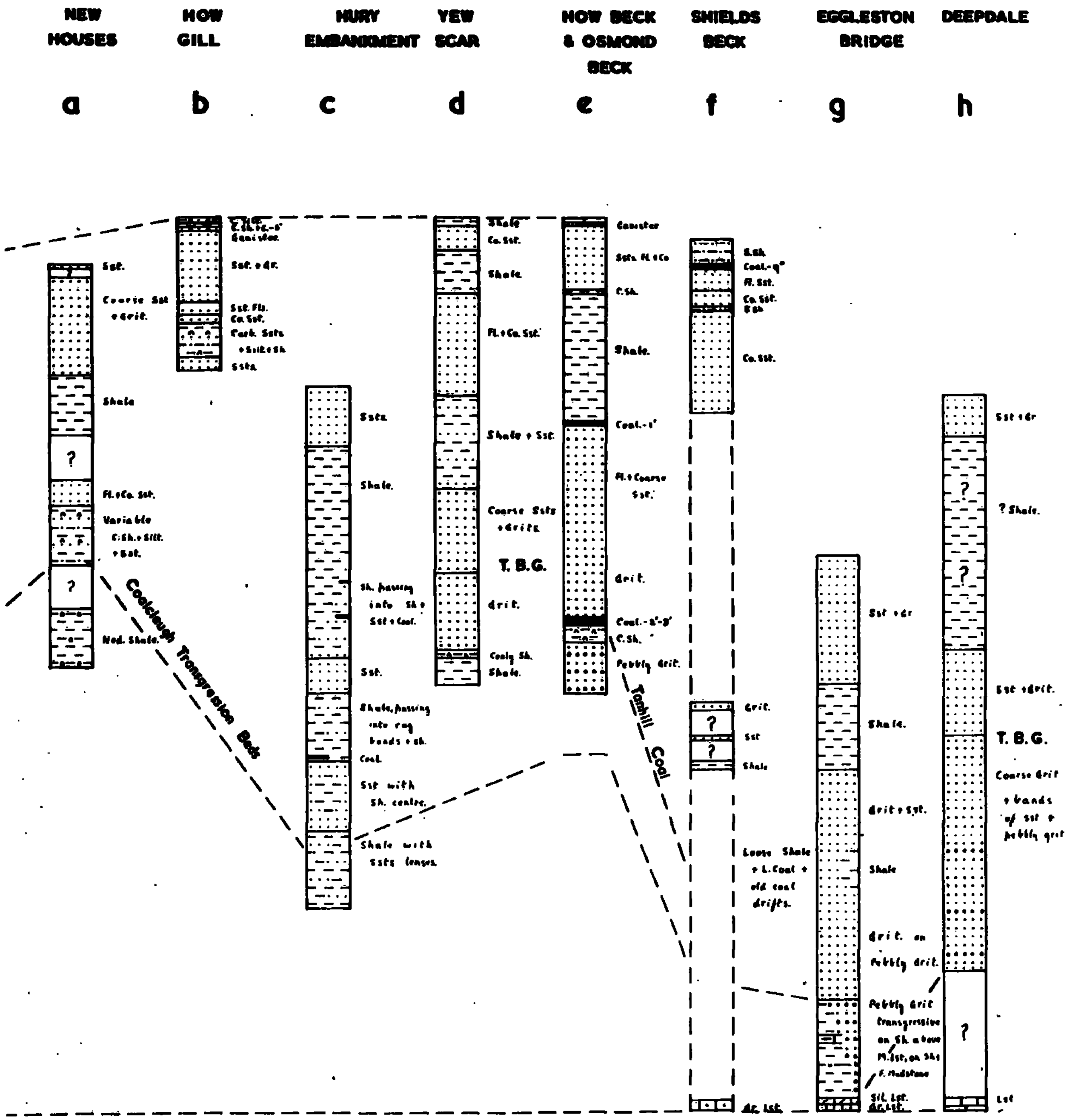
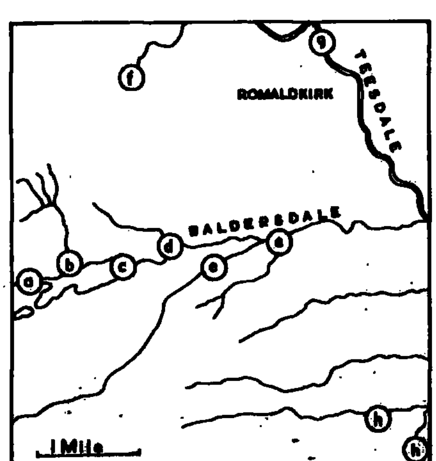


FIGURE 12





COMPARATIVE SECTIONS

OF

THE U. STONESDALE CYCLOTHEM

Feet 40 20 0

FIGURE 13

(f) Upper Stonesdale Cyclothem and Coalcleugh Transgression Beds.

(i) General. This is the thickest and most variable of the cyclothems. Within it there are both horizontal and vertical changes of facies from Yoredale to Millstone Grit. The cyclothem is very well exposed throughout Baldersdale and its tributaries, but its great thickness, combined with the horizontal attitude of the strata in the centre of the syncline, make complete sections extremely rare.

The reasons for using the name Upper Stonesdale for the basal limestone of the cyclothem were stated above (p. 73). Above this limestone, on the Askrigg Block, come the Mirk Fell Beds comprising ganister, ironstone and shale, in that order. Although there is a brief mention of the limestones in the Mallerstang Memoir (1891), these beds were first named by Chubb and Hudson (1925), the latter author giving further details in his paper of 1941. They are succeeded by the Kettlepot Ganister and Coal which was thought by Carruthers (1938) to be distinct from the Tanhill Coal. There appears to be some doubt about this as the authors of the Mallerstang Memoir took them to be the same seam. At the top of the series come the Tanhill Grits. Owing to the variable nature of the strata above the Mirk Fell Beds, the terminology of the Askrigg Block has not been used here for beds above the Mirk Fell Ironstones.

On the Alston Block the basal limestone is the Lower Felltop. This is the original "Fell Top" of Westgarth Forster, nowadays written as one word. Above this come the Transgression Beds of Carruthers (1938), distinguished from the beds connected with the Rogerley Transgression as the Coalcleugh Transgression Beds by

Dunham (1948), who describes them as "limonite-stained flaggy sandstones, with ganister in places, medium to coarse-grained, but rarely becoming grits". There are overlain by the Coalcleugh Coal and Shell Bed (Carruthers 1938), the latter called the Coalcleugh Marine Beds by Dunham. A micaceous flaggy sandstone above this is known as the Hipple Sill or Low Grindstone, but the highest sandstone of the cyclothem, immediately below the Upper Felltop Limestone, is unnamed.

In this area the beds in the middle of the cyclothem have two distinct lithologies, one of which is similar to that of the Coalcleugh Transgression Beds of the Alston Block and the other which compares with the Tanhill Grits to the south. The extent of the latter is shown in the map (Figure 9), the grits having been named Transgression Beds Grits. These consist of a single band in the western part of the area, but in the eastern part there may be three separate bands, the two lower ones being distinguished as the pebbly grit and the middle grit. For convenience the Coalcleugh Transgression Beds are referred to as the "mixed facies", and the Transgression Beds Grits as the "grit facies".

Once again there is a good exposure of much of the lower part of the section in Deepdale just off the map. The grits seen there above the Upper Stonesdale Limestone can be followed westwards until they form the steep cliffs of Crag Hill. Beyond the road there is a great deal of drift, but outcrops of the grit and sandstone occur near Battle Hill and on Ladyfold Rigg with a shale overlain by sandstone forming the dip slope on the north side of Stonefold Rigg. West of Ladyfold Rigg solid rock is lost from sight and mapping had to be done by features, a difficult task in so variable a series.

However in Yoke Sike both the Felltop Limestones are seen, with much of the intervening strata.

At the County Boundary there are good exposures of non-marine beds but the Upper Stonesdale is not seen again east of the Westmorland scarp. The top of this is formed by the grit facies, mapped by the old surveyors as Millstone Grit. North east of the scarp are long peat-covered dip slopes, the streams on which reveal loose grit boulders and occasional solid exposures, which become fewer eastwards as the drift cover increases. Along the scarp there are many exposures of the limestone in the streams from Little Knipe onwards, and the fossil grit at the base can often be mapped between them. It can also be used to distinguish the Upper from the Lower Stonesdale. The overlying shale occasionally occurs in the streams as well, but it is not till Birkbeck Gill that any ironstone is found. From there to Mickle Gill the Upper Stonesdale forms a good feature and in Mickle Gill there is a clear section almost up to the grit facies. West and north of Iron Band the feature continues, but, in common with the underlying strata, drift obscures almost all the solid rock E.N.E. of Low Crag.

Soulgill Beck and, in particular, Rowantree Beck give excellent sections and east of them, in spite of poor exposures, the mapping is fairly reliable. Another check of the full cyclothem is obtained from No Name Beck and outcrops of the Lower Felltop Limestone in Shields Beck, Wadycarr Sike and in the River Tees enable the base of the series to be followed accurately. Unfortunately the top is never seen east of No Name Beck and its position has to be conjectured.

With the exception of the hill tops above the dale and one or two downfaulted blocks, the whole of Baldersdale is composed of rocks of this cyclothem. In the River Tees, off the map, they form the river bed and the river gorge for a distance of over four miles. Similarly the River Balder, below the reservoir, cuts down through thick grits and shales. North of the Balder in Wilden Beck, Holy Beck and Thackwood Beck there is a great deal of grit exposed and the small tributary becks of the Lower Balder also contain good exposures of the higher beds of the cyclothem, but between the railway and the Tees drift covers all the solid rock, and the river at no point cuts down far enough to expose the Lower Felltop Limestone. On the Old Series 1-inch Map Sheet 102 S.E., a limestone is shown extending for two miles along the north side of the river from Birk Hat to below Hury. This was not shown on the 6-inch sheet and it is all covered now by the water of the reservoirs.

The north side of the reservoirs is almost free from glacial drift and as the Upper Felltop Limestone is exposed in most of the streams mapping is easy. South of the Reservoirs however the only guide to the top of the cyclothem is the limestone in How Beck and so the position of the non-marine rocks in the beck leading into the Subsidiary Dam and at Clove Lodge is conjectural. However, Hunder Beck and its tributaries have cut right down through more than 100' of strata to expose the Lower Felltop Limestone in at least four places, with most of the rocks above. A major E.-W. fault, the Hunder Beck Fault, and many minor faults help to repeat the sections, though at the top of Hunder Beck, west of Dun Moss, the marker bands are lost, and mapping is made increasingly difficult by peat and drift.

Excellent exposures exist all the way up the River Balder and in its tributaries above the reservoirs with the Upper Felltop

Limestone marking the top of the cyclothem. The sandstones and shales, however, are so variable that the following of individual bands is extremely difficult, especially near the junction with Black Beck. Towards the County Boundary no marker bands can be found and the non-marine beds cannot be correlated accurately. The same is true of the upper reaches of Soulgill Beck which have many exposures, but as all the becks run either along the strike or down dip, an insufficient thickness of strata is penetrated for a marine band to be found.

(ii) Upper Stonesdale and Lower Felltop Limestones. As with all the higher marine bands, the lithology of this limestone is extraordinarily constant throughout the area, in contrast to the varied nature of the ones below. Generally it consists of two thin limestones 1' - 2' thick separated by shale. Consequently while it is readily identifiable when seen, good exposures are very rare because it usually has shale both above and below it, and so does not form a feature.

An exception to this is along the Westmorland scarp where for some distance it is underlain by a sandstone (p. 77) the top of which is distinctly coarse, occasionally a grit, and contains marine fossils. This is characteristic of the base of the marine series in many other places. In Deepdale the top of the underlying sandstone contains fossil fragments and in the north east of the area the exposures in Shields Beck and Wadycarr Sike show a rock containing pebbles of quartz, felspar and calcite, cemented by finer-grained quartz and calcite, with occasional fossils. This also occurs in the Tees where there is 1'6" of gritty limestone at the base of the

Lower Felltop. The gritty nature of the limestone is less obvious in Hunder Beck and its tributaries, but it can be recognised in Yoke Side and the lower bands in Mawmon Sike and Crawlaw Sike are distinctly siliceous. They weather a deep red-brown colour, with quartz pebbles standing out on the surface. Above the lower band are shales about 4' - 8' thick in the central area and slightly fossiliferous, but they are thicker in Westmorland and in the River Tees, where they contain fossiliferous mudstone bands.

The shales are overlain by the distinctive second limestone band, which is a fine-grained, grey, rather siliceous limestone, full of fossil fragments, weathering a light brown colour, the clear calcite of the fossil fragments showing up well against the matrix. It is exposed in all the outcrops of Hunder Beck and its tributaries and loose pieces can be recognized in many parts of the area where the solid rock is not seen. An example of this is in Dowcrag Sike where quite a lot of loose limestone can be found in both the head-waters at the same height above O.D. Originally it was thought that the Lower Felltop passed into the argillaceous limestone exposed just above, but the lithological character of the loose pieces is such that there can be no doubt that this was wrong, and that the Lower Felltop horizon is close to the loose blocks. In the next beck, east of High Cleve Hill, Carruthers (1938, p.243) found a limestone "rotted to an ochre famp, but cores of crinoidal and shelly limestone remain". This is barely exposed now, but it is undoubtedly the Lower Felltop, though Carruthers considered it to be the Upper Felltop, for it has below it the fossil grit associated with the former bed.

The upper band of limestone is seen in Deepdale and in many of the becks along the Westmorland scarp. In Rowantree and Soulgill Becks this alone is exposed and nothing can be found of the gritty limestone, though it is possible that the latter exists, as exposure of the underlying beds is very poor. Certainly, the gritty limestone is picked up again in the beck north of East Wham and in No Name Beck, in both of which the overlying beds are not exposed. In the latter beck the gritty limestone is probably finer-grained than anywhere else and is seen under the microscope to be only slightly calcareous since it is mainly composed of mud with about 25% of subangular quartz grains about 0.2 mm. across. In the River Tees the upper band of limestone is again found, though it is cut out at Eggleston Bridge by the transgression beneath the basal grit, and it is necessary to go nearly a mile downstream and beyond the margin of the map to see it.

Undoubtedly the limestone in Baldersdale under the water of the reservoirs is the Lower Felltop. A thorough search was made of the reservoir banks when the water was low but nothing could be found in place. However quite a lot of loose limestone was found at some places which had obviously not travelled very far and which was lithologically similar to the Lower Felltop.

Usually these two bands complete the marine series, but at two points, in Yoke Sike and Crawlaw Sike, a fossiliferous shale overlies the limestone, containing a few gastropods and lamellibranchs. In Mickle Gill there is a third hard band composed of a fossiliferous mudstone, with brachiopods and small phosphatic nodules. It makes the whole marine series nearly 30' thick, an exceptional thickness.

<u>(iii) Mirk Fell Ironstones, Shale and Sandstone.</u> Except where an overlying unconformity removes them, there are always shales above the Upper Stonesdale Limestone. These usually contain nodules, particularly near the base. In Mickle Gill the shales become rather arenaceous about 60' above the bottom of the Upper Stonesdale Limestone, developing into 14' of sandstone flags and sandy shale. These are presumably the equivalents of the Mirk Fell Ganister which has otherwise not been recognized in this area. Shale comes in above this sandstone, containing three lenticular bands of ironstone, which are composed mainly of siderite and calcite with a very few angular quartz grains and contain Spirifers well preserved in calcite. They are very similar to the Mirk Fell Ironstones described by Hudson (1941) and if his section is compared with the one for Mickle Gill they will be seen to be almost identical for thickness and lithology except for the disappearance of the Mirk Fell Ganister. This was said by Chubb and Hudson (1925) to thin southwards and it evidently dies out northwards as well.

An ironstone is also seen in Birkbeck Gill, between the faults, but no other definite exposuresof the Mirk Fell Ironstones havebeen found. There are however some possible ones. One is in Dowcrag Sike about 50' below the base of the grit facies. It is no longer an ironstone, but instead is an argillaceous limestone the lower band of which contains many complete brachiopods, mainly Spirifers. Another exposure is at Combs in the River Balder (899181). It is a fossiliferous, ferruginous mudstone, slightly calcareous, and containing many brachiopods preserved in calcite and some phosphatic nodules. It overlies 6' of non-marine shale whose base is not exposed. Finally there are some fossiliferous shales and mudstones in Soulgill and Rowantree Becks, particularly well exposed in the latter.

Above the ironstone in Mickle Gill is more nodular shale, capped by some very badly weathered mealy sandstone, perhaps 20' below the base of the grit facies. The beds underlying the grit facies are usually hidden under debris, but in the headwaters of Soulgill Beck, one mile east of Dow Crag, there are some poorly exposed shales resting on a ganister which at some points has a good coal above it. The coal is about 40' below the base of the grit facies and presumably overlies the Mirk Fell Ironstones. It is tempting to correlate it with the Kettlepot Ganister and Coal of Stonesdale, the Mirk Fell Shales having thinned from about 100' to 30' in the intervening 8 miles.

(iv) Coalcleugh Transgression Beds. The beds which follow have two separate lithological facies, the approximate distribution of which is shown on the map (Figure 9). One of these facies occurs in the centre of the area where there is an extraordinarily variable series of every sort of non-marine rock shales, siltstones and sandstones, usually rather micaceous and carbonaceous, with some coals, ganister and siliceous sandstones and thin grits. This is the 'mixed facies' of this thesis, which is correlated with the Coalcleugh Transgression Beds of the Alston Block. Not only is it impossible to join up isolated outcrops with any certainty, but it is very difficult to generalize about any single outcrop since the lithology changes so rapidly every few inches, both vertically and horizontally. Nevertheless where the series is dominantly arenaceous it has been mapped as a sandstone and where it is mainly shale it has been left blank.

These beds were described by Carruthers (1938) and Dunham (1948) who have both shown that on the Alston Block they consist of a very variable sandstone series. These are undoubtedly the same beds and they were recognized as such by Carruthers in Rowantree and Soulgill Becks. The two outcrops though only ¼ mile apart are different. In Soulgill a compact sandstone overlies an 8" coal which, according to Carruthers, probably thickens and splits into two seams not far away. In Rowantree Beck no coal occurs, though the variable carbonaceous rocks above a ganister may represent it.

On either side of these becks the strata are drift-covered, but there are occasional outcrops to the east which have been correlated with the mixed facies. At the quarry south of Three Chimneys (918203) there is 1' of very badly weathered conglomerate, extremely ferruginous, overlain by 3' of coarse siliceous sandstone. It has unidentifiable pebbles, including clay pellets 2 cms. across. Beyond Lane Head no exposure occurs and it is likely that there is no longer any arenaceous rock, since in No Name Beck nothing can be seen between the Lower Felltop Limestone and an ironstone which should overlie the mixed facies. Since exposure in this stream is otherwise excellent this must mean that there is continuous shale between the Lower Felltop and the ironstone.

Further east a thin grit or sandstone can be traced along to Shields Beck, at the top of which it forms a flat feature on which there is much grit in place and a number of loose blocks, particularly on Toddyshaw Hill. The south side of the Botany Ridge shows a similar increase in the amount of grit eastwards, though it is not so easy to trace as the lower beds are obscured by the reservoirs.

A. False-bedded, lenticular sandstones of the Coalcleugh Transgression Beds in Hunder Beck.

B. Compact, lenticular sandstone and ganister of the Coalcleugh Transgression Beds in Mawmon Sike. The Coalcleugh Marine Beds appear as a nodular band in the shale bank, and are thrown up to the right by a fault.

It is probable that the coarse sandstone and grits seen at New Houses and south of the reservoir (948185) are above the mixed facies, the latter being represented by variable carbonaceous rocks exposed on the reservoir bank at New Houses and in How Gill, below the grits.

In the stream below Clove Lodge there are 90' of non-marine rock, the top of which is not far below the Upper Felltop Limestone. Unfortunately a fault at the top of the section throws up the sequence so that the limestone is not exposed. The mixed facies is probably 30' thick, but in common with other exposures round the reservoir the absence of the marine Coalcleugh Marine Beds prevents one from being quite certain about its identification. It may be lower down, beneath the nodular shale at the water's edge.

South west of Close Lodge in Hunder Beck are the best exposures of the mixed facies in the Stainmore Area. Upstream from Blackton it appears in the stream bed, dipping gently north, under great banks of loose shale. On the east side of the stream landslips complicate the section, but on the west side this mass of variable siltstones and sandstones rise up the bank, sometimes reaching a thickness of 30', but suddenly lensing out as shown in the photograph (Plate IV-A), so that nothing but shale remains. There can be no doubt that this is not due to faulting as the overlying ironstone can be followed right along from the continuous shale into the shale above the mixed facies. The mixed facies here is the usual carbonaceous siltstone and sandstone type with some ganister. No coal can be seen, but an old level shows that it was once obtained, apparently from a seam occurring within the sandstone. The beds themselves are strongly false bedded, depositional dips being as high as 25°, but the foreset beds are in no single direction, occurring at random and changing very rapidly both vertically and laterally.

For ¼-mile upstream, into Mawman Sike, nothing but shale is seen below the ironstone, and then just before reaching the waterfall, lenticular bands of siltstone appear in the shale and above them, in a matter of 20 yards or so, a sandstone and ganister come in, 10' thick, with a 3" coal beneath them. These form the waterfall and a steep cliff south of it. The lenticular nature of the sandstone and its passage into continuous shale can be seen in Plate IV-B. The nodular Coalcleugh Marine Beds also appear in the centre of the photograph, thrown up to the right by a small fault.

The ganister occurs again in Crawlaw Sike below Crawlaw Stone (934165), but north of the N.E. faults it passes into 6' - 8' of hard flaggy sandstone interbedded with shale. In Coal Gill and Hunder Beck (909163) the ganister is also exposed, but between these outcrops and Crawlaw Sike a thick sandstone is developed beneath it. This is well seen in Hunder Beck (914164) and can be followed along Crawlaw Rigg into Yoke Sike, where it is about 25' thick.

West of Crawlaw Rigg the features are rather poor and the equivalents of the mixed facies cannot be identified for certain at the top of Hunder Beck. East of Yoke Sike features can be traced along to Ladyfold Rigg, the crags of which are formed by sandstone of the mixed facies, but the mapping of this part of the area is largely conjectural owing to the lack of outcrops of all the marine bands between the Crow and the Botany limestones.

The bottom of the River Balder from the reservoirs to Black Beck is made up almost entirely of mixed facies, with occasional exposures of the underlying shales as well. The former can be traced round from Hunder Beck, appearing as thin siliceous sandstones near Start House, at the base of Gill Sike, with outcrops of shale beneath them in the banks of the Balder. The sandstones probably form the top of the right bank for a mile upstream, though there is no outcrop until a point near Balder Head is reached (913185) where flaggy sandstones come in above the shale. For the next 1½ miles mixed facies occurs on both sides of the river, usually as a very variable carbonaceous sequence, but there is one distinct band of siliceous sandstone which can be traced for several hundred yards. In West Carni Gill this is 14' thick and it underlies a 6" coal which was once worked.

There are two coal horizons in the River Balder. The lower one, already mentioned, in Soulgill and Lower Hunder Becks, occurs within the mixed facies and has a good roof of siliceous sandstone or ganister. Consequently it has been worked at many places, indicated by the presence of old levels. This is the seam marked on the 1-inch geological map. It extends from east of West Carni Gill, where the position of the seam is very uncertain, to Combs, on both sides of the river, and it is seen to be at least 1' thick at Combs. Opposite Combs, the higher coal seam first appears. It overlies the sandstone and siltstones with shale above it, and is about 6" thick.

The mixed facies is then hidden under higher rocks, but reappears again in Black Beck as sandstones with a 9" coal in the shale above. This coal seam was also noted by the old surveyors, who traced it down into the Balder as a conjectured band. There is no evidence at all for its occurrence below the faults shown on the present map and it probably dies out before the faults are reached, as no coal can be found even in the small sike (885175) where the section of strata is complete.

(v) Transgression Beds Grits. To the east and west the mixed facies of the Coalcleugh Transgression Beds passes into thick grits and sandstones, termed the 'grit facies' or Transgression Beds Grits.

It is unfortunate that the passage to the west takes place across that part of the country which is masked by peat and drift, but nevertheless the evidence of the marine bands, particularly the Lower Felltop Limestone, shows that the base of the grit facies is approximately at the same horizon as the base of the mixed facies. Even the old surveyors, without the use of the marine bands, traced the grits of Stainmore Common into the mixed facies of Rowantree and Soulgill Becks, although they were misled farther south into correlating them either with the sandstone immediately below the Upper Felltop Limestone or that below the Fossil Sandstone.

From Soulgill the mixed facies passes into grits and sandstones south of Broad Stone Rigg. Good features and outcrops of solid and loose rock are continuous from there to Stainmore Common. This is formed by the dip slope of the grit facies, whose thickness cannot be accurately measured, but it probably comprises at least 30' of grit, underlain by flaggy sandstones which were once extensively worked in the old "slate" quarries in the middle of the common. The various crags named on the map are all scarp features of the grit which can be traced round Millstone Band into the head of Black Beck (856172) where over 40' of grits and coarse sandstones are exposed. They are then cut off by a fault, but reappear again further down Black Beck, forming the cliffs of the valley for ½-mile before either dipping under the river bed or lensing out. The evidence is not too clear at the point where their outcrop finishes, but they probably do both.

Harton Crag is a strong feature covered by loose blocks of coarse sandstone, none of which are seen in place. The grain size is about 0.1 mm., considerably finer than the grits to the north and south. It is either the equivalent of the sandstone below the Upper Felltop Limestone or of the grit facies which have become finer than usual. If the former, then a fault must be introduced west of Harton Crag, between the crag and Birkbeck Gill, to cut out the basal grit, while in support of the latter interpretation is the occurrence of sandstones as well as grits on Stainmore Common. It is considered that the Harton Crag sandstone is probably the Transgression Beds Grit, or a sandstone a little below this horizon, and it was mapped as such by the old surveyors.

The grit facies occurs in the downfaulted block south of Birkbeck Gill, made up mainly of grit with flaggy sandstones as well. South of Wham there is a continuous outcrop along the top of the escarpment, with an outlier on High Edge. This continues as far as Black Tewthwaite, beyond which point the outcrop turns north until it dips down under peat near Fox Yird. It is a quartzose, feldspathic grit of varied grain size ranging from 0.1 mm - 1.0 mm., usually massive, but occasionally flaggy with very gentle false bedding. Sandstone is not uncommon, normally underlying the grit. North east of Redgill Moss the beds dip down into the headwaters of the Balder where higher strata come in, and eastwards they pass laterally into the mixed facies, though this cannot be proved directly.

The eastern part of the area is mainly composed of the Transgression Beds Grits, much thicker than those in the west, sometimes forming as many as three separate bands. Beyond Ladyfold Crags, composed of mixed facies sandstones, the first outcrop of grit is in the old quarries south of Battle Hill, but the grit is very thin and this possibly is just part of the mixed facies. East of the road, however, the grit facies suddenly comes in to form the spectacular feature of Crag Hill. The old surveyors were compelled to draw in a N.W. fault west of Crag Hill, but there is no evidence for it. The explanation here advocated is simply that a lateral expansion of the grits takes place. From Crag Hill eastwards the grits remain very thick, over 60' being exposed in one continuous quarry face just west of the railway. In this quarry face there are several bands of sandstone and at least two bands of distinctly coarse grit containing quartz pebbles more than 5 mm. across.

This pebbly grit is a feature of the lowest beds of the grit facies at many places. In the Tees below the viaduct at Barnard Castle it also occurs, obviously transgressive on the underlying nodular shale, but less than ½-mile away there are nothing but thin sandstones in the shales at that horizon. The basal grit, reached in the River Balder, is also pebbly, though its relation to the underlying strata cannot be ascertained. Following up the Tees from its junction with the Balder lower and lower beds are seen until the pebbly grit is again reached and there is definite evidence that it is transgressive on the beds below. Proof of this occurs just outside the area mapped, in the left bank of the river. At the point where the Lower Felltop Limestone first appears it contains both the usual limestone bands and has 8' of shale above it, below

30' of pebbly grit. Thus the base of the grit is 26' above the base of the Lower Felltop Limestone. Half-a-mile upstream, the grit is about 15' above the Limestone and 300 yards above that it is resting on the basal gritty limestone itself. At Eggleston Bridge, a mile from the first-mentioned outcrop, the disconformity has lifted a little to expose 5' between the bases of the pebbly grit and Lower Felltop Limestone. Thus it is an irregular disconformity and may be no more significant than the usual transgression at the base of a sandstone or grit.

This pebbly grit is not found on the high ground north of the Lower Balder, which is mainly formed from the thick middle grit. There seem to be three arenaceous bands in this part of the area, the lower one a pebbly grit, the middle one a very thick grit, and the higher one a sandstone. Up the Tees from the junction of the River Balder these three can be distinguished, though the two top ones merge near Eggleston Bridge. Down the Tees the same three bands occur, until near Barnard Castle they all thicken and probably the lower two also join together.

Exposures in the River Balder above the railway are good. Above the pebbly grit is a thin carbonaceous shale overlain by a 2' - 3' coal once extensively worked. It has a closed outcrop below Osmond Beck, but upstream is thrown up again by a fault, and extends for a mile in all. It then dies down to a coaly shale, and a shale 40' thick or more comes in beneath it. In view of the regular nature of the base of the overlying middle grit, this shale must be the lateral equivalent of the pebbly grit whose western boundary is traced on the map.

The River Balder runs down through steep cliffs which give almost continuous exposures of the thick massive middle grit. This contains much sandstone, particularly in the upper half, and like all the Transgression Beds Grits has very variable current bedding. It also occurs in How Beck and Osmond Beck. In the latter a 1' coal overlies it, but this is not seen anywhere else, and certainly does not occur in the beck just above Yew Scar.

During the building of the Hury Reservoir a geological section was drawn up for the embankment. It is not possible to correlate it precisely, but it shows very well the extremely variable nature of the strata. The old surveyors continued a N.N.E. fault, which undoubtedly exists to the south, north of the River Balder for 1½ miles. It can be shown that it does not continue north of the reservoirs as it would cut through the Upper Felltop Limestone, and it probably does not run across the reservoir. It is shown on the map as a conjectured fault only and was undoubtedly put in to explain the disappearance of the grit facies to the west.

Though there is a thin band of grit above Lunedale west of Shields Beck, it is not until Wady Carr (977224) is reached that the grit facies appears. This is exposed in Thackwood Beck and Holy Beck and on the top of the hill north of Grace's Cottage. All these grit outcrops probably run into each other, producing a considerable thickness, and they must be the equivalent of the middle grit of the Balder and Tees. Confirmation of this is obtained from the occurrence of a coal seam at Wady Carr in the shale beneath the grit. This may extend as far as Shields Beck, where there are also old coal drifts under the Grit of Toddyshaw Hill. In addition, a bore hole on Buck Hill (995204) penetrated 1' of "foul coal" at 610' O.D. and a coal also appears in the Tees below the middle grit. Thus there is an extensive horizon of coal development below this middle grit, though it must not be supposed that the coal is continuous. Furthermore it is evident that the pebbly grit seen in the Tees does not extend as far west as Wady Carr.

(vi) Coalcleugh Marine Beds. On the Alston Block above the Coalcleugh Coal thin shales with marine fossils, the Coalcleugh Marine Beds, are developed. These also occur above the mixed facies of the Coalcleugh Transgression Beds in this area, though their outcrop is sporadic.

The marine band is best seen in Hunder Beck and its tributaries. In Mawman Sike, a few feet above the top of the ganister, there is an ironstone showing very good cone-in-cone structure and containing some fossils. It is composed of quartz fragments, cemented by ankerite, often rather muddy. This band is lenticular, varying from 0' - 2' thick, and it can be traced for some distance down the left bank of the stream into Hunder Beck until it definitely overlies the variable carbonaceous rocks of the mixed facies. Below the ironstone there is also a dark calcareous sandstone with a few fossil fragments. A similar rock is found in Upper Hunder Beck (912164), here a pale grey fossiliferous calcareous sandstone.

Usually, however, a hard ganister with no marine fossils underlies the ironstone. The latter is more fossiliferous in Crawlaw Sike, though it is rather muddy. In Coal Gill (914160) a calcareous mudstone is in the position of the ironstone, in two bands 6" thick, the upper rather nodular. Fossils and phosphatic pebbles occur in this upper band and a Spirifer was found in the overlying nodular shale. There is no sign of the Coalcleugh Marine Beds in Yoke Sike, though they may be faulted out, but it can be followed round through Gill Sike into the River Balder.

By Gill Sike the cone-in-cone structure can hardly be distinguished though the fossils and phosphatic pebbles remain. In the River Balder the band is a lenticular muddy limestone, rather fossiliferous, which may occasionally disappear. It can be traced as far as the coal level opposite West Carni Gill, beyond which point it dies out altogether.

A thin ironstone also occurs in No Name Beck (933210) which, by comparison of the overlying rocks, is undoubtedly at the same horizon. It contains much fossil debris, besides cone-in-cone structure, and is composed mainly of ankerite and calcite with little clastic matter. A similar rock is seen in Soulgill, above the mixed facies, though its precise position is not certain. It has cone-in-cone structure, phosphatic nodules and many complete Spirifers. In Rowantree Beck there is some hard fossiliferous shale just above the mixed facies, but the exposure is very poor.

The Coalcleugh Marine Beds form a very good mapping horizon over a limited area, though they disappear even within that area. Without them it would not have been easy to prove the variability of the Coalcleugh Transgression Beds. A second outcrop of ironstone in Gill Sike (921180) was at first thought to be the same bed. It occurs in large lenticles 2' - 3' long in the shale overlying the Coalcleugh Marine Beds. However the cone-in-cone structure is much less regular; there are no marine fossils and the composition is more micaceous and carbonaceous, so it is probably non-marine.

(vii) Shale and Sandstone. Above the Coalcleugh Marine Beds there usually are shales, well exposed in Hunder Beck, where their nodular nature is apparent. In Coal Gill and Upper Hunder Beck a coal seam occurs 30' above the Marine Beds. It is 1' thick in Hunder Beck, and 3" is now seen in Coal Gill, but it must thicken very rapidly as it was once extracted from the opposite side of the gill. Above this coal there are shales which gradually become more arenaceous, but there may be lenticular sandstone or siltstone bands in these shales, reminiscent of the mixed facies. These are particularly well seen in Gill Sike where a ganister comes in between the nodular shale and the sandy shale, and also in Rowantree Beck where there are several bands of hard siltstone among the shales.

In the area of the mixed facies the sandy shales pass up into flaggy sandstones, which become compact. These are the normal white massive Yoredale sandstones and they are particularly well exposed between the River Balder and Hunder Beck where they were once extensively quarried for freestone. South of Hunder Beck the only outcrops are in Yoke Sike and on the features on either side, but here the compact sandstone rests directly upon nodular shale. In the tributaries of the River Balder above the reservoirs the sandstone is invariably exposed, but it thins east of West Caini Gill to only 3' of flaggy sandstone in Foul Sike Gill. In this stream there is another compact sandstone some 20' lower. This may be the equivalent of the massive sandstone elsewhere, but is more likely to be a thick development of the sandstones and siltstones mentioned above that occur in the shale.

Beneath all the exposures of the Upper Felltop Limestone in the Upper Balder the sandstone is found to have thickened. Outside the beck it is not easy to map, and the old surveyors traced it into the grit facies. This is not correct, as it always maintains its normal sandstone lithology when found beneath the Upper Felltop, and on the hill sides there is a similar sandstone overlying the grit facies. South of the Balder the only exposure of this sandstone is in Red Gill where it lies upon 20' of shale, but on the north side it can be followed more easily, mainly by the features and loose blocks of sandstone. It is exposed in the gill (861173) together with the underlying sandy shale.

As the outcrop turns round to the east it is lost under drift, but the upper reaches of Soulgill Beck (874192) reveal strata whose exact position is not certain. The stream runs along the strike to expose the following section:-

	Ft.	Ins.
Carbonaceous siliceous sandstone		9
Shale	2- 6	-
Coal		2
Shale	5-10	-
Carbonaceous siliceous sandstone	3- 4	-
Shale	20	-
Sandstone	1	-

At first sight it might be supposed that these beds belonged to the mixed facies of the Coalcleugh Transgression Beds, and this is a possibility. They resemble them in many ways, and 150 yards upstream, more or less along the strike, are 20' or more of typical grit facies and the possibility must be considered that this is the actual transition between the two facies. For proof the Coalcleugh Marine Beds would have to be found and they were not, in spite of a thorough search for loose pieces. The grit facies can be traced on to the feature formed by Sheep Lair Hill and lithologically the beds in Soulgill are not as variable in detail as the mixed facies, bearing a greater resemblance to the overlying shales and siltstones of Rowantree Beck which were mentioned above. The Marine Beds are therefore believed to underlie the stream exposures.

In Rowantree Beck the transition upwards from shale, through sandy shale and sandstone flags, to compact sandstone is shown well, and the sandstone band can be followed eastwards, with occasional exposures in the becks. It forms the waterfall at the head of No Name Beck, where it overlies 50' of shale with thin sandstone ribs. North of the Botany Ridge it is not well exposed, but it can be followed with the aid of features and loose sandstone blocks as far as the quarry, still worked, south of Shields Beck (964221). It contains 34' of almost continuous sandstone, overlain by a 9" coal. This thickening increases even more to the east in Bail Hill Quarries, where the sandstone is probably about 50' thick and has become coarse and gritty in places.

South-eastwards exposures are very poor, though it must be this sandstone that underlies the drift north and south of Hunderthwaite, for the middle grit appears in an inlier in Wilden Beck. Above it are shales and sandy shales overlain by the top sandstone which has thinned to its usual 5' - 10'. In the Tees it has thickened and coarsened again, but as the band is traced round on to the south side of the Botany Ridge, the thin, fine-grained facies is maintained for some way. The normal transition from shale to sandstone is seen above the middle grit in the beck below Gill House (973202), but in the beck above Yew Scar the sandstone appears to have split into two. In How Gill and near New Houses a coarse facies comes in, particularly well developed in the latter beck where at least 23' of grit and coarse sandstone are found. There might have been some doubt whether the Bail Hill Quarries were really in the top grit band, as the Upper Felltop Limestone is not found in that part of the area, but the stream exposures on the south side of the Botany Ridge amply confirm this, revealing the Upper Felltop Limestone close above the grit in How Gill.

South of the Balder, the shale above the middle grit is overlain by a sandstone which becomes coarser to the east, developing grit bands in Osmond Beck. This facies is also seen below Washfold Bridge (999170) but westwards this passes into a sandstone, usually flaggy, rarely exposed above the great banks of shale in the beck south of Ravock Rigg. Between there and Crawlaw Sike there is very little exposure, but the shale in Duck Sike is almost certainly the one below this sandstone.

This sandstone does not complete the cyclothem for the Upper Felltop Limestone never rests directly upon it. The sandstone may have a ganister top as in How Beck and How Gill, in both of which there is also a thin coal and the 9" coal above Shields Beck may be at the same level. Sometimes the coal or ganister occurs in the overlying shale, as in Yoke Sike, East Carni Gill and Rowantree Beck, where there are two carbonaceous horizons. Normally there are about 10' of shale between the compact sandstone top and the Upper Felltop, but this may include sandstone flags as well.

<u>(viii) Discussion.</u> The lithological resemblance of the Mirk Fell Ironstones to the Coalcleugh Marine Beds in this area is very

noticeable and during the early part of the mapping they were thought to be the same band. The ironstones of Mickle Gill were so similar to those of Mirk Fell 8 miles away that it seemed certain that they would be traceable over this area. If the ironstone of the Coalcleugh Marine Beds were the same, then the mixed facies of the Coalcleugh Transgression Beds could be correlated with the Mirk Fell Ganister which it has been suggested (Rowell, 1953) passes south into the Grassington Grits.

However, there is little likelihood of this being so. It would mean that the grit facies changes laterally into the sandstone under the Upper Felltop Limestone and there is no evidence for this. In addition, the section in Rowantree Beck would be difficult to explain for two separate marine bands are found there, one above and the other below the mixed facies. If the upper band is the equivalent of the Mirk Fell Ironstones, with what can the lower one be correlated? It is quite separate from the Lower Felltop Limestone and nothing marine has ever been reported from either the Alston or Askrigg Blocks at that horizon. The only other place at which a marine band has been found below the mixed facies in this area is at Combs, in the River Balder. The explanation must be that this lower marine band is an extension of the Mirk Fell Ironstones.

Undoubtedly the lithology has changed more in the mile or two from Mickle Gill than in the 8 miles from Mirk Fell. There is much more terriginous matter suggesting that the borders of the sea are near. This is confirmed by the absence of the Mirk Fell Ironstones in the rest of the area.

It is interesting to notice that the two cyclothems below the Mirk Fell Ironstones on the west of this area and on Mirk Fell are almost entirely made up of shale, the only arenaceous bed being the relatively thin Mirk Fell Ganister. In contrast, the remainder of the area and the Alston Block contain thick sandstones in both these cyclothems. This may govern the extent of the Mirk Fell Ironstones through differential compaction, the shale area having sunk further than the sandstone area so that the sea only invaded the former. If this is so the compaction difference only became noticeable after the incursion of the Upper Stonesdale Limestone, as this was deposited evenly throughout the entire area.

The isopachytes drawn on the map to show the thickness of beds from the base of the Upper Stonesdale to the base of the Coalcleugh Transgression Beds or Transgression Beds Grits are very generalized, partly because the upper limit is seldom clearly defined and partly because of the lack of exposures. Undoubtedly if there were more information they would be more varied. There is, however, a real and considerable increase in thickness towards the west. This is partly due to the subsidence which enabled the Mirk Fell Ironstones to be deposited, but is also a measure of the disconformity at the base of the transgression, though how much it is difficult to say.

The precise position of this disconformity is conjectural. Transgressions are seen beneath the pebbly grit in the Tees, and beneath the mixed facies in the centre of the area. On the Alston Block this has been shown by Carruthers (1938) to cut out the Lower Felltop Limestone, and he considered that it was related to an unconformity immediately below the Tanhill Grits to the south. Chubb and Hudson (1925), on the other hand, consider the unconformity to be lower down, below the Tanhill (Kettlepot) Coal and Ganister.

In this area, apart from the visible transgressions, the coal seams offer the only clue. There is throughout the area one major horizon at which coal may be developed, within the mixed facies, and also below the middle grit of the grit facies. As already mentioned, it is found in the River Balder, at Wady Carr and Shields Beck, in the River Tees, at the head of Soulgill Beck, and it also occurs east of the mapped area, being still worked near Winston, 5 miles east of Barnard Castle. Though one would never suggest that this is one seam, for it is certainly discontinuous within the present area, the horizon may represent a period particularly favourable to coal formation, corresponding to the Tanhill Coal to the south. If this is correct, then Hudson's view that the unconformity, admittedly very small, underlies the Kettlepot Ganister is the more likely, as there is no evidence of the coal having been eroded and it is seen to overlie a transgressive group.

The isopachytes (Fig. 9) showing the thickness of strata above the transgression do approximate as regards direction with the boundaries of change from mixed to grit facies. The thickest rocks are the arenaceous ones which have not compacted to the same extent as the shales. Yet the axis of least thickness is east of the centre of the mixed facies area, shown by the outcrop of the Coalcleugh Marine Beds. It is suggested these represent a marine incursion over an area limited by the amount of compaction that the rocks beneath underwent, and thus restricted to the ground underlain by the thin and relatively shaly mixed facies. The explanation of this shift of the axis is that subsidence must have been greater in the west during these times to produce an increase of shale in that direction, as happened when the Mirk Fell Beds were deposited.

Thus the detailed sequence of events above the disconformity may be as follows. In the centre of the area and to the north there were deposited the lower half of the mixed facies and at the same time sandstone or a ganister were laid down to the east and west, with a pebbly grit coming in near the eastern boundary. In this connection it is interesting that the authors of the Mallerstang Memoir (p.152) considered that a pebbly grit underlying the Tanhill Coal passed northwards into flagstones. Above these basal beds there is the horizon of coal formation. Then while the mixed facies continues in the centre, the thick middle grits are deposited on the flanks at the same time as the Tanhill Grits in the south. These are followed by a minor period of coal formation, after which the mixed facies is compacted to a greater extent than the grit facies to enable a marine incursion to invade the centre of the area and deposit the Coalcleugh Marine Beds. Finally a shale to sandstone sequence was laid down over the whole area, the sandstone becoming coarser and thicker towards the east.

(ix) Summary.

1) The Upper Stonesdale Limestone of the Askrigg Block is considered to be the equivalent of the Lower Felltop of the Alston Block. This correlation is based mainly on the identification of two limestone bands on both sides of the syncline, the lower one arenaceous, separated by shale.

2) The Mirk Fell Ganister is represented by sandstone ribs in shale, seen only in Mickle Gill in Westmorland.

3) The Mirk Fell Ironstones are well developed in the west, but die out eastwards so that they were not deposited over the eastern part of the area and have no equivalent on the Alston Block.

4) The strata above a disconformity or transgression show two different lithological facies; in the centre is the "mixed facies" of the Coalcleugh Transgression Beds, correlated with the beds of that name on the Alston Block, while in the eastern and western parts of the area there is a "grit facies", called the Transgression Beds Grits, comparable to the Tanhill Grits of N.W. Swaledale. In the eastern part of the area three grit bands have been distinguished, the two lower ones being referred to as the pebbly grit and the middle grit; in the western part of the area there is only one grit band, considered to be the equivalent of the middle grit of the east.

5) The beds above the transgression rest on lower strata towards the east and north, though the isopachytes in Figure 9 are also a measure of greater deposition below the transgression towards the west.

6) The pebbly grit of the east, the lower part of the Coalcleugh Transgression Beds, and the Kettlepot Ganister are roughly contemporaneous and all lie immediately above the transgression, and below the major coal horizon.

7) The major coal horizon is that of the Tanhill Coal to the south and the Winston Coal to the east. It lies below the middle grit of the grit facies of this area, and within the mixed facies. Coals are exposed in the following places:-

Soulgill Grain, above a ganister, below the middle grit.

Soulgill Beck, within the mixed facies.

Upper Baldersdale, from Combs to West Caini Gill, within the mixed facies.

Hunder Beck, within the mixed facies.

From Shields Beck to Wady Carr, below the middle grit.

Lower Baldersdale, between the pebbly and middle grit.

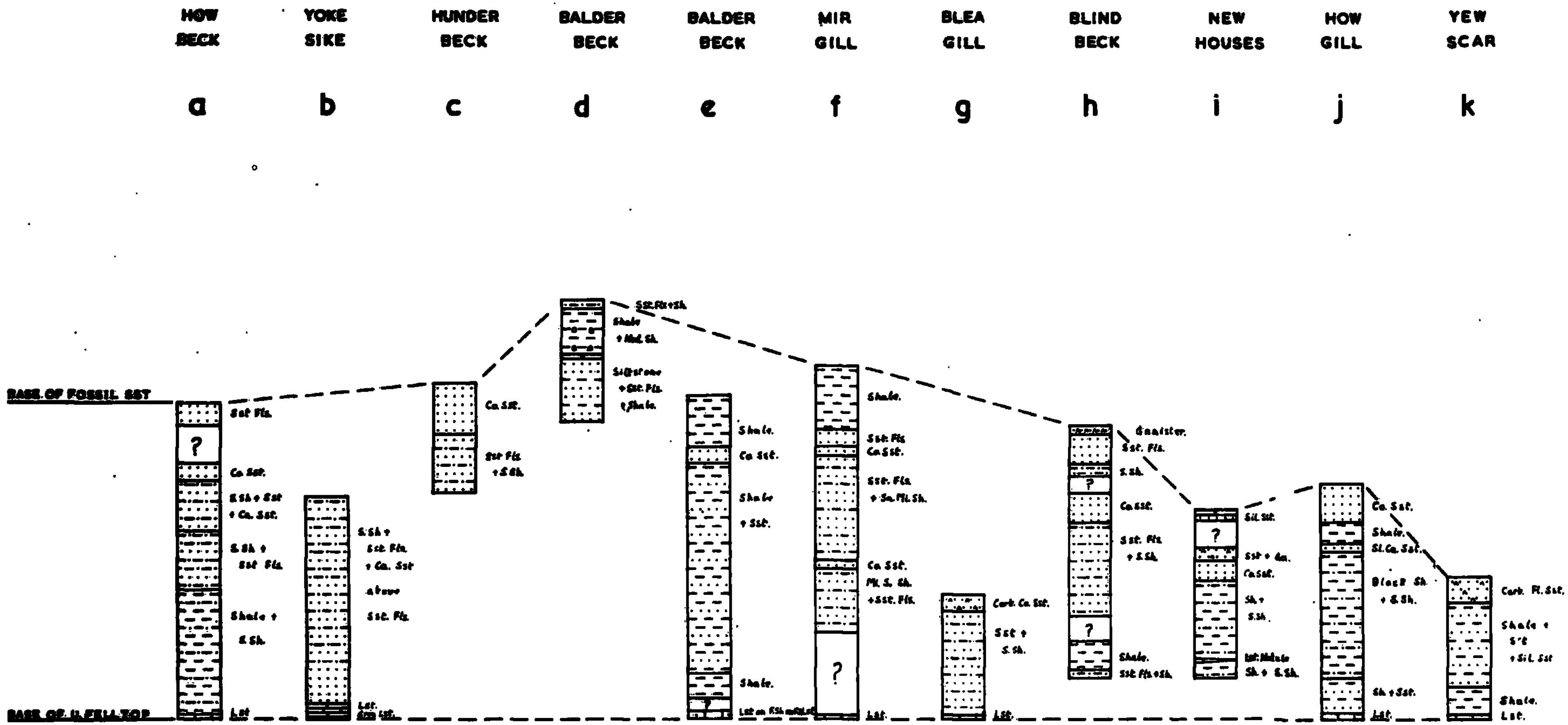
Buck Hill bore, below the middle grit.

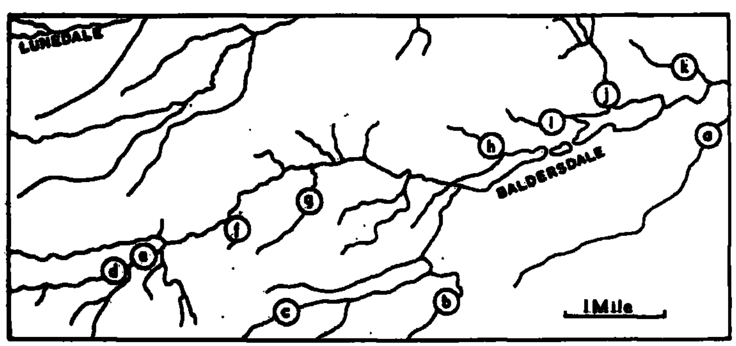
8) The middle grit of the eastern part of the Stainmore Area is the equivalent of the single grit band in the west and the Tanhill Grits to the south. These can be roughly correlated with the upper half of the mixed facies, though deposition of the grits may have continued longer in some places.

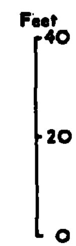
9) A second horizon of coal development, the Coalcleugh Coal, is very restricted in occurrence as it has only been found in Upper Baldersdale above Combs, and in Black Beck. The coal above the middle grit in Lower Baldersdale may be at the same horizon.

10) The Coalcleugh Marine Beds have an outcrop restricted to the centre of mixed facies deposition. They have no equivalents in the area of grit lithology.

11) The top of the cyclothem is taken at the base of the Upper Felltop Limestone which is correlated with the Hearne Beck Limestone of the Askrigg Block.







COMPARATIVE SECTIONS

OF

THE UPPER FELLTOP CYCLOTHEM

FIGURE 14

(g) Upper Felltop Cyclothem.

(i) General. On the Alston Block the name Upper Felltop has long been used for the basal limestone of this cyclothem, though in Westgarth Forster's section the equivalent horizon, according to the primary survey, was the "famp", No. III (Dunham 1948, p.45). The Alston terminology is preferred to that of the area to the south as there appears to be a little doubt as to the correlations of the beds above the Tanhill Grits. Chubb and Hudson (1925) describe the Hearne Beck Limestone of Shunner Fell and correlate it with one found in Lad Gill on Arkengarthdale Moor, above the Tanhill Grits. Carruthers (1938) distinguishes a second limestone, the Candleseave, above the Lad Gill Limestone, and his section is also used by Trotter (1952). Carruthers' arguments for the two limestones are not very convincing. They are based mainly on isolated sections and the thickness and lithology of the underlying beds which are extremely variable. On the other hand, the authors of the Mallerstang Memoir (1891) mapped only one band, the "calcareous bed", and it seems probable that Chubb and Hudson's sequence is correct.

The beds of this cyclothem are well exposed in the small streams running down into Baldersdale and there are occasional outcrops elsewhere. Though there is a great deal of non-marine strata east of Ravock Rigg and north of Casset How, the first complete sequence with marine bands is in How Beck. West and south west of this beck drift hides all the strata on the south side of the Balder Reservoirs, and the mapping is conjectural. In Yoke Sike and in Hunder Beck below Hunder Hill the lower and upper parts of the cyclothem respectively are found, but west of the latter peat obscures nearly all the solid rock.

An almost complete section is exposed in Balder Beck, though as it is broken by a fault it is not possible to link the two halves together. In all the right bank tributaries of the River Balder the Upper Felltop Limestone outcrops and in Mir Gill there is a complete section, though much of the detail is hidden by rock debris. Gill Sike contains the last exposure of Upper Felltop, for south of it the horizons have had to be traced without the aid of marine bands.

North of the Balder exposure is very bad west of West Caini Gill and all the mapping round Caple Rigg into Rowantree Beck is conjectural. East of West Caini Gill the Upper Felltop Limestone and the beds immediately above it are seen in all the becks, though it is not till the N.W. fault downthrows all the strata that the higher beds appear. A very good complete section occurs in How Gill, but beyond it the marine beds are less easy to find. There are some poor exposures in the beck above Yew Scar and near Park House, but nothing outcrops round the north side of the Botany Ridge except a little sandstone below Harker Hill, and some loose pieces of Upper Felltop Limestone at the top of No Name Beck.

(ii) Upper Felltop Limestone. This limestone has an extremely characteristic lithology which can be recognized over the entire area. Typically it is a bluish-grey pure limestone, with impurities which produce darker bands. It is packed with layers of brachiopods and crinoid stems thus increasing its banded appearance, particularly on the weathered surface, which is a yellow or orange-brown colour. This makes it very distinctive and easily recognized even where only one or two loose blocks are seen.

It is exposed in Stony Sike (880168), Cross Gill and Great

Aygill Sike to be repeated by a fault in the latter and in Balder Beck. It is especially fossiliferous in Stony Sike, weathering a much paler colour than usual, and as there is an increase in the amount of clastic matter it is more crumbly and splits easily along the bedding planes. In the tributaries further down the River Balder it maintains its typical character, though it is less well exposed. This is sometimes due to the "famped" nature of the rock. In Blea Gill there were a great many loose blocks of limestone lying about, but nothing could be found in place. However, by digging away the bank at the expected horizon for some time a soft very fossiliferous shaly rock was exposed about 2' in from the overlying sandstone. This was obviously the same horizon as the limestone.

The contact of the limestone with the underlying rock is seldom seen and it is probable that the typical limestone described above does not lie directly on the underlying sandstone. In Balder Beck there is a thin sandy micaceous rock, very fossiliferous at the base, with 6" of fossiliferous shale separating it from the normal limestone. A tough calcareous sandstone with fossils at the top underlies the limestone in a tiny beck opposite Combs.

There is little variation in the lithology of the limestone in Rowantree Beck, West Caini Gill or Yoke Sike, but eastwards it loses its distinctive weathered appearance. On the fresh surface it looks the same in spite of an increase in clastic matter, particularly quartz and mica. This is particularly noticeable in an exposure east of the Tees at Burnley where it is a very micaceous rock, but the layered nature of the fossils makes it quite unmistakable.

At four places in the area there are at approximately the horizon of the Upper Felltop a great number of loose pieces of limestone lying around on the surface. One is in Red Gill (875161), another below Little Aygill Bogs (891174) and the third is in Mawman Sike not far above the outcrop of the Coalcleugh Marine Beds. All of them are similar in that they occur in areas where loose limestone is very rare and yet in a matter of a few square yards more than a dozen loose pieces can be found. In view of the constant nature of the Upper Felltop Limestone it should be easy to say whether they represent that horizon or not. However, the lithology of these limestone blocks is variable. Occasionally a typical Upper Felltop piece is seen, but generally the rock is paler, more crystalline and crinoidal, though some pieces are darker, even sandy or muddy. Fossils are not so common and are more fragmentary, though one or two haploid corals have been seen.

If the limestone does not come from solid rock near at hand, then either glaciation or man is responsible. A glance at the pieces shows that they have not been carried by ice as they have angular edges except where normal weathering has rounded them slightly and glaciers do not deposit rock selectively. There is no conceivable reason why anyone should have carried limestone up to these remote places and there is quite a covering of soil and grass around the individual pieces, though man as an agent must remain a possibility. It seems probable therefore that there is a marine horizon nearby.

It is not the Botany Limestone which lies well above this horizon since Shacklesborough, above Mawman Sike, is composed of Botany Grit. If it is either the Fossil Sandstone or the Lower Felltop Limestone the problem remains as both of these have characteristic lithologies unlike the loose pieces, and in Little Aygill

Bogs there are genuine outcrops of Upper Felltop Limestone at about the same height in the bank of the Balder less than ½-mile away on either side.

Thus, on the assumption that these are not man-made limestone dumps, they must represent small pockets in the otherwise continuous Upper Felltop sea in which variable rather crinoidal limestones were formed with occasional corals and some clastic matter. Presumably the limestone is thicker than elsewhere, but proof of this awaits the finding of a solid exposure.

The fourth occurrence of this loose limestone occurs on the eastern boundary of the map, in the beck below Washfold Bridge. There are many pieces of limestone in the beck and in its bank which are angular and unmarked by ice. Some of them have the Upper Felltop lithology though the majority do not and these may be more than 2' thick. This patch of loose pieces is less convincing than the others as it could very easily have been carried by ice only a short distance either from the Botany Limestone or from one of the lower limestones. In conjunction with the other places, however, it certainly is a strange coincidence that once again at the expected horizon of the Upper Felltop Limestone there should be a similar assortment of loose limestone blocks.

(iii) Shale and Sandstone. This cyclothem is unusual in having little or no shale above the marine band. A few feet do occur in Balder Beck and in the becks running into the lower Balder, but the limestone is often directly overlain by sandy shale grading up into flaggy sandstones which may, as in Mir Gill, contain bands of compact sandstone. On the whole the strata are rather arenaceous in the west and become more shaly towards the east.

Near the top of the sequence there is always a hard band of compact sandstone which makes a good feature, thin though it is, and which is easily mapped. This is probably the sandstone seen in North Gill, above the road bridge (992176), and if this is so there is a lens of grit in the shale below, which outcrops by the bridge itself and on the hill to the south east. Correlations in this part of the area, however, are not very certain as the only marine rocks are the loose limestone blocks thought to be the Upper Felltop Limestone. Between the shale and the compact sandstone there is a 2" coal, seen just off the map downstream, which is the only coal found in this cyclothem.

The compact sandstone is picked up again on the south side of Baldersdale in Crook Beck (992186) and it forms a good feature on either side of How Beck, with occasional exposures to the west of it. In Osmond Beck (988194) there are at least 30' of shale above the supposed position of the Upper Felltop as compared with no more than 10' in How Beck, and there is a similar increase in shale near Gill House compared with the beck above Yew Scar, only ½-mile to the west.

The section drawn up for Yoke Sike is extremely arenaceous, particularly if it is considered in conjunction with the one for the top of the cyclothem in Hunder Beck. Not only is there no real shale above the Upper Felltop, but there is none below the Fossil Sandstone either and the extensive sandstone outcrops at the foot of Coal Gill are no doubt at the same horizon, though there is the possibility that the faults are wrong and that the sandstones should be placed below the Upper Felltop Limestone.

To the east and north of Shacklesborough the compact sandstone outcrops. It is rather carbonaceous, particularly in Blea Gill, and has flaggy sandstones above it. West of that beck a shale comes in above the sandstone, becoming 15' thick in Mir Gill. From the very scanty evidence available this seems to extend to the north west, for 6' of shale underlie the Fossil Sandstone near Potter Reed (873183) and in Balder Beck there are 10' of shale, slightly flaggy at the top, beneath it. It should be possible to join up the two sections for Balder Beck, but the compact sandstone of the lower part could not be found beneath the Fossil Sandstone, and the latter could not be found above the compact sandstone, so the probability is that there is an increase in the thickness of the cyclothem here, the shale of the lower section passing into the rather variable shales, siltstones and sandstones of the upper one.

There are many exposures of shales, sandy shales and flaggy sandstones in the north-easterly running "Grains" of Pinkhill Moss (865178) which have been mapped as part of this cyclothem. The only marine exposure is the one of Fossil Sandstone mentioned above and so the horizon of the non-marine strata is not certain. Undoubtedly the structure is not as simple as it seems and more exposures, or even features, would show some faulting so that the non-marine strata exposed may be representatives of the Coalcleugh Transgression Beds, though it is doubtful whether they extend so far west.

The old quarries round the side of White Hill are probably in the compact sandstone, but all the solid rock is now covered up. Below Harker Hill (952215) there is some sandstone in place, but the marine top of the cyclothem is never seen on the north of the Botany Ridge. On the south side it is found in many of the streams and it is apparent that cyclic deposition is better developed than elsewhere the strata becoming more arenaceous upwards with the Fossil Sandstone lying upon sandstones or ganisters, though a compact sandstone may still occur some distance below the top.

(iv) Discussion. The Upper Felltop Limestone undoubtedly exists throughout the centre of the area, though owing to weathering and the poor exposure of the shale above and below it it may not always be found. There is doubt, however, as to its extension to the west and east. No exposure of it has been found directly above the grit facies of the Transgression Beds Grits in the west except for one loose piece in the beck (860173). This was well above the upper sandstone of the Transgression Beds Grits, and though it could have been carried a short way by glacial action, is more likely to have come from a nearby horizon. There is also the loose limestone already mentioned in Red Gill.

In the east the exposure of the Upper Felltop Limestone in How Beck is definitely above the grit facies, but beyond this beck no exposure has been found except the one mentioned above at Burnley in County Durham. There is plenty of opportunity for it to outcrop, especially in the left bank of the Tees, though the horizon is usually obscured by scree, but even loose pieces have not been found. The probability is therefore that it does not exist, having either never been deposited or been eroded away. Though the Tees area was not mapped in detail, for there is a great deal of minor faulting, particularly around Shipley, no evidence was found for a transgression above the Upper Felltop Limestone, and, as stated above, shale seems to increase towards the east. There is then the possibility that the limestone was never deposited, probably due to the differential compaction undergone by the grit facies compared with the more shaly mixed facies. This could explain the lack of outcrop away from the centre of the area, but in contrast the solitary outcrop in Durham occurs only 600 yards away from where the grit facies reaches its greatest thickness, unless it is that it thins again rapidly east of the River Tees.

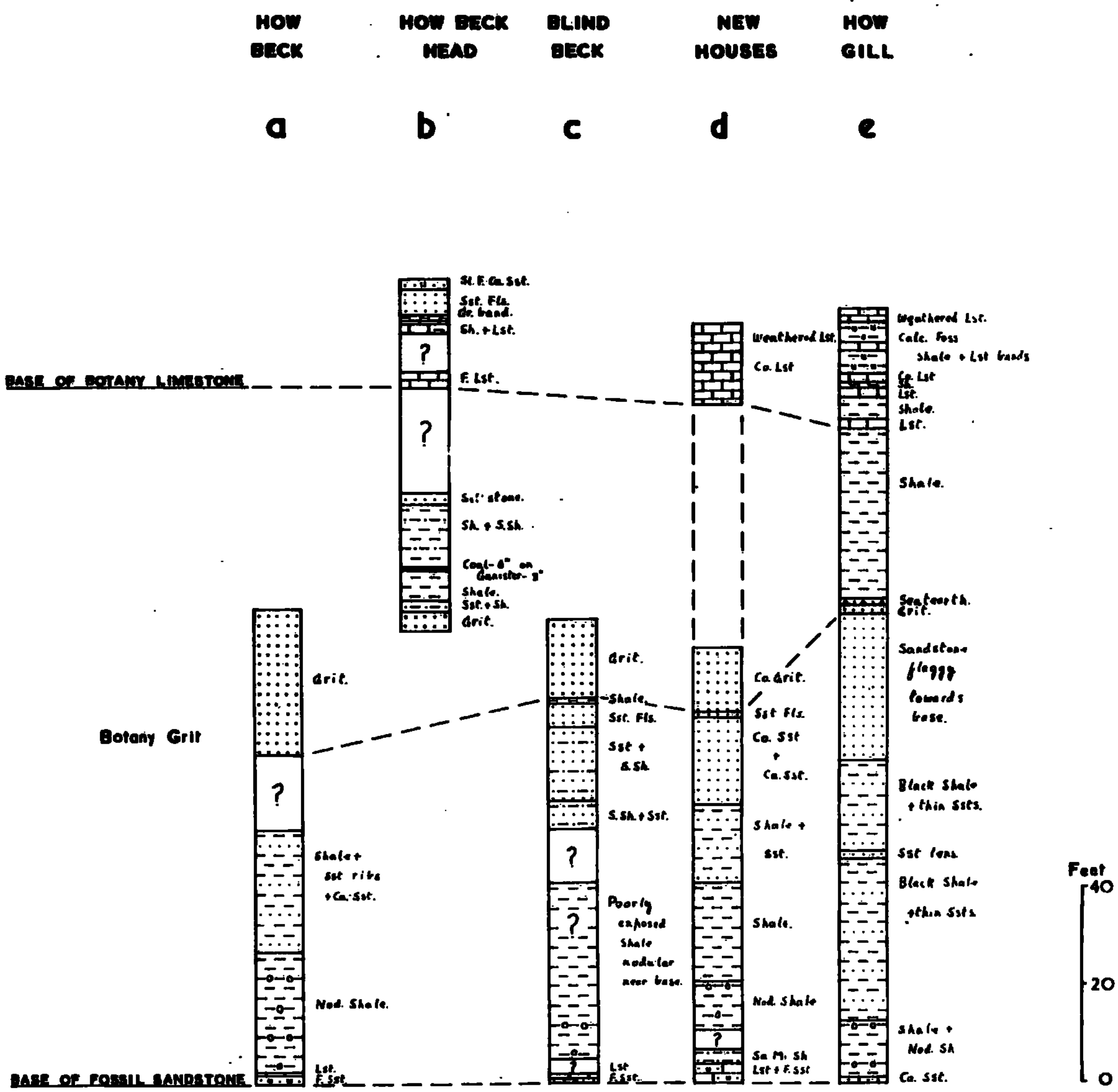
It is not possible to relate the limestone pockets to thickening in the underlying beds, since they occur quite spasmodically above both the Transgression Beds Grits and above the centre of Coalcleugh Transgression Beds. They might be considered as a "reef facies" comparable to that of the Clitheroe and Craven districts. Rayner (1953, p.246) suggests three fundamental characters for the reef facies:-

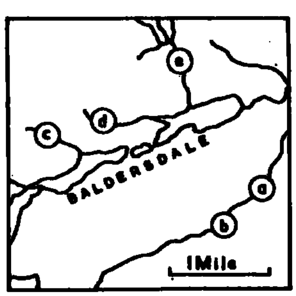
1) Normally poorly fossiliferous calcite mudstone as the dominant rock type.
2) Fauna of a special reef type, locally abundant.
3) Large masses of rock show little or no bedding.

In these pockets calcite mudstone is more common than in the normal Upper Felltop Limestone; it is less fossiliferous, no patches with abundant fossils having been found, and the rock is less well bedded than the normal type. It is not possible to say more than that, especially as no outcrop of these pockets was found and that their existence even has not been proved.

There seems very little doubt about the correlations of this limestone with the areas to the north and south. Dunham (1948) states that the Upper Felltop Limestone of the Alston Block is a bluish slightly crinoidal limestone, in some sections replaced by an ochre or "famped". It seems then that the lithology persists northwards, though, as is seen in the east of this area, it loses its distinctive weathering colour. This is not so to the south where the descriptions of Chubb and Hudson (1925) for the Hearne Beck Limestone and for the one in Lad Gill show that the lithology alters very little in a distance of more than 15 miles. Indeed a specimen from Hearne Beck can only be distinguished from specimens of this area by its slightly more sandy nature. The layers of fossils, the alternate dark and light bands in the fresh specimen, and the orange brown weathering are identical. Thus the Upper Felltop Limestone in the Yoredales of the Alston Block can be traced south into the Hearne Beck Limestone in the Millstone Grit of the Askrigg Block.

Above the limestone of Lad Gill are 50' of shale with crinoid stems, followed by a very calcareous grit which, as is shown below, is correlated with the Fossil Sandstone. There is therefore a continuous marine series on Arkengarthdale Moor which was deposited while non-marine rocks were being laid down in this area. These non-marine rocks continue northwards onto the Alston Block, though they may be thinner in places, such as Hunstanworth (Dunham 1948, p.42).





COMPARATIVE SECTIONS
OF
THE FOSSIL SANDSTONE CYCLOTHEM
AND
THE BOTANY LIMESTONE

FIGURE 15

(h) Fossil Sandstone Cyclothem and Botany Limestone.

(i) General. In the Mallerstang Memoir (1891) a "Fossil Grit" is mentioned several times as occurring above the calcareous band on some of the high fells north of Swaledale. In the present area a similar bed was also mapped by the old surveyors, particularly on the eastern side, where on the 1-inch map Old Series 103 S.W. it was taken as the base of the Coal Measures. On the Alston Block no marine horizon has been named above the Upper Felltop Limestone, and so a name similar to that of the Askrigg Block has been selected, the Fossil Sandstone, since it is generally a sandstone rather than a grit.

The term Botany Limestone for the highest marine bed is so well known since Garwood's description of the Botany Beds in his major work of 1912, that its use needs no explanation and the grit beneath it has been called the Botany Grit since it is exposed so conspicuously round the Botany Ridge.

The outcrop of these beds is limited to the tops of the fells on either side of Baldersdale and to two small downfaulted areas in Hunder Beck and Balder Beck. Exposure is good, as the two marine bands and the grit make conspicuous features and several good stream sections cut into the softer rocks. Nevertheless on the south side of Baldersdale glacial drift makes mapping very difficult, particularly around the slopes of Goldsborough and on Lamb Hill, in spite of a very full section obtained in How Beck.

On the north side of Shacklesborough exposure of the Fossil Sandstone is fairly good, but its position to the south is only conjectured from features. Similarly the outlier of Caple Rigg is mapped entirely by features and the occurrence of a single outcrop.

In contrast, the mapping of the Botany Ridge itself was extremely straightforward, faults being easily traced, one running E.N.E. producing a repetition of the succession. The marine beds, however, were not found on the north side of the ridge owing to the thick covering of peat.

(ii) Fossil Sandstone. This is a coarse sandstone, occasionally gritty, containing fossil fragments. It is usually badly weathered, but sometimes crystals of calcite can be seen in it, and it may be overlain by a sandy limestone.

One of the most complete outcrops is just below the road bridge at West New Houses; it is essentially a fossiliferous sandy limestone, about 4' thick, but the details are difficult to ascertain as the exposure is not continuous. It is quite well developed in Blind Beck to the west, but in How Gill to the east it is very difficult to find though there are one or two loose pieces. The same is true of the beck above East Thorngarth Hill (965201), but a solid exposure is seen near Park House (969207). The bed never occurs outside the streams this side of the reservoir, but as the outcrops of it and the underlying Upper Felltop Limestone both occur at constant levels in the streams there is no doubt that the bands more or less follow the contours and that the N.E. fault west of Goldsborough does not continue north of the reservoirs as shown on the Old Series Geological Map. There are no other solid exposures on the Botany Ridge, but one or two loose pieces were found in a grassed-over quarry below White Hill (912193).

In the west, the single outcrop near Caple Rigg (874184) is of interest. Only about 1' of rock is exposed above 6' of shale and it is the normal fossil sandstone at the base. Above it, however, is a very badly weathered marine rock looking like a cherty or siliceous limestone. South of this there is a good exposure in Balder Beck of a sandstone 5' thick containing scattered fossils and with a limestone, not very sandy, on top. In Hunder Beck the outcrop extends some way along the beck and it shows the variable nature of the rock from a sandstone, sometimes gritty, with fossil fragments into a sandy limestone, laterally as well as vertically. In places marine fossils cannot be found at all in the sandstone.

A gritty sandstone also occurs in Mir Gill and Bleagill Hearne, but in How Beck it is mainly a sandy limestone. The Fossil Sandstone can also be found in the Old Quarry at Burble Beck (987188) where it is at least 4' thick and it was around Currack Rigg that the old surveyors used it to trace the base of the Coal Measures. They also mapped it on the Durham side of the Tees as "grit with shells" for it extends for at least 1½-miles, broken once or twice by faults, as an easily followed horizon, north of Shipley.

(iii) Shale and Sandstone. As the sections show very well, the Fossil Sandstone is overlain by shale, nodular at the base. This is particularly well developed on the south side of the Botany Ridge, for it is frequently exposed outside the major stream sections and also forms large shale features, easily mapped. Undoubtedly the strata are also essentially argillaceous in the less well exposed parts of the area, as there is always a considerable thickness of hidden rock between the Botany Grit and the Fossil Sandstone.

The shale either passes up into sandy shale or sandstone ribs start to enter the shale. There does not seem to be a regular increase of arenaceous matter; instead the sandstones come in as lenses such as the one seen in How Gill. This is a compact sandstone, 1'6" thick at one point, and yet it cannot be found in the opposite bank. In How Beck there are also lenticular sandstones high in the shales, some rather calcareous, but non-marine.

Below Kelton Hill there is a thin white compact sandstone, of which only 2' are exposed but which nevertheless forms a distinct feature and was once extensively quarried. Its horizon cannot be proved as there may be more faults than are apparent west of Kelton Hill, but a thin band of rock only forms a good feature if there is soft strata above and below, and so this is thought to be one of these sandstone lenses in the shale, dying out to the east. A similar sandstone band, though more flaggy and slightly calcareous occurs about 20' above the Fossil Sandstone in Hunder Beck, though it cannot be traced very far.

In addition to these lenses of sandstone there is also a thick sandstone above the shale which extends the length of the Botany Ridge. It is sometimes flaggy, but at New Houses is seen to be compact as well, and in How Gill is 50' thick. On Goldsborough there is, above the flaggy sandstone, 6' of siliceous sandstone becoming distinctly carbonaceous in the upper half and with a ganister top. This appears to be overlain by 2" of coal, which is sometimes seen at the base of the overlying grit, but it is considered that this coal lies above a transgression which cuts into the top of the sandstone (see below, p. 124).

(iv) Botany Grit. This is a compact or false bedded grit which outcrops almost continuously on the north, east and south sides of the Botany Ridge, and forms outliers on Kelton Hill, Shacklesborough, and Goldsborough. In addition, an E.-W. fault, downthrown south, enables it to form the cuesta of Hare Crag and also Loup's Hill.

The grit is composed of rounded or sub-angular grains varying from 0.1 to 3 mm. in diameter, but occasionally there are larger pebbles. Quartz is the dominant mineral with feldspars including plagioclases, orthoclase and microcline, but they have frequently been weathered out. The direction of depositional dip was taken wherever possible and 17 readings were obtained. This is too few for a statistical analysis to be made, but they all lie within a sector from 70° to 220° and all except two between 120° and 220°, so it appears that the current direction was from the north.

As the top of the grit is seldom seen it is not possible to say much about thickness variations, but there is probably an increase towards the south as there is a 40' face of grit in Catty Crag Quarry, and to the east, in Tinkler's Quarry, the grit is at least 30' thick. In addition the formation of such an extensive dip slope as the one between the two quarries, with grit outcrops all over it and no cover of drift, shows that the thickness is considerable. The grit can just be found in the stream bottom at How Beck and it is then upfaulted twice. The first fault raises it onto the top of the stream bank from where it continues eastwards to Tinkler's Quarry. The second and bigger fault produces the two outliers of Goldsborough and Bathe Haw.

The Goldsborough outcrop shows the transgression at the base of the grit, which is at least 30' thick and pebbly near the base. Beneath the grit there is a coal, 2" thick, which would appear to

A. The Botany Grit lying with a transgressive base on a sandstone (? Grindstone Sill) above Hillgill Bridge.

B. Closer view of above photograph.

be below the transgression, but at one place it cuts down into the underlying carbonaceous sandstone. In addition, though its outcrop is not continuous, it is seen at various places round the mesa, in spite of the fact that the underlying carbonaceous sandstone appears to have an eroded top. It seems, therefore, better to consider the coal as above the transgression. Confirmation of this is obtained from Catty Crag Quarry where a thin coal occurs 1' above the base of the grit. On the other flat topped hill or "mesa", Shacklesborough, 20' of grit, sometimes pebbly, are seen, but no sandstone and no base to the grit.

However, at the East Hunder Quarries (931190) the base of the grit is distinctly pebbly, containing quartz pebbles up to 1 cm. long. It rests sharply on 4' of sandstone at one point, while a few yards to the east it is underlain by shale and sandstone flags. At several other places the grit was seen overlying the sandstone. In the stream north of Jenny Quarries (932204) and in How Gill (952215) the base of the grit does not appear transgressive, but in the Old Quarry near Scaletree Plantation (964210), at Blind Beck and at New Houses there is a distinct break between grit and underlying sandstone. The transgressive base of the grit is particularly well seen above New Houses (Plate V) and it can just be made out near Scaletree Plantation.

In How Gill the grit is only 2' thick, which is exceptionally thin. There is, however, no doubt that this is the Botany Grit, as, quite apart from the obvious similarities in the sections shown, this bed can be traced right along the south side of the Botany Ridge, though actual exposures do not occur within about ¼-mile on either side of the beck. The feature is continuous, however, and the lack of exposures near the beck confirms that the grit has thinned. The thinning is of very local extent, nevertheless, for within a mile on either side there are at least 13' of grit at New Houses, and 16' at Scaletree Plantation.

(v) Shale. Above the top of the Botany Grit come 30' - 40' of beds, mainly shale, exposed continuously in How Gill. At the bottom here is a seat earth of very carbonaceous, micaceous siltstone, but with no coal observable above it. Nevertheless, about a mile west (943202) there are some old diggings in the shale with some loose coal and shale on the surface, showing that the coal does develop to the west. Further evidence comes from How Beck Head where there are 6" of coal or ganister, exposed about 9' above the top of the grit.

In How Beck Head there is sandy shale as well as shale, and one band of siltstone, and so there may be arenaceous bands in the shale above the Botany Grit, as well as below it. This may be the explanation for a tiny outcrop of sandstone at Howgill Grange (955204), which is about 20' - 30' above the top of the grit, and which cannot be found in How Gill itself 150 yards away.

(vi) Botany Limestone and Overlying Beds. This marine bed is thicker and has a higher proportion of pure limestone than any seen in this area above the Crow Limestone of Deepdale. Generally the series consists of a compact pure limestone, frequently nodular in appearance, with bands of fossiliferous shales, containing thin intercalations of limestone. The limestone itself may be siliceous, muddy, crinoidal or sandy, the lithologies changing rapidly laterally. The variations in detail of the Botany Limestone can be shown by comparing the section below of the Sealetree Quarry with the ones shown in Figure 15 for New Houses, which was taken from Greenhill Quarry, and How Gill.

	Ft.	Ins.
Weathered limestone, probably compact	6	0
Compact limestone	2 - 8	
Shale and nodular limestone	2	6
Compact limestone	6	0

Fossils are more abundant than in the lower limestones, but extraction is difficult from the compact limestone. Corals were mainly Clisiophillid type, though one specimen of <u>Aulina rotiformis</u> was found in a wall above a quarry. In all respects the Botany Limestone is typical of the normal Yoredale Limestones of the Middle Limestone Group.

Between the three major outcrops mentioned above there are many other exposures of limestone on the hill slopes, but as one goes west of Greenhill Quarry it is less easy to find. It can be seen in Rokehole Sike (939197), but this is the most westerly outcrop for along Hazelgarth Rigg nothing but a few loose boulders can be found of the limestone itself.

Along the top, or on the north side of the Botany Ridge, the limestone should outcrop again, but nothing is exposed, and the boundaries are drawn in simply with the aid of features. Thus the limestone may thin to the north as well as to the west, though the lack of exposures could be simply due to an increase in the proportion of shale, the total thickness of the marine beds remaining much the same.

Certainly there does not appear to be any thinning towards the south for the outcrop at How Beck Head, though largely obscured by quarry debris, shows a total thickness of at least 20'. Above the highest limestone, and resting on a thin shale, is a 2" band of hard, siliceous grit containing fish teeth. This is overlain by 5' of non-marine flaggy sandstone with 2' of coarse fossiliferous sandstone above. It is slightly calcareous, and, on its own, would be mistaken for the Fossil Sandstone. However, it is clearly seen to rest above the Botany Limestone, separated from them by non-marine beds.

The E.-W. fault cuts out all the overlying strata so a return must be made to the Botany Ridge to see if anything similar can be found. Along Hazelgarth Rigg this same fossil grit has been traced for nearly ½-mile just above the expected horizon of the Botany Limestone. It has also been seen near Botany Farm at the head of How Gill (951208) and (952210). It is doubtful whether the fossil sandstone or grit is here separated from the Botany Limestone itself by non-marine beds. None are exposed and it may be that they have lensed out since How Beck Head.

Nothing clear can be distinguished above this fossil grit. Just east of Botany Farm (956214) there is a thin band, 2' thick, of sandstone. Probably the Botany Limestone runs just north of this, but it is not exposed. West of Howgill Grange (951202) there is some loose grit, and a good feature which may be due to an overlying grit band, but the loose pieces may have come from the Botany Grit exposed above the fault to the north west. On Hazelgarth Rigg there are some grassed-over quarries and some loose sandstone above the fossil grit. It therefore appears that arenaceous strata lie not far above the Botany Limestone, but their nature and height above it are not certain.

(vii) Discussion. There is no doubt that the Fossil Sandstone of this area is the equivalent of the Fossil Grit to the south, which extends over a very wide area. Chubb and Hudson (1925) describe it from Arkengarthdale Moor and from Shunner Fell, though it is omitted in the vertical section for the latter. It has now been traced into Durham, a distance of 20 miles, the only difference in the adjacent beds being the introduction of a wedge of non-marine strata below the Fossil Sandstone itself, which was mentioned above. Dunham (1948, p.42) mentions marine beds 16' thick 11' above the Upper Felltop Limestone in the Roddymoor boring and in shafts at Hunstanworth. It has been found on the surface as well. No details are given of the lithology but the term in brackets "Cockle Beds" is used, and this may refer to a shelly sandstone.

Correlations of the Botany Grit with outside areas are rather difficult. In Chubb and Hudson's section for Arkengarthdale 200' of strata are shown between marine beds, and they include the Grit of Water Crag and two thick sandstones. There is therefore considerable thickening, particularly of the arenaceous strata, to the south. Possibly the equivalent of the Botany Grit is the Grit of Water Crag, in which case the sandstones recorded in this area within the shales above and below the grit thicken southwards to form bands 30' thick.

On the Alston Block shale overlies the marine beds with the Grindstone Sill above them (Dunham 1948). This is normally a flaggy sandstone 30' - 50' thick, but may contain a lens of coarse grit. Above it are the shales with sandstones, which are overlain by the First Millstone Grit of the old surveyors. This is thought to transgress onto the beds below. Nothing definite is known of the marine beds in the grits but in the Roddymoor bore a thick, though probably discontinuous, marine series is shown above this basal grit. On the Durham side of the Tees there are very thick flaggy and compact sandstones above the Fossil Sandstone, with grits above them, overlain by the Botany Limestone (see below p. 130), though their exact thicknesses would only be obtained by detailed mapping over a large area, much dissected by faults. Thus there is a thickening of either a sandstone lens in the shale or the sandstone beneath the Botany Grit in an easterly direction.

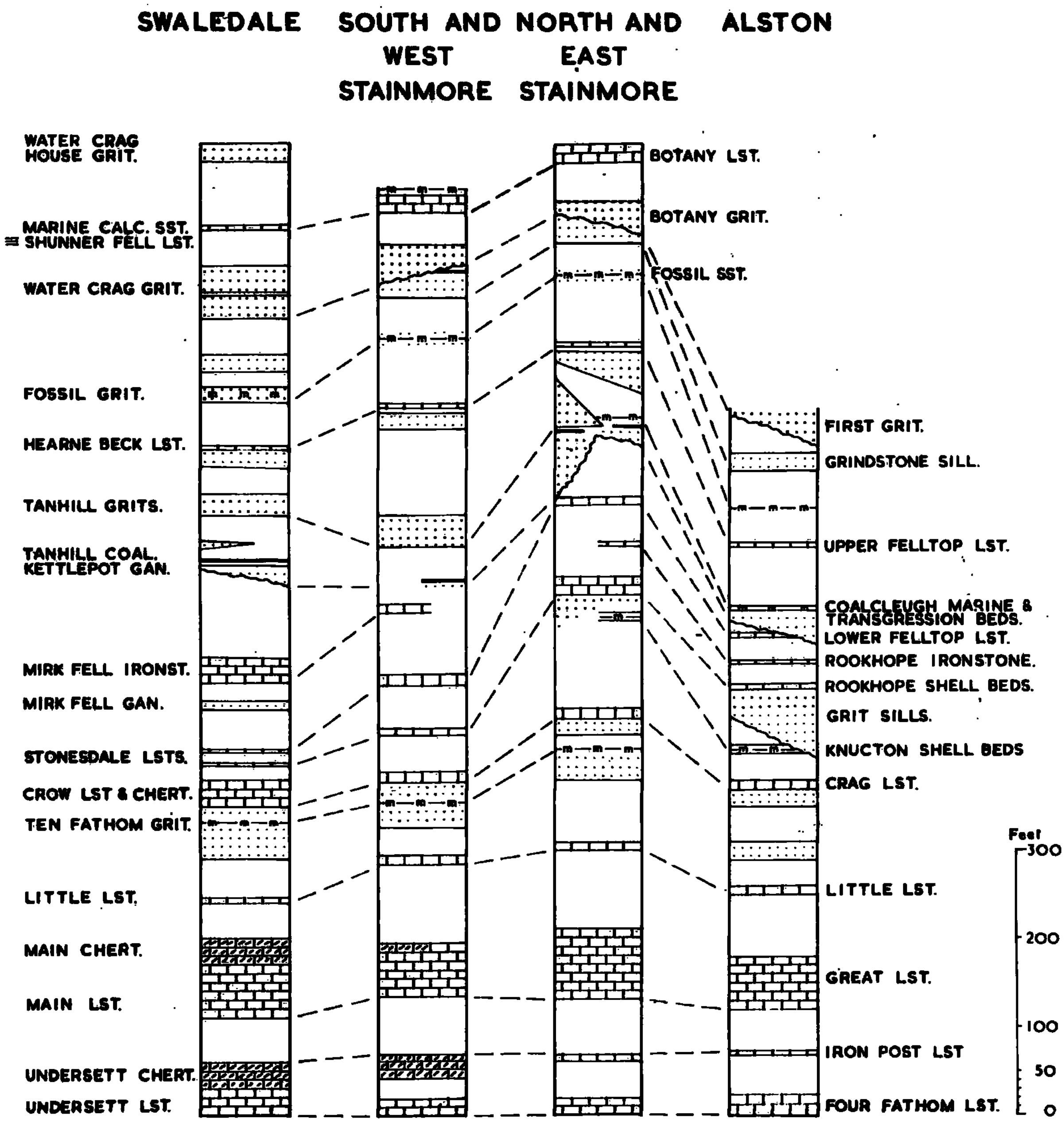
The question is whether the Botany Grit is equivalent to the Grindstone Sill, or whether it is the First Millstone Grit of Durham. It must be remembered that south of Staindrop the basal Millstone Grit as mapped by the old surveyors is the Transgression Beds Grit. Consequently it is not known which of the succeeding beds is the First Millstone Grit of Durham.

If the Botany Grit is the Grindstone Sill, then the Botany Limestone in Durham must be cut out by the First Millstone Grit, the transgression of which lifts sufficiently at Botany to expose the limestone. If the Botany Grit is the First Millstone Grit, then the Grindstone has either thinned or been partially removed by the transgression above. Evidence for the transgressive nature of the Botany Grit has already been given, and, apart from the local thinning in How Gill, it extends over an area of at least 10 square miles. It seems, therefore, that this is the First Millstone Grit of Durham, lying unconformably on the Grindstone Sill. The transgression lifts a little in How Gill, and more east of the Tees to expose a greater thickness of Grindstone. This corresponds to the Roddymoor bore where the marine strata above the basal Millstone Grit would become the equivalent of the Botany Limestone.

The Botany Limestone can undoubtedly be correlated with the Shunner Fell Limestone. Not only are the underlying sections almost identical, but above it is a grit with fossil casts, indistinguishable lithologically from the fossil grit above the Botany Limestone. Chubb and Hudson considered that the marine calcareous sandstone of Arkengarthdale was the same horizon. It is possible, however, that it is actually the equivalent of the fossil grit above, the limestone itself not being present in the section.

Northwards, the Botany Limestone presents a problem. It has never been recorded from the Alston Block, though a marine series was penetrated in the Roddymoor bore. This may be due to the poor quality of exposures at this horizon, and certainly this could be the explanation north of Staindrop. South of Staindrop an E.-W. fault is shown on the Old Series Geological Map (103 S.W.), letting down a wedge of Yoredales north of extensive Millstone Grit outcrops. There is no doubt that Yoredales exist, as near the railway viaduct in Langley Beck is a Crag Limestone to Rookhope Shell Bed succession, but south of these outcrops with their steep northerly dips are two exposures of limestone. Assuming, as the map shows, that there are no faults between, the two exposures must be of a limestone well down in the Middle Limestone Group. By a strange coincidence the fault lies immediately to the south of these exposures, with no underlying beds between them and the fault. An examination of these limestones shows them to be compact, slightly siliceous limestones, fairly fossiliferous, and rather nodular in appearance. They bear an extraordinary resemblance to the Botany Limestone and are completely dissimilar to any of the Upper Limestone Group Limestones seen. There is no positive evidence for a fault to the south of these limestones, the country being extensively drift-covered, and a fault could with equal ease be placed to the north. In fact, in order to link this fault with the Lunedale one, of which it is an extension, the old surveyors had to insert an additional S.E. one. A further point is that it is most unusual for a fault to have the same horizon of grit on one side, and the same limestone on the other, for a distance of 2½-miles. It seems, therefore, very probable that this is the Botany Limestone, overlying a grit which is exposed just to the south, though it is never seen directly beneath the limestone.

Thus detailed mapping may reveal further exposures of a marine bed in Durham, but it is unlikely that it will be the thick massive limestone of the Botany Ridge as the old surveyors would not have missed it. It may be that the overlying Second Millstone Grit transgresses sufficiently to remove it, but another possibility is that it was either not deposited or was laid down in an attenuated form. The non-marine strata above the Fossil Sandstone on the Botany Ridge are not particularly arenaceous compared either with Arkengarthdale Moor or with the Alston Block, though information is scanty. Possibly the Botany Ridge and part of Durham to the east being relatively shaly were compacted more than neighbouring areas so that a thicker marine series could be laid down in this temporary trough than to the north and south.



SUGGESTED CORRELATIONS OF UPPER YOREDALES AND MILLSTONE GRIT ACROSS STAINMORE

FIGURE 16

(i) Correlations.

Suggested correlations between Swaledale and Alston are shown in Figure 16. The section for Swaledale is made up from those given by Chubb and Hudson (1925) and Hudson (1941). Carruthers (1938) also gives a section for North West Swaledale and this is repeated by Trotter (1952). This is so much at variance with Hudson's work and with the details given in the Mallerstang Memoir that it has had to be ignored. For the Alston Block a very general section has been drawn up, based on the comparative sections of Dunham (1948). Some detail has been removed and the transgressions have been emphasised.

On Stainmore it was seen that there could be very little doubt about the equivalence either side of the syncline, either of the beds below the Crag to Crow Limestone, or above the Upper Felltop Limestone.

In the middle, however, the correlations of the marine beds were not absolutely proved, and a glance at the generalised sections on the map might suggest that they were wrong. The more obvious conclusion to be drawn from these sections is that they should be correlated as follows:-

S.E. and East.	West.	N.E. and Centre.
....	(Mirk Fell (Ironstones	Lower Felltop Limestone.
Upper Stonesdale Limestone	(Upper Stonesdale.	Rookhope Shell Beds.
Lower Stonesdale Limestone	(Lower Stonesdale.	Knucton Shell Beds.
Crow Limestone	Crow	Crag Limestone.

Trotter (1952) suggests a similar correlation and it greatly decreases the differences in thickness between the west and the other parts of the area. It would also enable one to trace the Grit Sills into the sandstone below the Upper Stonesdale of the western part of the area.

There are on the other hand several arguments against it:-

1) The Grit Sills cannot be found on the Askrigg Block so there is no reason why they should not disappear within this area.

2) The lithological similarity of the Lower Felltop Limestone and Upper Stonesdale Limestone throughout this area.

3) The isolated exposures of marine beds beneath the Coalcluegh Transgression Beds in Rowantree Beck, etc., would have to be explained.

4) The evidence quoted above for the disappearance of the Knucton Shell Beds.

5) The absence of the top marine band in the S.E. though a transgression could be the explanation.

Hudson (1941) put forward another correlation for the Upper Yoredales:-

North West Swaledale.	Alston.
Mirk Fell Ironstone Series	(Lower Felltop Limestone. (Rookhope Ironstone. (Rookhope Shell Beds.
Mirk Fell Ganister	Grit Sills.
Stonesdale Limestone	Knucton Shell Beds.
Crow Limestone	Crag Lime.

This has the advantage of linking the Mirk Fell Ganister with the Grit Sills, but it does not take into account the double nature of the Stonesdale Limestone. The evidence of the western section is quite emphatic that there are two Stonesdale limestones with a few sandstone ribs in the shale above to represent the Mirk Fell

Ganister. These two marine bands can hardly be thought to pass northwards into the Knuctons, which have been shown to thin southwards. In addition the suggested equivalence of the Mirk Fell Ironstones with the Rookhope Shell Beds, Ironstone, and possibly the Lower Felltop Limestone as well is most improbable, considering the thickness of these beds in some parts of the area.

There is the possibility that the mapping of the north east part of the area is wrong and that consequently part of the section drawn up for the north east and centre is incorrect. There is no doubt about the other two sections as each marine band is definitely seen to be above the one below it. This is not so on the north side of the Botany Ridge and there is always an element of doubt when mapping depends very largely on the interpretation of features. The difficult point is to distinguish the Rookhope Shell Beds from the Lower Felltop Limestone, as it is possible that the two marine bands found in the Tees are the two Rookhope Shell Beds and that the Lower Felltop Limestone has been cut out there by the transgression at the base of the pebbly grit of the Transgression Beds Grits. In support of this is the great thickness, with intervening non-marine strata, of the Rookhope Shell Beds in the Selset Bores and the very great variations in thickness of the strata between the Shell Beds and the Lower Felltop Limestone. On the other hand there is the evidence in Deepdale which points to a similar thinning of the non-marine strata eastwards, and the comparative constancy of the lithology of the Lower Felltop Limestone.

Finally there is the possibility that while the mapping of the north east of the area is correct, the identification of the limestone below the transgression as Lower Felltop is wrong. In other words, the Lower Felltop of Alston may not occur in this area at all, having been removed by the transgression above, and the marine band thought to be the Lower Felltop is the Upper or Main Rookhope Shell Bed. This would result in the following correlations across the syncline:-

North West Swaledale.	Alston.
....	Lower Felltop Limestone.
Mirk Fell Ironstones	Rookhope Ironstone.
Upper Stonesdale Limestone	Main Rookhope Shell Beds.
Lower Stonesdale Limestone	Lower Rookhope Shell Beds. Knucton Shell Beds.
Crow Limestone	Crag Limestone.

This correlation would mean that the transgression removes a much greater thickness of beds than hitherto suspected, as the Lower Felltop Limestone would be absent from the Stainmore Area and North West Swaledale and the Rookhope Ironstone would be absent from the centre and east of this area. The sections which Carruthers drew up for North Teesdale and Swinhope both show a shelly sandstone for the Rookhope Main Shell Bed with no limestone above it. The Lower Felltop Limestone, as mapped, of this area has a gritty or sandy base, but there is always a pure limestone above. On lithological grounds, therefore, one would be inclined to reject this correlation but the only positive evidence against it within this area is the finding of an ironstone, thought to be the Rookhope Ironstone, below the mapped Lower Felltop. Nevertheless the evidence is not conclusive and until the area to the north has been surveyed and the limestone in the Tees at Eggleston Bridge definitely identified this alternative correlation must remain a possibility.

Comparing the present map with that of the old surveyors, it will be seen that the mapping of the lower strata is not very different. The Four Fathom, Great, and Little Limestones presented no difficulties and much of the Ten Fathom Grit and Crow Limestone south of the syncline was mapped in the same way. Above the Crow they did not attempt to correlate the marine bands and seem to have considered that there was only one "Felltop" Limestone, though in some places two separate bands (the Lower and Upper Stonesdale Limestone of the present work) were mapped.

Within the syncline, in the River Balder and Hunder Beck, some limestones are marked. Apart from the Botany Limestone these were all thought to be below the Millstone Grit, presumably the "Felltop" Limestone. These exposures, however, have been shown in this account to include the Rookhope Shell Beds, Lower Felltop Limestone and Coalcleugh Marine Beds in Hunder Beck, and the Upper Felltop and Fossil Sandstone in Balder Beck. No attempt was made to use these marine bands for correlation purposes and many more exposures were overlooked, particularly within their "Millstone Grit".

The result was that the well developed grit in the west of the area, now thought to be the middle grit of the Transgression Beds Grits, was traced eastwards into a variety of beds. Above Lunedale they joined it to what are now called the Coalcleugh Transgression Beds of Soulgill and Rowantree Becks. North of Baldersdale they continued it into the sandstone below the Upper Felltop Limestone in West Carni Gill. Around Shacklesborough it was mapped into the sandstone below the Fossil Sandstone.

In the east of the area the transition from grit facies to mixed facies was explained by faults downthrowing to the east. The largest of these faults is above Lunedale, east of Shields Beck, for the Grit Sills increase in thickness at about the same point and the old surveyors here included the Grit Sills in their "Millstone Grit". This fault, and the one north of Baldersdale have now been shown to cut through several marine bands. The one west of High Crag cannot be proved to be incorrect, but there is no positive evidence for it.

The Botany Limestone was placed high in the Millstone Grit and this account agrees with that position and with a similar position for the limestone of How Beck Head. The old surveyors were, however, misled by the Fossil Sandstone which has now been shown to be below the Botany Limestone. They took it to be the base of the Coal Measures, but only recognised it south of the Balder in How Beck and around Curracк Rigg, and, north of the Balder, on the eastern extremity of the Botany Ridge. They did not find it in the streams running down the south of Botany Ridge, where it can be seen to underlie the Botany Limestone, nor did they recognise it further west. Consequently the E.-W. fault running through How Beck Head was shown to downthrow to the north and let down a block of Coal Measures. This has now been shown to be incorrect and the grit of Goldsborough is correlated with the Botany Grit and not placed high up in the Coal Measures.

In his paper of 1938, Carruthers draws up a complete section for the Lune Valley from the Great Limestone to the Transgression Beds Grits in the western part of the area which he calls the 'Grit of Iron Band' and considers to be the equivalent of the First Millstone Grit of Durham. He also includes shorter sections for the

Botany Ridge and for Yawd Sike (How Beck in this account). The strata in his section from the Great to just above the Little Limestone, taken from the River Lune above Blake House, is straightforward enough, except that the Upper Coal Sill is shown rather thicker than the field evidence justifies.

He continues above the Crag Limestone with a composite section from Rowton Sike (Dowcrag Sike) and Spurrig End (Borrowdale Beck). The latter, he states, goes "almost to the floor of the Grit Sills". Nothing of the Grit Sills was found in this beck and in any case it contains a nearly perfect section right up to the Transgression Beds Grits. He does show that the Firestone Sill was poorly developed, but he did not find the Faraday House Marine Band. An exposure of this at Grassholme Bridge he considered to be the Knucton Shell Beds, which are lithologically very similar. The mapping evidence, which was confirmed by the Selset Bores, leaves no doubt that the Shell Bed at Grassholme Bridge underlies the Crag Limestone. This is exposed on the surface and was thought by Carruthers to be bands of lime plate in the overlying shale.

His lime plate is overlain by the Grit Sills and above them is a gap before he continues his section from the sequence in Rowantree Beck. He considers the two marine bands below the Coalcleugh Transgression Beds to be the Rookhope Shell Beds, but these are more probably the Mirk Fell Ironstone and Lower Felltop Limestone. The shell bed he shows below the lower limestone could not be found, but otherwise the recent examination shows a comparable sequence especially of the Coalcleugh Transgression Beds up to the top limestone. This was not exposed when Carruthers visited the area, but it can now be seen and has the lithology of the Upper Felltop

Limestone. The exposure of limestone east of Iron Band which he considered to be its equivalent is over two miles away and can only be the Lower Felltop. Thus there is no evidence in the field for placing his 'shelly sandstone' and grit of Iron Band above the Upper Felltop Limestone. The former incidentally is not a 'shelly sandstone 10 or 12 feet thick' but consists of one or possibly two thin argillaceous limestones which, as has been shown above, are probably the equivalent of the Mirk Fell Ironstones. The grit of Iron Band was thought by Carruthers to be the First Millstone Grit of Durham, but it cannot be shown to overlie the Upper Felltop Limestone and all the field evidence points to its correlation with the Coalcleugh Transgression Beds.

With regard to the two sections that Carruthers shows for Botany (How Gill) and Yawd Sike (How Beck) there cannot be much dissagreement as regards details, and, as he says, there is no doubt that they pass through equivalent strata. However, it was unfortunate that he chose How Gill for his section as it is the one place where the Botany Grit is particularly poorly developed and at How Beck Head only the top of this grit is seen before it is faulted up to reappear on the summit of Goldsborough. The Goldsborough grit, he considered, as the First Millstone Grit of Durham, lying about 40 fathoms above the Botany Limestone of the How Beck Head quarry. This cannot be so if, as all the evidence shows, the east-west fault downthrows south and if the dip to the north east is taken into account. Proof that the Goldsborough grit lies only 10 fathoms above the Fossil Sandstone comes from the small outlier of Bathe How where one would expect the grit to outcrop if the dip remained constant and which is very close to the How Beck exposures.

Carruthers believed that the Botany Limestone was the Lower Felltop and the underlying Fossil Sandstone and the Upper Felltop Limestone of How Gill were the Rookhope Shell Beds. As further evidence for this he claimed to have found the Coalcleugh Transgression Beds and Marine Beds above the Botany Limestone of How Beck Head. The non-marine strata above the limestone, however, are not the variable carbonaceous sandstones of the Coalcleugh Transgression beds, but ordinary sandstone flags, and the shelly grit above does not resemble the Coalcleugh Marine Beds of this area which are generally an ironstone or muddy limestone.

Carruthers ignores the thick grit facies of Lower Baldersdale which underlies the Botany and Yard Sike (How Beck) sections, but to explain the grits of the Botany Ridge he invokes two large E.N.E. faults which let down the First Millstone Grit of Durham. Precisely where they run is not known but they could only run through substantial features and possibly through solid outcrops. On the south west side of the ridge the grit can be followed right round to beneath the Botany Limestone and Carruthers still does not explain the occurrence of a continuous grit right along the southern side of the Botany Ridge which is definitely below the limestone. The recent mapping of the area has shown that the old surveyors were substantially correct and, indeed, the surface exposures are so good that there can be very little doubt that the Botany Limestone is well up in the "Millstone Grit" of Durham.

On the basis of the correlations which have been put forward the strata of this area can be related to Bisat's goniatite zones. There are three horizons in neighbouring areas where goniatites have been found within strata discussed in this thesis:-

(1) Mount Pleasant Bore; shales between the Undersett Chert and Limestone; Girtyoceras ? costatum Ruprecht and other goniatites referable to Girtyoceras-high P_2 age.

(2) Swaledale; Mirk Fell Ironstones; Cravenoceras cowlingense-low E_2.

(3) Shunner Fell; Shunner Fell Limestone; Anthracoceras cf. paucilobum-E_2.

These occurrences and others in the Yoredales are described by Rayner (1953). She suggests from the evidence available that the base of E_1 lies between the Undersett and Main Limestones; that the top of E_1 is not far above the Little Limestone and the top of E_2 is high up in the Upper Limestone Series. The base of E_1 seems fairly certain, though Trotter (1952) places it just above the Scar Limestone. The top of E_1 is less easily defined for not only are there no reliable goniatite finds between the Main and the Mirk Fell Ironstone but also, as emphasized by Rayner, there is disagreement as to whether Cravenoceras cowlingense is E_1 or E_2. Regarding the top of E_2, if the Shunner Fell goniatites are accepted it places the Botany Limestone within E_2 and so it appears that all the strata of this area were deposited in Eumorphoceras times except for the beds of P_2 age below the Main Limestone.

(j) Summary.

(i) Four Fathom Cyclothem. The history of sedimentation in the area mapped begins in late P_2 times with the marine incursion which deposited the Undersett and Four Fathom Limestones. While marine deposition is continuous in Swaledale and around Bowes to the top of the Undersett Chert, to the north and west a wedge of non-marine strata was laid down. Later the sea again advanced to deposit the Iron Post Limestone with which the top of the Undersett Chert is correlated. Above this come more non-marine rocks which extend into Swaledale as well.

(ii) Great Cyclothem. The Main or Great Limestone of early E_1 age is the thickest limestone in this area. It is doubtful whether the coral band known as the Frosterly Marble can be traced south of Lunedale, though there is a similar band near Bowes. The Main Chert is exposed near Bowes (Figure 5), but disappears very rapidly to the north and west. The Coal Sills Group is mainly composed of slightly transgressive non-marine sandstones and shales but irregularly developed marine bands occur within the group. They show that the area is marginal to the sea which in Swaledale was depositing continuous marine strata, with occasional incursions into Stainmore.

(iii) Little Cyclothem. The Little Limestone extends over the whole area, as does the Faraday House Marine Band, though this may have been removed at some points by transgression at the base of the overlying sandstone. The Ten Fathom Grit can be divided into two parts by the Faraday House Marine Band, the upper part being correlated with the Firestone Sill of the Alston Block. The lower part is found to pass into a thick sandstone in Lunedale, which is called the Pattinson Sill, but its relationship to the Pattinson Sill of Hunstanworth is obscure. Thickness variations are greater than in previous cyclothems, the beds reaching their greatest development in the centre of the area.

(iv) Crow Cyclothem. The Crow Limestone of the Askrigg Block is the equivalent of the Crag Limestone of the Alston Block. Above this basal marine band the Knucton Shell Beds and Grit Sills of Alston just reach Lunedale, the latter becoming very thick and coarse towards the Tees. To the south and west both groups die out, the non-marine strata becoming much thinner and less arenaceous.

(v) Lower Stonesdale Cyclothem. The Lower Stonesdale Limestone is thought to be the equivalent of the Rookhope Shell Beds of the Alston Block, but the correlations are less certain than for the previous cyclothems. The thickness reaches a maximum in the centre of the area and decreases to the east and west, particularly towards the east.

(vi) Upper Stonesdale Cyclothem. This cyclothem contains the lateral and vertical change of lithology from Yoredale facies to Millstone Grit. In general the cyclothem can be divided by the transgression at the base of the mixed facies of the Coalcleugh Transgression Beds or the grit facies of the Transgression Beds Grits.

Below the transgression the Upper Stonesdale Limestone is considered to pass into the Lower Felltop Limestone of the Alston Block. The Mirk Fell Ironstones of late E_1 or early E_2 age only occur in the western part of the area. Above the transgression the coals, particularly the Tanhill Coal horizon, are used for correlation, though the Coalcleugh Marine Beds are useful over a limited area. These do not occur on the Askrigg Block nor over any part of this area where the grits are well developed. The Tanhill Grits of N.W. Swaledale are considered to be the equivalents of the Coalcleugh Transgression Beds of Alston, as suggested by Carruthers (1938), but the actual transgression is believed to be below the Kettlepot Ganister and not above it as he suggested.

(vii) Upper Felltop Cyclothem. The Upper Felltop Limestone of the Alston Block has been shown to be the equivalent of the Hearne Beck or Lad Gill Limestone of Swaledale. The strata above this basal limestone are entirely marine in Swaledale, but the overlying Fossil Sandstone is separated from the lower marine band by a wedge of non-marine beds in the present area and on the Alston Block.

(viii) Fossil Sandstone Cyclothem. The correlations of the beds above the Fossil Sandstone with Swaledale are very firmly based, as the succession on Shunner Fell and on the Botany Ridge are practically identical. Thus the Fossil Grit of Swaledale is correlated with the Fossil Sandstone; the Water Crag Grit and the Botany Grit are taken to be equivalent and the Botany Limestone with its overlying fossil grit are the representatives of the Shunner Fell Limestone of late E_2 age and its overlying grit.

The tracing of these beds to the north is more difficult. It is probable, however, that the Fossil Sandstone is represented by marine beds above the Upper Felltop Limestone and that the Botany Grit is the First or Basement Millstone Grit of Durham which transgresses onto the beds below. In this area this transgression cuts into an underlying sandstone which may be the equivalent of the Grindstone Sill. The Botany Limestone has never been reported from the Alston Block, but it is considered that a limestone, mapped by the old surveyors between Staindrop and Eggleston, is equivalent to the Botany Limestone.

III. STRUCTURE.

(a) General.

The Northern Pennines have been shown by various authors, Kendall (1911), Marr (1921) and Versey (1927) to have remained a morphological unit or stable block since early Carboniferous times. This unit is bounded on the north, west and south by the Stublick, Pennine, Dent and Craven fault systems, while the eastern boundary is hidden under younger rocks. During Carboniferous times the deposits within this unit were thin compared with those in the regions to the north and south, and the post-Carboniferous earth movements affected it much less than they did surrounding areas.

The stable unit is divided by the Stainmore Syncline into a northern or Alston Block (Trotter and Hollingworth 1928) and a southern or Askrigg Block (Hudson 1938). The structural history of the Alston Block and its surrounding areas has been discussed by Trotter and Hollingworth (loc. cit.), Turner (1927, 1935), Shotton (1935) and Dunham (1933, 1948). They are in broad agreement as to the sequence of events which are shown below in a summary based on Dunham (1948, p.75):-

(1) Caledonian compression in a N.W.-S.E. direction folding the Lower Palaeozoic rocks E.N.E. with the development of E.N.E. and W.N.W. cleavage.

(2) Early Carboniferous movement which progressively uplifted the Alston Block relative to the Northumbrian trough along the lines of the Stublick Fault, and corresponding movements on the Swindale Beck-Lunedale Fault relative to the Stainmore Area, at least in D_1 times. Movement may have also taken

place along the Crowdundale Fault, but nothing is known of the position of the western margin of the block except that it must have been west of the Outer Pennine Fault.

(3) Inter-Carboniferous gentle warping of block.

(4) Hercynian N.-S. compression producing master joints on the block at 060°-070° and 155°-160°; E.-W. folds on the Alston Block, the Bewcastle anticline and possibly the Stainmore syncline.

(5) Hercynian tension depressing the Alston Block along normal N.N.W. and E.-W. marginal faults.

(6) Hercynian compression E.N.E., producing the thrusts of the Cross Fell Inlier, the Burtreeford Disturbance and tear faults north of the Stublick Fault. The intrusion of the Whin Sill and related dykes took place at about the same time, though this may have been slightly later than the Burtreeford Disturbance.

(7) Rotation of block relative to adjacent areas producing tear faults in the Brampton District and N.E. folding on the block at Hunstanworth and elsewhere.

(8) Possibly late Hercynian gentle domal uplift of block and formation of conjugate vein-fissures, N.N.W., E.N.E. and E.-W. to W.N.W.

(9) Tertiary intrusion of W.N.W. tholeiite dykes en echelon during differential sideways movement.

(10) Tertiary uplift and tilting of the block to the east with major movement along the Outer Pennine fault and some movement along the Stublick Fault.

(11) Small sideways movements in mineral veins producing post-

mineralization slickensides.

The structure of the Askrigg Block has not received the same attention, but Turner (1935) states that it is divided into two dissimilar halves, north and south of Wensleydale. The southern one is practically devoid of faults or folds except in the south eastern part. The northern one, on the other hand, is traversed by a great number of E.-W. or N.W.-S.E. ore-bearing faults, some of which, to the west, act as tears to the Dent Line. On the northern margin of this half of the Askrigg Block are the Stowgills and Middleton Tyas anticlines.

(b) Major Folds.

The Stainmore Syncline is an asymmetrical syncline trending E.N.E. and pitching in the same direction, the general structure of which has been investigated by means of structure contours (Plate II). The contours are drawn on the base of the Great Limestone whose outcrop is shown, but all the principal marine bands were used as key horizons for calculating the elevation of the limestone base, those up to and including the Crow Limestone giving figures accurate to within 50'. Owing to thickness variations the higher ones give less accurate figures, and for the Upper Felltop Limestone and above the error may be as much as 100'.

The syncline is 'flat bottomed' with a trough running along the line of the River Balder in an E.N.E. direction, forming a belt one mile wide of beds dipping extremely gently to north of east. In Teesdale there is evidence that the trend of the trough swings round until it runs due east. To the north of the axial trough the beds rise at the average rate of 500' per mile, gently at first but becoming steeper, until the gradient is about 800' per mile. To the south the average rise is about 300' per mile, but this more gradual gradient is partly due to the levelling out of the beds towards the top of this limb and partly to the E.-W. Hunder Beck Fault which repeats the outcrop. Over a limited distance the dip is as steep on the south of the syncline as it is on the north.

The amplitude of the syncline is about 900' on the south but much greater on the north. From the accompanying structure map it is seen to be at least 1200', but if the strata below the Four Fathom Limestone had been mapped the contours would rise to over 2000' both west and east of Cocklake Side, so that the maximum amplitude would be about 1600', as estimated by Dunham (1948, p.63).

East of the area mapped it is not easy to follow the syncline. It is still apparent in the Tees, though it is broader and shallower, and the southern limb can be followed down the Tees below Barnard Castle, its direction swinging to the E.S.E. until it forms the northern limb of the Middleton Tyas Anticline. The northern limb is less easy to trace. It can certainly be found on the Durham side of the Tees but after a mile or two the regular southerly dip dies out. There are occasional small flexures with a southerly dip beyond, but the strata generally dip fairly steeply to the north or north east.

North of the syncline the contours drop down sharply towards the Lunedale Fault showing the anticlinal structures associated with this fault which is discussed below. The half-dome of the Lunehead Mines (Dunham 1948, p.17) is also apparent. It is in effect a nose, as defined by Nevin (1949, p.47), directed to the S.S.E. on strata rising to the N.N.W.

South of the syncline there is a long asymmetrical anticline pitching at either end, which appears to have two "highs". The eastern one is not absolutely established as it is mainly dependent upon the identification of the limestone at the quarry (982143) as the Little Limestone. However the average pitch to the east is about 90' per mile, with a steeper but smaller pitch to the west. South of the Stainmore Summit Faults the strata rise gently southwards.

The pitch of the syncline averages 125' per mile, but is rather variable. In the west it is as much as 225' to the mile, but it becomes gentler towards the east, averaging only 65' per mile.

Even here it is irregular in detail, a local steepening usually being associated with N.W. or N.N.W. faults downthrown to the east. This occurs in Lunedale south of the Bink House Fault, and north of the fault in Sleightholme Beck in Rove Gill and on Ravock. Along a line joining these two belts are two faults running in the same direction, both throwing to the N.E. Thus there is a continuous belt across the area, trending N.W. to N.N.W., with faults or steepening dips to the N.E. This belt finishes just north of the River Lune; it does not affect the Great Limestone above the Brough to Middleton-in-Teesdale road.

On the flanks of the syncline but not in the centre there is also an increase of pitch in the eastern part of the area. It is particularly noticeable on Crag Hill north of Deepdale where the pitch is over 100' in ½-a-mile and there is also a sudden drop of all the beds N.W. of Romaldkirk, but it is uncertain whether this is due to folding or faulting.

Hickling (1950) has shown that the average easterly dip across the Durham Permian is between 1 in 35 and 1 in 60, a figure which is similar to a range of 1 in 36 to 1 in 46 for the base of the Permian in Yorkshire. He suggests that this general regional dip extends both to the east and to the west. In the Stainmore Area the general parallelism of the main drainage towards the east strengthens the belief that it was also affected by a similar Tertiary tilt. To investigate the possible pre-Tertiary structure a structure contour map (Plate III) was constructed after removing the regional dip, which was assumed to be due east at 100 ft. to the mile or approximately 1 in 50. The true direction may be slightly north of east, as an average of the stream directions showed that they trend in that direction, but this direction makes no material difference. The faults have not been altered, since, though there is evidence of movement along them in Tertiary times, it is not possible to estimate their throw prior to the Tertiary uplift.

The result of Hickling's survey was to show that the Durham coalfield consisted of shallow domes and basins, with the contours trending east and west. The modified structural map of the Stainmore Area exhibits an asymmetrical syncline, pitching very gently at either end, so that it is in effect a shallow basin. To the south of this basin are two anticlines, both pitching to the west. Thus the present pitch of the Stainmore Area to the east may, as with the Durham coalfield, be entirely due to Tertiary movement.

STATISTICAL ANALYSIS OF STRUCTURAL TRENDS

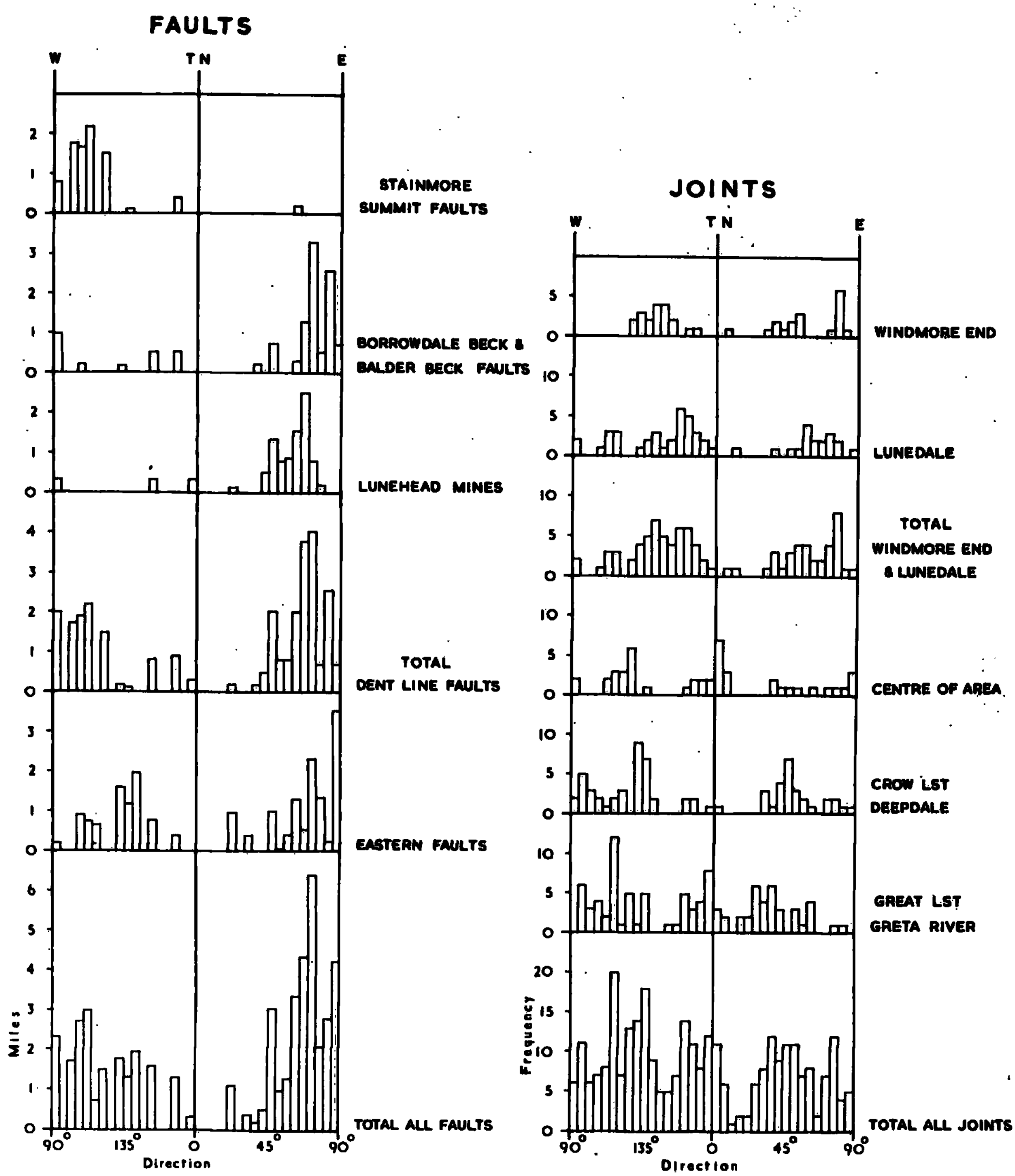


FIGURE 17

(c) Faults and Minor Folds.

(i) General. The area mapped is bounded by the Lunedale Fault on the north and the Stainmore Summit Fault on the south. Within this area there are a number of E.-W. or E.N.E. faults, some of which extend for more than 3 miles, and crossing them or branching off them are many N.W. or W.N.W. faults.

An attempt was made to analyse the fault directions by constructing histograms to show the length in miles of the faults, at 5° intervals. All the faults shown on the map are included except for those S.S.W. of the Stainmore Summit Fault and the Lunedale Fault. Faults with a throw of less than 10 ft. are excluded and those which are conjectured (shown by broken lines) have their distance halved, so that the certain faults have more effect in the analysis.

Peaks are seen in N.E., E.N.E., E.-W, W.N.W. and N.W. directions, there being relatively few faults either side of a N.-S. line, but otherwise not a great deal can be obtained from the figure. The area was therefore divided into two parts, a western half containing all those faults which can be linked with the Dent Line and including the whole of the Lunehead Mines, and an eastern half containing the remaining faults.

(ii) Eastern Faults. Two dominant trends now remain in the histogram for the east of the area. They are N.W. and E.N.E.-E. There is a smaller peak for W.N.W., but this is almost entirely made up of conjectured faults whose directions are very uncertain. It is worth noting that the two dominant trends compare very well with those shown by Dunham (1948, p.66) for the Alston Block, but that their directions have shifted between 5° and 10° in an anticlockwise direction.

There are three main E.-W. or E.N.E. faults in this part of the area, all of which downthrow south. The first almost traverses the length of the Botany Ridge and though it is never seen, it can be inferred from the obvious repetition of outcrop of the Botany Limestone and Grit that the throw reaches about 120'. The old Geological Survey map shows two separate faults connected by a short one running W.N.W. No evidence for this was seen, and an outcrop of fossil shale, thought to be on the horizon of the Botany Limestone in Bullhill Sike (942198), shows that the eastern portion of the fault runs further north than they have placed it. It seems, therefore, that the strike fault is continuous. There may still be the short W.N.W. fault because there is certainly a drop in level of the Botany Limestone from Hazelgarth Rigg to Rokehole Sike, but as this may also be due simply to a steepening of the pitch of the syncline, the fault has been omitted from the present map.

The second important E.N.E. fault runs through How Beck Head where two branches are seen. The maximum downthrow to the south is over 100', since the Botany Grit of Goldsborough at about 1250' O.D. is dropped below Yawd Sike which runs at 1150' O.D. Towards How Beck Head the displacement decreases so that the total effect of the double fault is about 60' - 70'. The beds against the fault show the drag effect of normal faults. East of How Beck Head the two faults diverge, the southern one changing its throw, for the Botany Grit on the north of Loup's Hill is some 20' lower than the Botany Grit on the south.

The last important E.-W. fault is the Hunder Beck Fault. It extends about 4 miles and is seen in three places. It can be found in Hunder Beck itself where the shale overlying the Coalcleugh Marine Beds is thrown against the Fossil Sandstone. The beds on either side dip away from the fault. At the foot of Coal Gill and in Crawlaw Sike the dip is to the north, though it is possible that the beds on the downthrow side do turn up again close to the fault itself. The maximum throw is about 150', a figure which is almost reached in both Hunder Beck and in Crawlaw Sike. Westwards it is lost under peat, and to the east its position is obscure, but it probably passes south of the shale exposed in Duck Sike. There is evidence that it has more than one branch, as in the old level (919165) two small parallel faults were put on the primary Geological Survey 6-inch map, and in Crawlaw Sike there are two faults trending N.E., the northern one downthrowing 40' to the S.E. and the southern one 8' to the N.W. The beds dip in the direction of throw in these cases.

The other main fault direction is N.W., there being three of these all downthrowing S.W. on the Botany Ridge. Their displacements are from west to east 50', 30' and 80' respectively, and they have the effect of cancelling out the pitch of the syncline along the Ridge. One stops at the E.N.E. Botany Ridge Rault and the other two almost certainly cut it. The mapping of all of them is fairly certain except that the exact position of the middle one is in places a little doubtful.

Practically all the remaining N.W. faults downthrow to the N.E. and are mainly associated with a steep dip in the same direction. They have been mapped in most cases to account for a considerable drop in level of a particular bed, and though there is usually corroborating evidence for a fault it is very difficult to say where the faulting begins and ends.

The most northerly of these N.W. faults is across Lunedale, the evidence for which is as follows. West of Bink House the height of the Little Limestone is known, from both surface exposures and a bore hole at Turner Holm, to be 200' higher than it is half a mile to the east. At Turner Holm, a spring, which is reported to steam in cold weather, comes from the solid rock, suggesting that the Great Limestone on the north or west is faulted against either the Coal Sills Group or the shale above the Little Limestone. Finally at Bink House the Rookhope Shell Beds, exposed west of the fault, cannot be found in the shale to the east and seem to have been faulted down.

Across Baldersdale just above the reservoirs there is a similar fault betrayed by the disappearance of the solid features so easily mapped north of the reservoirs, by very disturbed shale in the banks of the Balder and by the sudden disappearance to the S.W. of the sandstone at Clove Lodge. In approximately the same direction a third fault runs across the north of Deepdale, its position marked by a break in the features, and by a steep dip in a limestone, considered to be the Crow, in the stream itself. The Limestone forms a small anticline, the fault cutting through the crest of the fold. Finally there is the small fault which throws down the Great Limestone in the River Greta and in Sleightholme Beck.

In the south eastern corner of the map there is another N.W. fault which is rather conjectural, but there is a considerable drop in level to the N.E. of all the strata. It may actually continue further to the S.E. than is shown, as in line with it there is a similar drop in level of the sandstone below the Undersett Limestone at Robin Hood's Scar in the Greta just beyond the map.

Perhaps the most interesting of all the faults in this general direction is one running W.N.W. in the N.E. corner of the map. It is noticeable that there is a very great drop in level of all the beds between the fells above the railway and the Tees, similar to that which is caused by the Teesdale Faults further up the valley. For instance the Lower Felltop Limestone drops from 1000' O.D. at Wadycarr Sike to 600' in the Tees in the distance of 1¼ miles. Undoubtedly there is a considerable apparent dip to the east and this could explain the fall in level if it were not for the fact that all the solid outcrops end abruptly just above the railway and that there is a feature which looks very like a re-eroded fault scarp. In addition, the most easterly outcrop of the Grit Sills shows a sudden change of dip to one of 22° to the S.W., which almost certainly implies a structural disturbance not far away. To the N.W. the Teesdale Fault lies on a direct line with this fault, but to the S.E. no fault downthrown to the N.E. can be traced, though there is one with a 40' throw to the S.W. well exposed in the Tees itself.

The N.N.E. fault west of Goldsborough has been mentioned in the stratigraphy section as the old surveyors continued it across the Balder and on to the top of the Botany Ridge, but as has been stated, it would then cut through more than one marine band. Nevertheless it does exist south of the Balder, and shale can be seen against the Botany Grit in Yawd Sike, near Catty Crag Quarry. Its position otherwise is very conjectural especially at its southern end where its relation with other faults is uncertain. Another N.E. fault crosses the lower Balder. Its throw, shown by the coal seam below the middle grit is about 30' but it extends for more than a mile.

There are some small faults north of the Botany Ridge which do not need detailed description, and some very tiny ones on the banks of the Hury Reservoir which may be caused by surface slumping. In Deepdale there are small ones trending slightly north of east. The one at Strand Foot (977154) may be longer than it appears, as the beds to the north of it dip steeply away from the fault and the exact location as well as the direction of throw of the fault were difficult to determine. Further up Deepdale the E.-W. faults above Green How downthrow 35' and 50' respectively, both being exposed in the stream bank, the latter as a double fault.

The interpretation of the evidence near Sandy Hill compares well with that of the old surveyors except that an additional E.N.E. fault has been mapped as a result of the finding of the Little Limestone in Glasgow Gill. The effect of the other two faults is to raise up the small horst of Sandy Hill.

A similar pair of faults occurs in Hunder Beck bringing up the Rookhope Shell Beds. The S.W. branch has been mapped with reasonable certainty, but the one running E.-W. has been drawn through drift-covered cliffs to account for the sudden rise in level of the Lower Felltop Limestone which is exposed to the north. There are also other faults in Hunder Beck and its tributaries, besides the main E.-W. Hunder Beck Fault. The two in Coal Gill are rather uncertain as regards throw and direction, though the southern one probably downthrows north as the Coalcleugh Marine Beds, seen just upstream, do not appear north of the fault. The long W.N.W. fault can be seen in Hunder Beck where the throw is only about 12'. To the west it cuts off the loose sandstone feature of Slates Hill, formed by the sandstone below the Upper Felltop Limestone, and in Yoke Sike it cuts out the Coalcleugh Marine Beds and much of the shale above them.

Compared with the old survey map, there are a few additional faults, but many have been removed. Though there are one or two small faults whose existence cannot be proved or disproved, the majority of these alterations can be justified on stratigraphical grounds, the changes being due to a more detailed understanding of the stratigraphy than the old surveyors possessed. For instance, the faults on the east of the area, which they inserted to explain a situation which has now been shown to be a lateral change from a grit to a mixed facies, have already been mentioned in the stratigraphy chapters. Similarly, the throw of the How Beck Head fault in the opposite direction was due to a misunderstanding of the position of the Fossil Sandstone. The primary surveyors introduced a N.E. fault north of Crawlaw Rigg to explain the disappearance of the feature formed by the sandstone of the Coalcleugh Transgression Beds, but as this has now been shown to lens out in a few yards in Hunder Beck the fault has been omitted from the present map. South of Bowes two small faults are shown on the old map, but no evidence for them could be found. The drop in level of the Undersett Limestone needs only an apparent dip to the north of less than 4^{o} and yet dips of up to 45^{o} can be seen in the Undersett Chert of Chert Gill.

(iii) Dent Line Faults. The histogram portraying the fault directions associated with the Dent Line shows that the majority of faults lie between N.E. and W.N.W., the important N.W. trend of the east of the area being absent. If these fault directions are divided further into three parts the results are more significant. The average trend for the Lunehead Mine Faults is 060°, for the Borrowdale to Balder Beck Faults 075° and for the Stainmore Summit Faults 105°. In other words, there is a swing in a clockwise direction from north to south.

The mineralization of the Lune Head Mines has been described by Dunham (1948, pp. 316-318) and much of the mapping was dependent upon information obtained from his Mineral Survey 6" map sheet (Yorks. N.R. 3 S.E.) as it is no longer possible to go underground owing to a blockage in the Main Adit Level. The main effect of the faulting is to produce two troughs separated by a relatively uplifted block. In the northern trough Coal Sills are let down between the Great Limestone, but the faults bounding the trough coalesce and a single fault downthrowing south east continues on the Yorkshire side of the county boundary. The northern fault of the southern trough throws about 100' at Deadmangill Bridge and when continued into Yorkshire as Wensley Vein still has a throw of over 60' before it gives off numerous branches, all of which are mineralized. The southern fault of the trough has a throw, calculated by Dunham from mining information, of 96'. This is reduced to 30' in the twin branches of Cavern Vein, while in Little White Vein, which is in a direct line with the fault, a throw of 4'6" to the south is recorded. The effect of these two main faults in Dowcrag Sike is to cut out the Coal Sills and lower part of the Little Limestone and to repeat the outcrop of the Firestone Sill and Crag Limestone. In Westmorland there are in addition two N.N.W. faults throwing west.

Much of the Borrowdale to Balder Beck faulting has already been described by Turner (1935), and on the whole the present re-survey agrees with Turner's mapping. However, a more detailed examination of the stratigraphy and the continuation of the mapping into Yorkshire have produced some modifications in the fault pattern.

The most important change is the continuation eastwards of the down-faulted block or graben some distance into Yorkshire. The north side of the graben, at the junction of Birkbeck Gill with Borrowdale Beck, is a single fault throwing the Upper Stonesdale Limestone against the Crow Limestone. Thus the throw is about 110'. In a westerly direction the fault cuts through all the strata down to the Four Fathom Limestone, though the throw is reduced. However, two branches are given off, both throwing to the south so that the overall effect is much the same. There is some slight disagreement with Turner as regards the exact position of these two side branches. For instance, the present survey showed no grounds for throwing down the Little Limestone in two stages and so both the branch faults are now shown to join with the main fault below this horizon. In addition, the southern branch is considered to join the main fault below the top of the Lower Coal Sill as on Turner's map it appears to pass through the well developed grit feature of the Lower Coal Sill.

At the junction of Birkbeck Gill with Borrowdale Beck, an E.-W. fault crosses the E.N.E. fault, the latter continuing to just beyond the County Boundary. The mapping of these faults is based mainly on the tracing of the fossil grit below the Upper Stonesdale Limestone, but the throw can also been seen to affect the Transgression Beds Grit. The E.-W. fault is conjectured through Mile Rigg Moss, but between Balder Beck, where the Fossil Sandstone outcrops, and Black Beck, where Transgression Beds Grits are exposed, a fault must occur throwing south, and this can be continued across Black Beck and a short way down the River Balder throwing down the Upper Felltop Limestone and the Coalcleugh Transgression Beds. The Upper Felltop Limestone is not exposed north of the fault though its position is inferred from the underlying non-marine beds. This failure of the Upper Felltop Limestone to outcrop on the north side of the fault, and the irregular nature of the shales and sandstones of the Coalcleugh Transgression Beds, makes the tracing of the fault very difficult, but it appears to have two branches where it crosses Black Beck, the northern one possibly continuing further than is shown on the map.

The fault on the southern side of the graben was shown on Turner's map to start just below Borrowdale Beck, throwing down the Four Fathom Limestone to the N.N.W. and continuing through Wham Mouth until it met a S.E. fault which ran from the north side of the graben. No positive evidence could be found for this S.E. fault, though, unlike the old surveyors who drew a similar fault straight through a large feature, Turner places it across low lying ground. However, the finding of the Fossil Sandstone in Balder Beck makes its existence most improbable, as a fault at this point would necessitate a repetition of the succession through the Transgression Beds Grits between this S.E. fault and the Fossil Sandstone and there is no evidence that thick grits occur there. This fault has therefore now been omitted and in addition a break is shown in Turner's continuous fault from Borrowdale Beck to Wham Mouth as, when the Great Limestone and in particular the coarse Lower Coal Sill are followed below Low Crag into the beck above Penistone House, they can be seen to drop in level to the S.E. This makes a fault, downthrowing north, improbable north of the beck. Instead a fault has been drawn in south of the beck which throws up the strata to the south, and this fault can be traced past Longcrag House up into the Transgression Beds Grits. Near Longcrag House the main fault starts, continuing through Wham Mouth into Balder Beck. Its direction is mainly determined by the mapping of the Transgression Beds Grits but sandstone is seen to be faulted against shale at Wham. Beyond the County Boundary the Fossil Sandstone is found to be downthrown to the level of the Upper Felltop Limestone, the outcrop of which is repeated in Great Aygill Sike.

There are also some minor faults in the Balder Beck area. One runs N.W. across the main E.-W. fault in Balder Beck throwing down the Fossil Sandstone and Upper Felltop Limestone to the S.W. Another fault cuts across the outcrop of Upper Felltop Limestone in Stony Sike probably upthrowing it to the S.W. Near Red Gill Moss a third fault throws up the sandstone below the Upper Felltop Limestone against a limestone, which, though only loose pieces were found, is considered to be the Upper Felltop.

Near Cumpstone House a smaller graben is dropped down as described by Turner. The northern fault is mineralized and extends from below the Four Fathom Limestone to above the Crow Limestone, but does not appear to let down Lower Stonesdale Limestone. The southern fault is shorter, meeting the northern fault before it reaches the Little Limestone. At its western end it is cut by a N.N.W. fault which throws down the Four Fathom Limestone to the west.

A small fault at Slapestone Bridge downthrows the Four Fathom

Limestone to the west but does not penetrate the Great Limestone, and near Brown Castle another larger fault throws down the whole succession from the Great Limestone to above the Little Limestone in a westerly direction. Beside the main road the Great Limestone is seen to be at a higher level on the east side of the fault than the Tumbler Beds on the west, and a similar drop in level occurs to the Coal Sills feature and the Little Limestone. This fault has been joined to a N.E. fault running parallel with Yard Sike. The latter fault is less certain as the drop in level of the Ten Fathom Grit towards the N.W. could partly be explained by the steep dip in that direction which is clearly seen near the Old Quarry (876138).

In the S.W. corner of the map some faulting is shown, but as no difference was found between Turner's map and description and the present survey they will not be discussed and are not included in the statistical analysis. However, it should be mentioned that the Clattering Fault, seen on the map at Clatteringdike Nook, is a S.E. fault downthrowing N.E. and extending into Yorkshire, thus forming the south side of another graben whose northern boundary is the Stainmore Summit Fault.

The Stainmore Summit Fault starts west of the present map at Low Dowgill and can be followed below Slapestone to Palliard Scar where the beds on the downthrown side dip away from the fault. 400 yards to the E.S.E. it runs through the Great Limestone, but the beds on the upthrown side dip at 40° away from the fault. This dip persists some distance to the east, it being seen again in the stream below the Great Limestone quarry on the road where the Tuft Sandstone north of the fault dips steeply away from the Tumbler Beds on the south.

The fault is again exposed in the railway cutting on the summit of the pass throwing the fossil sandstone of the Lower Coal Sill against the Great Limestone, but beyond The Summit a branch diverges towards the S.E. downthrowing to the north. The result is another graben. The old Geological Survey map shows the graben extending only about 2½ miles, but the evidence of the present survey suggests that the northern fault splits into two branches, one of which can be followed as far as Sleightholme Beck. Between the County Boundary and Aygill Cottages the Little Limestone and Upper Coal Sill are well exposed in the headwaters of the River Greta, with the Main Limestone on the slopes above on the upthrown side of the fault. Beyond Aygill Cottages the tracing of these northern faults is more difficult. In the River Greta below Spital High Cottages a carbonaceous sandstone which is probably at the top of the Lower Coal Sill was found quite close to the Main Limestone suggesting that a fault runs between them downthrowing south. In addition in the beck (932114) there is a limestone considered to be the marine band above the Lower Coal Sill which dips to the N.W. at 4°. When this dip is projected it should outcrop near the carbonaceous sandstone. Yet the Main Limestone outcrops in the bed of the River Greta at the same level just to the north. Thus the evidence seems fairly conclusive for continuing the northern branch of the Stainmore Summit Fault in its original direction beyond Aygill Cottages.

There are, however, two branches of this northern fault. For the other one there is little concrete evidence except that beds up to the Crow Limestone are exposed to the south of Aygill Cottages and it is not possible to explain the occurrence of the marine band above the Lower Coal Sill at the same height just to the north without a fault between them. Beyond the boundary of the map this

Lower Felltop Limestone is downthrown against the Four Fathom Limestone giving a displacement of about 650' at the bridge, but just beyond the map on the Durham side of the River Tees the throw is increased to over 750' for it appears that the Fossil Sandstone is brought against beds below the Great Limestone. The fold structure here is of interest for though the general dip is towards the south or S.E., near Eggleston Bridge there are two small anticlines, the southern one a rather gentle flexure, the northern one very steep, and the fault runs through the crest of this steeper anticline.

The Lunedale Fault zone can be traced into Durham where, in the neighbourhood of Ferryhill, it is known as the Butterknowle Fault. Hickling (1950) states that the Butterknowle Fault affects both Permian and Coal Measure strata. A consideration of the structural maps which accompany his paper shows that the adjacent folding esentially consists of two anticlines with the fault downthrowing south and running through the intermediate syncline. The form of the folding and the displacement direction of the fault are the same for both pre-Permian and post-Permian movements, though the effect of the former was greater. Thus the final result is the sum of the two movements.

This pre-Permian and post-Coal Measure displacement of the fault to the south would appear to contradict the general view (Dunham 1948, p.75) that the Alston Block was depressed relative to surrounding areas in Hercynian times, at least as regards the Lunedale Fault. However, a closer inspection of Hickling's map of the pre-Permian structure reveals that though the fault itself throws to the south, the effect of the adjacent folding is to raise the strata towards the south since both of the anticlines have steeper northern limbs. Thus the total result is to depress the strata north of the zone of faulting and folding.

(d) Mineralized Veins.

Mineralization in this area is mainly confined to the Lunehead Mines which are described in detail by Dunham (1948). He shows that the mines contain barite, some witherite, galena and aragonite. No fresh information concerning the mineralization was obtained during the present survey in spite of modifications to the stratigraphy made during the mapping.

Elsewhere, the only mineralized veins are at Cabbish Mine and in Hunder Beck. At Cabbish Mine several veins containing barite and galena were penetrated by adits (Wilson and others, 1922) but their exact location could not be fixed from the surface evidence. One of the faults, the Cabbish Vein, is certainly mineralized and a great deal of barite was found in the stream north of the fault which runs N.E. through Longcrag House indicating it may also be mineralized.

The long E.-W. Hunder Beck Fault is mineralized for ½-a-mile west of Coal Gill and a little barite was found at the surface. Old Levels were made on either side of the mineralized part of this fault, but it is unlikely that they were successful as no loose ore could be found around their entrances. On the Old Series Geological Map 102 S.E. a short vein is shown trending E.N.E. just north of the junction of Coal Gill with Hunder Beck. No evidence could be found of this vein or of any workings at this point and it was not shown on the primary 6" map.

(e) Jointing.

Though the rocks in this area are not well enough exposed for a really satisfactory examination of the joint directions, an attempt was made to record the directions of jointing in the limestones. No joint directions were taken for sandstones or shale as they were usually found to curve very rapidly. Exposures of a minimum area of 4 square yards were used for the limestones, the distance apart of each record being at least 20 yards.

All the joint directions taken were plotted on the structural map, using 10^{o} intervals, and they are also shown in the histogram (Figure 17) at 5^{o} intervals. As the result for the total showed no significant trends, an attempt was made to sub-divide the joint records in the expectation that the dominant trends might change in different parts of the area. The result was not very successful, no dominant directions occurring in any of the separate histograms. In the Lunedale and Windmore End area, however, there is a tendency for the joints to concentrate in N.N.W. and E.N.E. directions, similar to the dominant joint directions found by Dunham (1933) in the Great Limestone of Weardale, but they spread over a much wider angle.

The remaining frequency curves show three main directions of jointing, two at right angles, and the third approximately bisecting the angle between the other two. In the centre of the area the directions are N.-S., E.-W. and just west of N.W. In the Crow Limestone of Deepdale they are N.W., N.E. with some covering a broad angular range around E.-W. In the Greta River, the joint directions on the Main Limestone lie mainly between N.N.E. and N. and between N.N.W. and N.W., with a large number around W.N.W.

Although nothing very definite was obtained about dominant joint directions, it is significant that there is an absence of jointing between 010° and 025°. Dunham (1933) following the hypothesis of Wager (1931), considered that the joint directions are symmetrically disposed about the direction of maximum pressure. From the evidence of the E.-W. Bewcastle Anticline which is also of early Hercynian age, he concluded that the general direction of pressure was north-south. Thus the absence of jointing in a N.N.E. direction, but its presence in a W.N.W. direction confirms this opinion.

(f) Discussion.

Since the strata mapped in this area lie almost entirely within one zone of the Namurian, the structural history of the area can only be considered by relating it to surrounding districts. The sequence of events in these districts was given above (p.147).

During early Carboniferous times the Alston Block was uplifted relative to the surrounding districts, shown by deposition of C_1 beds south of the Swindale Beck Fault, while north of it no beds earlier than S_2 have been found (Shotton, 1935). This relative movement appears to have continued during Eumorphoceras-zone times as the total thickness of strata is considerably greater than that deposited on the Alston Block. This is clear from the comparative sections for Alston and for this area shown in Figure 16. The figure does not bring out the thickness differences between the Stainmore Area and the Askrigg Block as the N.W. Swaledale section is very generalized, but Rowell (1953) has produced evidence for a similar decrease in thickness towards the south.

This conception of the Stainmore Area as a trough between the stable blocks of Alston and Askrigg is further emphasized by the absence of any definite direction of joints in the limestone of this area. It is true that Wager (1931) was unable to find constant joint directions in the rocks above the massive facies of the Great Scar Limestone north of the Craven Faults, but Dunham (1933) showed quite clearly that the joints run consistently in the Great Limestone on the Alston Block. It is probable, therefore, that while the rigid mass of the Alston Block was fractured along definite planes, the regular joint pattern gradually disappeared in the more flexible Stainmore area, though in Lunedale the joint directions still resemble those of the Alston Block, and there is throughout the area a conspicuous lack of joints in the N.N.E. direction.

Apart from the formation of master joints, this N.-S. compression had little effect on the Alston Block, although some small E.-W. folds were produced. In the Stainmore Area an asymmetrical basin was formed in the north with an elongated dome in the south. Other E.-W. folds were formed on the Askrigg Block, for example along the north side of Upper Swaledale.

Following the depression of the Alston Block relative to surrounding areas, E.N.E. compression produced the thrusts of the Cross Fell Inlier and the Burtreeford Disturbance. The Cross Fell Inlier thrusts are believed to be the continuation northwards of the disturbances known as the Dent Line (Turner 1935), which in a restricted sense is a belt of vertical and inverted strata running from Wharton Fell, 7 miles south of Brough, to the Cross Fell Inlier. West of the present area at Low Dowgill beds of the Dent Line are so strongly folded that Turner (loc. cit.) considered that the rigid block offered exceptional resistance at this point, which seems to imply that the Stainmore Area is still part of one of the stable blocks. It is apparent, however, that the Dent Line has here been pushed to its most easterly point, and it is suggested that the Stainmore Area may have moved east relative to the more stable areas until the drag effect of the resistance to the north and south prevented any further movement, the inverted strata at Low Dowgill being due to the concentration of pressure at this point. The faults described above as 'Dent Line Faults' acted as tears, as Turner says, the irregularity of the dips near the faults showing that at some time the beds were affected by considerable horizontal stress.

The case for conceiving the Stainmore Area as a less rigid area than the Alston Block is weakened by the absence of any structure of the size of the Burtreeford Disturbance. This is an east-facing moncline, probably caused by the same E.-W. compression which produced the Dent Line. It is possible that the N.N.W. zone of folding and faulting downthrowing E.N.E. in this area is a similar structure. This belt, however, does not affect the Great Limestone north of Lunedale and it appears to be a tension structure, the faults being normal and the folding much more gentle than that of the Burtreeford Disturbance. Its position is east of the Burtreeford Disturbance, though this displacement could be caused by a lateral shift of the Stainmore Area along the Lunedale Fault.

The age of the eastern faults is difficult to determine. Evidence from the Alston Block suggests that the Whin Sill shows no relation to previous structures except to the Burtreeford Disturbance and the Lunedale Fault. The eastern faults having similar trends to those of the Alston Block are probably related to them and can therefore be considered as post-Whin Sill and pre-mineralization. In this area the Hunder Beck Fault is slightly mineralized, and Dunham (1948) suggests that the mineralization is probably late Hercynian, though the possibility of a Tertiary age of the deposits (Trotter, 1944) must not be dismissed. No further evidence of the age of mineralization was discovered here, but it is thought that the eastern faults are distinctly earlier than the final Tertiary uplift, for the following reason.

The most striking difference between the Dent Line faults and the eastern faults is their relation to the topography. Every gap in the Westmorland scarp is directly due to faults in the solid rock. A graben runs along the Lunehead Pass, a single fault continuing into Yorkshire; there is a fault running across the low-lying ground of Shot Moss. Both Birkbeck Gill and Wham contain major faults and the Stainmore Summit Fault follows the lowest part of the pass. Between these breaks the scarp is continuous and exposure of rock is so good that it can be clearly demonstrated that no faults exist. The only exception is Yard Sike which runs down a gap north of Beldoo Moss. It is possible, however, that the N.E. fault shown on the map does continue farther to the N.E., no exposures being visible in that direction.

In contrast, the eastern faults play a very minor part in the topography. It is true that they cause minor breaks in the features but the major topographic outlines of the area are completely independent of the faults. There is not a single stream, even if its pre-glacial course is considered, which is influenced by the faulting. There may be a tendency for the faults to appear more frequently in the streams, but this is due to better exposure, the drift-covered ground between the streams hiding many unmapped faults.

This difference between the influence of faulting on the topography in the two parts of the area may be partly due to the relative steepness of the slope overlooking the Eden Valley, the short swift streams cutting down more rapidly along the fault lines than the more gradual streams to the east. Nevertheless this explanation alone is not entirely satisfactory, mainly because, as Fawcett (1916) showed, the passes were formed by eastward flowing streams, the headwaters of which were later captured by the steeper ones flowing down the scarp. In post-Triassic times, (Turner 1935), movement took place along the Dent Line raising the country to the east relative to the Eden Valley. This movement is certainly post-Triassic and presumably Tertiary. It appears that it also took place along the Hercynian tear faults of the present area, producing the series of down-faulted blocks already described. The drainage to the west concentrated along the freshly made fault lines, as did the easterly flowing streams in the western part of the area, but in the centre and eastern part a series of parallel consequents appeared, flowing in the direction of tilt of the block and quite unaffected by older faults, whose fault planes had either consolidated or were hidden by strata, probably Permian or Mesozoic, which were unaffected by the faults.

Thus the tectonic history of this area begins in the early part of the Lower Carboniferous with movement along the Lunedale Fault dropping the Stainmore Area relative to the Alston Block. The N.-S. Hercynian compression which followed folded the area into an elongated basin in the north with a corresponding shallow dome in the south, the formation of joints being very irregular compared with those of the Alston Block. Later pressure in an E.-W. direction produced tear faults diverging from the node of the Dent Line in a fan-wise direction, but produced no folds with a N.-S. axis.

During late Hercynian or early Tertiary times the faults of the eastern part of the area were formed, to be followed by a regional tilt towards the east along the lines of the Hercynian tear faults associated with the Dent Line.

The evidence of the joint directions and sedimentation suggests that the Stainmore Area was less stable than those areas to the north and south. It cannot, nevertheless, be regarded as a trough comparable in scale with the Bowland and Northumbrian depressions respectively south and north of Marr's Rigid Area. The inversion of the beds of the Dent Line at North Stainmore and the absence of any folds in a N.-S. direction suggests that considerable resistance was offered to the E.-W. pressure, though this apparent rigidity could be due to the protection provided to the Stainmore Area by the two stable blocks on either side.

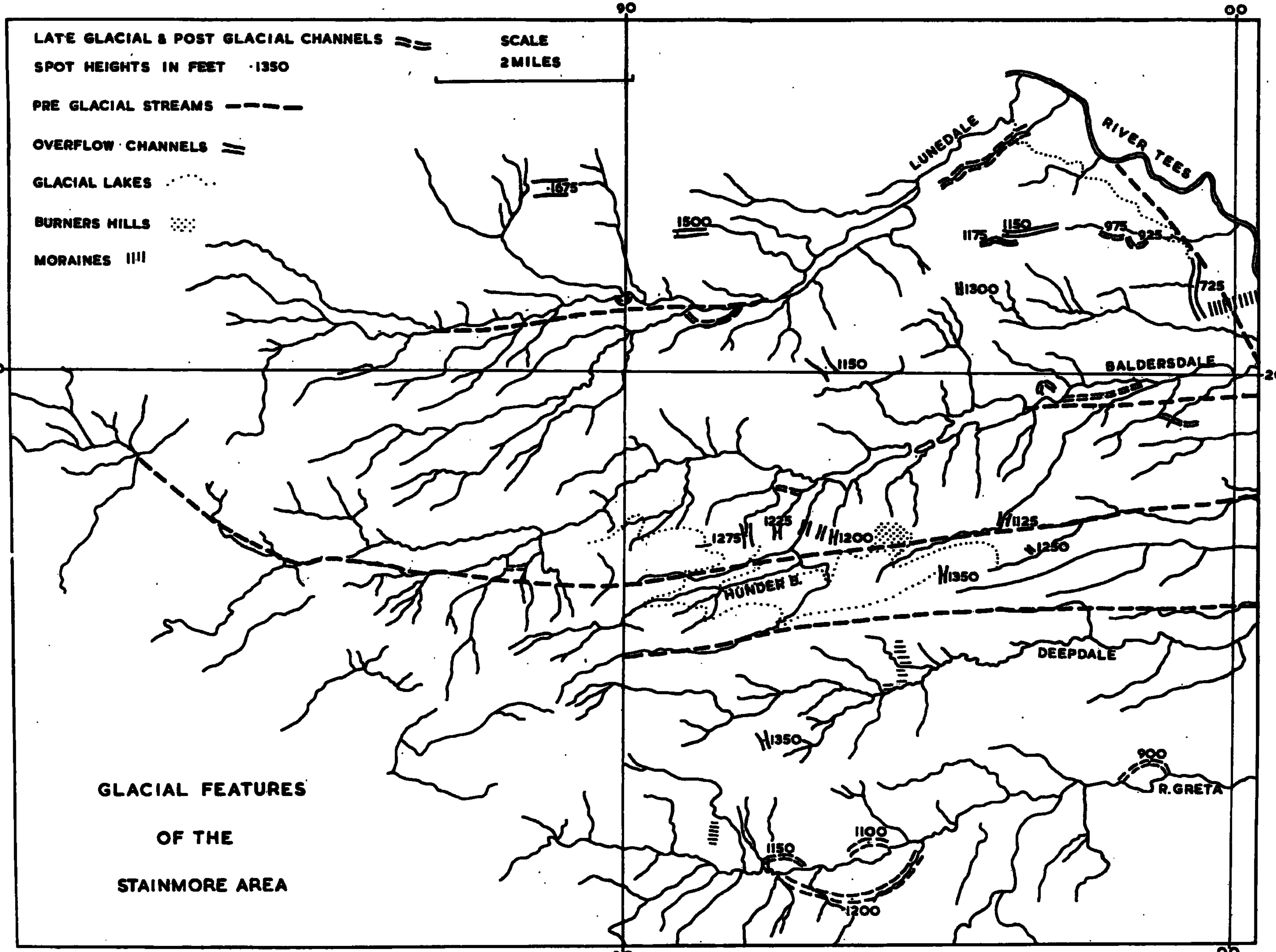

LATE GLACIAL & POST GLACIAL CHANNELS
SPOT HEIGHTS IN FEET ·1350
PRE GLACIAL STREAMS
OVERFLOW CHANNELS
GLACIAL LAKES
BURNERS HILLS
MORAINES
SCALE
2 MILES
90
00
20
LUNEDALE
RIVER TEES
BALDERSDALE
HUNDER B.
DEEPDALE
R. GRETA
1675
1500
1175
1150
975
925
725
1300
1150
1275
1225
1200
1125
1250
1350
1350
900
1100
1150
1200
GLACIAL FEATURES
OF THE
STAINMORE AREA

FIGURE 18

IV. TERTIARY, PLEISTOCENE AND RECENT.

(a) Pre-Glacial.

It has been suggested by Trotter (1928) that the Stainmore Area, in common with the Alston Block, was probably covered by a considerable thickness of Mesozoic deposits. These were removed during an early Tertiary cycle of erosion which reduced the area to a peneplain, and it was on this peneplain that the present drainage was initiated. The drainage of the Alston Block formed a semi-radial pattern, but in the Stainmore Area a set of parallel flowing streams trending just north of east were developed. This difference in drainage pattern in the two areas may be a reflection of the effect of the Tertiary uplift which in the Stainmore Area was probably a simple tilt to the E.N.E. Trotter also considered that the peneplain was directly connected with the structure and that, therefore, the uplift of the Alston Block was later than the formation of the peneplain. However, Dunham (1948, pp.64-65) has shown that the supposed peneplain (the existence of which he does not consider proved) cuts across strata from the Middle Limestone Group to the Coal Measures. Therefore, though there may have been movement since the peneplain was formed, the doming of the Alston Block was earlier than the formation of the peneplain.

The investigation of this area has shown that the formation of the Stainmore Syncline was pre-peneplain, since the form of the syncline has little connection with the topographical depression of Stainmore. The apparent similarities in the cross section of the Great Limestone and the peneplain which Trotter (1928) shows across the Stainmore Area are due to an incomplete understanding of the rock structure.

However, the tilt to the E.N.E. was evidently later than the peneplain, as the pre-glacial drainage can be interpreted as a series of parallel consequents developed on a peneplained surface which had been tilted to the east.

The courses of the pre-glacial streams are not easy to follow in an area which was later so extensively covered by glaciers, but it appears that the River Lune, Deepdale and the River Greta still approximately follow their earlier courses. Above the Grassholme Reservoir the River Lune may have originally followed a course south of its present position, and below the reservoir it may have run more to the north than it does now, but no pre-glacial channels were seen to prove this.

The River Greta and Deepdale, particularly the former, seem to have been so thoroughly eroded by ice that all traces of any pre-glacial channel have been removed. This is evident from the continuous outcrop of solid rock down Sleightholme Beck and across the River Greta to Rovegill and Sealgill showing that no pre-glacial channel occurs across the valley.

A pre-glacial channel can be traced below the Hury Reservoir in Baldersdale. It is south of the present River Balder and is apparent from thick deposits of boulder clay in the banks of the river just below the reservoir embankment. Below this point the present Balder runs through solid rock, but due east, in How Beck and Osmond Beck, there are breaks in the rock outcrop where only drift can be seen, thus showing that there once was a channel, running due east, which was later filled by drift.

Above the Hury Embankment it is not possible to trace the pre-glacial Balder, but as the present river above the reservoir runs through cliffs of solid rock it must have been well above the level of the present valley. Thus it does not appear that the Balder was a very important stream in pre-glacial times. A stream which was at least of equal strength was one which followed the line of the present Hunder Beck. Its course can be seen in Hunder Beck itself just above the junction with Mawman Sike. For about 150 yards glacial drift forms the walls of the gorge on either side of the stream, in contrast to the cliffs on either side of this stretch where over 100 ft. of solid rock are exposed.

This channel can be followed in an easterly direction between Goldsborough and Yawd Sike, south of How Beck Head and the grit of Loup's Hill. At this point there is a break in the continuous outcrop of Botany Grit from Hare Crag to Loup's Hill of 250 yards marking the old valley line. In Hunder Beck the pre-glacial river bed is lower than 1075' O.D., a height which is below the probable level of the pre-glacial River Balder at an equivalent point to the north. The reason for the dominance of Hunder Beck over the River Balder in pre-glacial times is that its headwaters included the present Tarn Gill and Crook Beck. Fawcett (1916) shows how the steeper western streams of Swindale Beck and Augill Beck captured Tarn Gill and Crook Beck respectively, both of which he considered had flowed into the River Balder. It is much more likely, however, that they at one time flowed into Hunder Beck since the present Balder is a late-glacial and post-glacial phenomenon which was developed after the Burners Hills lake had blocked the natural drainage of Hunder Beck.

Fawcett has also shown that at one time the River Tees flowed to the east down Langleydale and he considered that a subsequent of the Greta captured it in pre-glacial times and so formed its present course south of the Eggleston gap. He seems to imply that the pre-glacial course was identical with the present one, but this is most unlikely. At the junction of the Balder with the Tees they both cut down through high cliffs of grit. Just upstream from the junction the Balder flows through very thick drift deposits. Whether these drift deposits have filled in a glacial or pre-glacial channel, it is most improbable that the post-glacial river returned to a pre-glacial course, cut in solid rock, to the east. The reason for thinking that the Tees had a pre-glacial course in the present valley is the lack of wind gaps east of the Tees for the rivers draining the Stainmore area, and not the relative maturity of the present course of the Tees below Eggleston Bridge, as Fawcett suggests. The actual course must have been S.W. of the present one, but its exact position is impossible to determine.

(b) Glacial.

(i) General. The two main factors in the glaciation of this area are the Teesdale glacier coming from the high ground around Cross Fell and the ice from the Vale of Eden which crossed over the low ground of the Stainmore Area into East Yorkshire. Dwerryhouse (1902) has shown that at one time the Stainmore ice caused the Teesdale ice to be deflected into Weardale, but the evidence which has been collected during the recent survey of the Stainmore area suggests that though the Stainmore ice may have been the dominant one most of the time, there were periods when the Teesdale ice predominated. It is this relative dominance of one ice stream over another which is the main theme in the history of the glaciation of the Middle Tees.

(ii) Lunedale. Dwerryhouse (1902) has described how the Lunedale ice caused the formation of a series of glacial lakes on the north side of the valley linked by lateral overflow channels. These were mainly outside the area surveyed, but an overflow channel north of Sleight Edge, with a gravel fan just to the east, was noted, which marks the eastern margin of this series of lakes.

Lunedale is covered with drift more extensively than any other valley in this area, showing that this was probably the most important of all routes for the Edenside ice. This came from the direction of Lune Head Moss which has thick drift deposits, and not over the Lune Head Pass where no drift deposits were found.

On the south side of Lunedale, on the Botany Ridge, there are some overflow channels. There is a possible one east of Harker Hill at 1300' O.D., and two more certain ones running eastwards at

Toddyshaw Hill and Bail Hill. These are at 1175' O.D. and 1150' O.D. respectively and therefore are similar in altitude to a spectacular series, well seen from the Woodlands road, on the opposite side of Teesdale. Though a thorough survey of Teesdale may modify this view, it seems probable that these channels were formed by lakes collecting either side of the Teesdale glacier which obstructed normal drainage. The relative insignificance of the channels west of the Tees suggests that a glacier was still filling the bottom of Lunedale, but that it was less powerful than the Teesdale ice. They may be a little later than the lake series of north Lunedale and were formed not long before the flow of ice down Lunedale ceased, for at 1050' O.D., on Bail Hill, there are a great number of Whin Sill erratics. It is most unlikely that these were deposited by the Edenside ice since, though Whin Sill erratics were carried by it, they were rare. It seems certain that they came from further up Teesdale, for just across Lunedale there are extensive Whin Sill outcrops. Thus the Teesdale ice must have continued later than the Lunedale ice which would have removed the blocks had it been above that height at a later date.

(iii) Baldersdale. Like the whole Stainmore area, Baldersdale was at first completely covered by ice, even the highest hills on its flanks have thin coverings of drift and an erratic of the Borrowdale Volcanic Series was found on Goldsborough. However, the most interesting glacial phenomenon in Baldersdale are the irregular mounds, called Burners Hills.

These consist of a number of small rounded hills, extending about half a mile in each direction, with steep grassy slopes.

Undoubtedly they are glacial features, but the nature of the material which forms them is difficult to determine. On the Old Geological Survey Map they are labelled "sand and gravel" and this may be true. There are only a few poor exposures in the hills, but no glaciated boulders, as normally exist in boulder clay, were found. Instead there is a great deal of angular rock, mainly sandstone, suggesting the deposits of a glacial lake.

Their height is considerable, for they rise to over 1300' O.D. which is well above the surrounding country and is an altitude only surpassed by the tops of the ridges either side of Baldersdale. Thus the lake must have extended right across Baldersdale, the drainage of the area being blocked by the Teesdale ice. The possibility of Baldersdale ice forming the lake is precluded by the height of Burners Hills. On the south side of the lake there are two small overflow channels cutting through the Botany Grit at 1350' and 1250' O.D. On the north side of the lake there is the deep windgap between Kelton Hill and Jenny Quarries. The most likely explanation for this windgap is that it was formed as an overflow channel from this glacial lake. At first the Lunedale ice prevented any overflow northwards, for the height of the Botany Ridge is barely 1300' O.D., but as the Lunedale ice became lower the lake was able to spill over into Lunedale, cutting out this broad channel to just over 1150' O.D.

Just west of Burners Hills and north of Hunder Beck there are a series of overflow channels, draining to the north, from 1275' O.D. to 1200' O.D. There is a very clear one at Caper Gill, and the present course of Hunder Beck takes the line of an overflow channel, as does Yawd Sike at How Beck Head where the solid rock is cut through at right angles to the original stream direction. These overflow channels were the outlets of a lake which was dammed to the east by a tongue of the Teesdale ice penetrating as far as Long Rigg where drift now blocks the original pre-glacial channel of Hunder Beck at 1125' O.D. The ridge to the south was too high for the lake to escape, and to the north a small glacier in Baldersdale caused the formation of the series of overflow channels in that direction. The ice was limited to the Balder because the col at its head was some 50' lower than the col at Wham, at the head of Hunder Beck. The latter col was too high to allow much ice to surmount it.

Thus it seems that there was a re-advance of the ice down Baldersdale after the first retreat during which the Burners Hills lake was formed. This explains the comparative lack of glacial drift in Baldersdale itself compared with the ground to the south, for the later glacier would have removed the glacial deposits of the more extensive earlier glaciation.

(iv) Deepdale. Very little of interest was noted in Deepdale which has no extensive covering of drift. Knotts Hills, however, are small morainic mounds probably left by a retreating glacier and Glasgow Gill is an overflow channel at 1350' O.D., due to the obstruction of the natural drainage of Black Beck by the Deepdale and Greta ice.

(v) Greta Valley. Though the glacial deposits of the Greta Valley west of Bowes are less extensive than those of Lunedale, the erosive effect of the ice was at least as great. It formed a wide

U-shaped valley, removing all traces of the pre-glacial course of the Greta. West of Bowes, where the valley widens, the erosive power of the glacier was less strong and a pre-glacial course may exist.

150' above the valley bottom Spital Hill is formed by a long thin ridge of drift at right angles to the direction of the ice flow. It has the appearance of a terminal moraine but its height above the valley bottom, and the absence of any moraine in the valley bottom, suggest that it may have been deposited during the first retreat, the later advance removing all evidence of a moraine from the valley itself.

(vi) Teesdale. Only one side of Teesdale was surveyed and so no complete conclusion can be drawn from the evidence seen. There was, however, a lake at one time in Teesdale itself, shown by deposits of sand, overlain by boulder clay, N.E. of East Field House at 700' O.D. This lake may have been formed behind the large terminal moraine of Gueswick Hills, just east of the present map. West of this terminal moraine is a narrow channel in the drift at 725' O.D., through which the railway now runs. This appears to be a drainage channel from the lake which cuts round the side of the moraine. Just east of the moraine of the Gueswick Hills another channel was later formed at between 625' and 650' O.D. which is just west of the present course of the Tees.

V. CONDITIONS OF DEPOSITION.

(a) Cyclic Deposition.

Rhythmic deposition in the Lower Carboniferous of the North of England was first remarked upon by Miller (1887) although the sections drawn up by Westgarth Forster (1809) clearly show the rhythmic nature of the "Lead Measures" (Dunham, 1950). It was Hudson (1926), however, who first described the Yoredale rhythm in detail from the succession of the Middle and Upper Limestone Groups of Wensleydale. Brough (1928) showed that similar rhythmic deposition occurred in the Middle Limestone Group of Northumberland and suggested that it might also be found in the equivalent strata on the Alston Block.

This was confirmed by Dunham (1950) who gives a comprehensive historical account of rhythmic sedimentation in the North of England and describes in detail its application to the Lower Carboniferous of the Alston area. He states the succession in each cyclothem (rhythmic unit) as:

(7) coal;

(6) ganister or underclay;

(5) sandstone;

(4) sandy shale, shaly sandstone or 'grey beds' (interbedded shales, siltstones and sandstones);

(3) unfossiliferous, (? non-marine) ferruginous shale;

(2) marine shale;

(1) marine limestone.

This unit is essentially the same as that given by Brough, but differs from Hudson's rhythmic unit in the omission of both a limestone conglomerate between the marine limestone and marine shale, and a sandstone or coaly shale between the coal and marine limestone. It suggests, therefore, that these items in Hudson's succession are of purely local distribution.

Dunham also states that other members of the succession may be missing or of restricted occurrence, particularly the coal and the marine shale. Since the limestone is the most persistent member and its commencement shows the most striking break in conditions, he follows Brough in taking it as the basal member of the unit.

In the Upper Limestone Group, as both Dunham and Hudson have shown, the cyclothem is less regular. The position of the limestone in the rhythm may be taken by marine sandstones or shales and unconformities or washouts occur at the base of sandstones, which are frequently transgressive. Nevertheless, crude rhythms, which are basically similar to those of the Yoredale cyclothems, can be discerned right up into the Millstone Grit and Coal Measures.

In the Stainmore Area the rhythmic units are imperfect, and many of the cyclothems employed as units for descriptive purposes in this work are actually composite cyclothems since they contain more than one marine band, though the minor marine bands may only occur locally. The most obvious examples of minor marine bands are in the Coal Sill Group and in the Upper Stonesdale Cyclothem. There may also be more than one arenaceous band in the unit, such as is found in the Upper Stonesdale and Fossil Sandstone Cyclothems, with no marine band to separate them.

In the Stainmore Area perhaps the most noteable exception to the standard unit is at the base of the marine horizon. Mention has been made (pp. 47 and 83) of the difficulty of distinguishing the limestone from the sandstone at the base of the Little and Upper

Stonesdale limestones since marine fossils occur in the top of the sandstones, and it is equally difficult to distinguish the sandstone with fossils from that without fossils. This fact suggests that there is not always a clear cut base to the marine horizon. Another point that was noticed was that in those marine bands which contained limestone there were marine beds, formed of shale or sandstone, below the basal limestone. For instance, the Crow Limestone is usually sandy at the base and the Lower Stonesdale Limestone is usually muddy. Johnson (personal communication) has recorded very fossiliferous shales, 2" - 3" thick, between the bottom of both the Great and Undersett Limestones and their underlying coals in the Mount Pleasant Bore. On the surface the contact is so seldom seen that this fossiliferous shale goes unrecorded, but in Windmore End Quarry a "fine-grained, black, slightly cherty limestone - 2" thick" was noted at the base of the Great Limestone (p. 33).

Miller and Turner (1931) have also emphasized the transition of sandstone into limestone both vertically and laterally in certain horizons in the Dent Fault and Shap Districts. They suggested that the apparent superposition of limestone on coal was coincidental since coal requires a roof of clay or sand for its formation and that this must have been removed by erosion in those places where limestone lies directly on coal.

The evidence from the Stainmore Area agrees with this suggestion. Coals at or near the top of the cyclothem are quite rare, and occur more frequently lower down the cyclothem. However, where they do occur at the top, such as below the Upper Felltop Limestone, a roof is found above the coal, and it is only below the

Great Limestone and the Four Fathom Limestone that limestones appear to lie directly on top of coal. Miller and Turner's suggestion that the roof is removed by erosion prior to the deposition of the limestone does not appear possible since the coal beneath the Great Limestone retains a persistent thickness for a considerable distance. Possibly, therefore, the fossil shale above it may be the roof of the coal seam.

The absence of a definite break beneath the limestone suggests that it is not the ideal base of the cyclothem. In the Coal Measures, Edwards and Stubblefield (1947) use the base of the coal; Weller (1930) in the Pennsylvanian of the central United States, takes the sandstone as the basal member because it is unconformable on lower beds. This is a possible base in the Stainmore Area, for many sandstones have been shown to be transgressive, and in the field it is normal to map the sandstone and overlying limestone of a different cyclothem at the same time since they are the best exposed parts of the succession. On the other hand, some sandstones do not have transgressive bases, grading up from non-marine shale below, and most of the sandstones are lenticular bodies which do not extend throughout the area, in contrast to the marine beds which usually are persistent. Thus the base of the cyclothem has been taken at the base of the marine beds, a line which can always be approximately defined even if it is difficult to separate marine from non-marine strata exactly.

(b) Conditions of Sedimentation.

Dunham (1948, p.54) describes how many of the lower limestones of the Middle Limestone Group of Alston coalesce southwards to form a continuous marine series with no intervening non-marine strata. Above the Middle Limestone, however, he considered that the contrary was probably the case since the non-marine portions of the Five Yard, Three Yard and Four Fathom Cyclothems appear to be thicker on the Askrigg Block than on the Alston Block and the Iron Post Cyclothem did not appear to be represented on the Askrigg Block. The present survey has shown, however, that as regards the Four Fathom Cyclothem this may not be true, since in Swaledale there is probably a continuous marine series between the Undersett (Four Fathom) Limestone and the Undersett Chert, the latter being in part the equivalent of the Iron Post Limestone. In addition, a continuous marine series between the Main Limestone and Little Limestone is probably the equivalent of a composite cyclothem on the Alston Block. Thus the beds above the Four Fathom Limestone show a similar dying out of the non-marine members of the cyclothem towards the south.

This suggests that the marine invasions came from the south, but the true direction may be the south-east, for Miller and Turner (1931) found that, in the Middle Limestone Group on the west of the Askrigg Block the limestones thicken, and the intervening strata thin towards the east. Hudson (1941) noted that the marine horizons of the Upper Limestone Group in the Roddymoor Bore were more calcareous than those in either Alston or North West Swaledale. In addition, an examination of the Mallerstang Memoir (1891) seems to show that in the west of the area described the succession is more akin to the Alston succession with the chert horizons of lower Swaledale absent in the Undersett and Main Cyclothems.

In the Stainmore Area the Crow Limestone is thickest in the south-east, near Bowes, and there is a complementary thickening northwards of the non-marine portion of the cyclothem, particularly the Grit Sills. On the other hand, the Knucton Shell Beds are present to the north but not to the south, though as they die out to the west as well as to the south the marine invasion may have come from the north-east. The non-marine strata of the Lower Stonesdale Cyclothem thicken northwards, though over a limited area there is a marine horizon, the Rookhope Ironstone, within them. The Mirk Fell Ironstones, however, apparently die out to the north and east.

Thus up to the disconformity below the Coalcleugh Transgression Beds and Transgression Beds Grits the evidence shows that the marine incursions came either from the south or east. Those marine bands which do not appear to conform to this are probably local exceptions. The Knucton Shell Beds and Rookhope Ironstone may well have come from the east, and an original extension of the Mirk Fell Ironstones south and east of the Stainmore Area may be obscured by their removal by the overlying transgression.

Above the disconformity conditions appear to change, for the non-marine strata become considerably thicker towards the south. This is due to the earlier onset of Millstone Grit conditions on the Askrigg Block. Though palaeontological information is too scarce to be precise, the change of facies in the Stainmore Area took place at approximately late E_1 or early E_2 times. In the south of the Askrigg Block, however, the basal fluvial-grit, the Grassington Grit, had already been deposited, the equivalent probably of strata below the Mirk Fell Ironstones. Dunham (1950) has suggested that the sandstone-filled washouts of the Upper Limestone Group of the Alston Block may be some of the sources of the thick grits of the Mid-Pennines. It is not possible to link individual wash-outs with bands of the Millstone Grit below the Upper Stonesdale Limestone, but above that horizon there is evidence from the Stainmore Area in support of Dunham's suggestion.

The mixed facies of the Coalcleugh Transgression Beds of Alston has been shown to pass laterally into the grit facies of the Transgression Beds Grits within the Stainmore Area. The map (Figure 9) shows how the mixed facies extends through the centre of the area, with grit facies on the flanks. The transition on the south must occur between the Stainmore Area and North West Swaledale. The mixed facies can be considered as the deposits of a broad southward flowing river which carried down the coarse sediments which were laid down on its flanks and at its extremity as deltaic accumulations. At times of relative stability coals were developed on the delta surface.

There is a local marine horizon in the north, the Coalcleugh Marine Beds, whose source is obscure, but the marine invasion of the Upper Felltop Limestone advanced over the whole area. This may have come from the south since it persisted in North West Swaledale for a longer period than on the Alston Block or in the Stainmore area, for non-marine beds are found between the Upper Felltop Limestone and the Fossil Sandstone, instead of a continuous marine series between the two, as in Swaledale.

The equivalence which has been demonstrated of the Botany Grit with the First Millstone Grit of Durham shows that Millstone Grit conditions had by this time set in over the whole area, though the overlying Botany Limestone suggests a return to Yoredale sedimentation. This does, however, emphasize the difficulty in distinguishing any one horizon at which it can be said there is a major change of facies. There is no doubt that a change of facies takes place between the Four Fathom Limestone and the Botany Limestone and the most striking change of conditions occurs at the disconformity in the Upper Stonesdale Cyclothem, but it is not a sharp division between a Yoredale and Millstone Grit facies.

(c) Breaks in Deposition.

The picture that Chubb and Hudson (1925) drew of an unconformity between the Yoredales and the Millstone Grit of the northern part of the Askrigg Block is too simple to explain all the evidence which has since been obtained from that area (Rowell, personal communication). It appears that there are several horizons at which strata have been removed by erosion, such as between the Main and Undersett Limestones, beneath the Mirk Fell Ganister and beneath the Kettlepot Ganister.

On the Alston Block Dunham (1948) and Carruthers (1938) have given details of 'transgressions' in the Coal Sills Group, beneath the Grit Sills (the Rogerley Transgression) and beneath the Coalcleugh Transgression Beds. It has been shown in the Stainmore Area that other sandstones may also be locally transgressive.

Evidence has been given of transgressions beneath the Tuft Sandstone; beneath all three of the Coal Sills; beneath the upper part of the Ten Fathom Grit; beneath the Coalcleugh Transgression beds and Transgression Beds Grits, and beneath the Botany Grit (First Millstone Grit of Durham). The latter two in the Stainmore Area are undoubtedly more substantial than the remainder and one does partially remove the underlying marine horizon, but nevertheless they are not of a size which warrants the term unconformity, since there is no angular discordance of dip between them and the lateral extent is not very great. For instance, the Rogerley Transgression of the Alston Block is the most important in that area (Dunham 1950) but it does not extend throughout the Stainmore Area. Dunham considers that this is a sandstone-filled washout which is probably correct in this instance, but a more general term with no genetic implication is required to describe those cases whose origin is more obscure.

The term 'transgression' does not seem entirely suitable, since while the sandstone base may be described as 'transgressive', 'transgression' implies a phenomenon of a more widespread nature than these relatively local affairs. 'Non-sequence' is normally employed to describe a break in the succession of palaeontological zones. Grabau (1924) has proposed the term 'disconformity' for a 'stratic' unconformity in which there is an erosion interval but no structural discordance between two sets of strata. It is here suggested that this is the most suitable general term for the Yoredale and Millstone Grit depositional breaks.

APPENDIX I.

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APPENDIX II.

PETROGRAPHICAL NOTES.

Slices were examined of representative rocks in the Stainmore Area.

(45) Quarry Hazle from Borrowdale Beck.

A massive micaceous sandstone consisting of about 85% of subangular quartz with a grain size varying from 0.05 to 0.2 mm. and showing undulose extinction. Cloudy orthoclase and a few grains of plagioclase, mainly oligoclase, are also present. Cleavage fragments of muscovite are scattered throughout the rock which contains some kaolinite.

(24) Great Limestone from Shields Beck.

A very pure limestone made up almost entirely of crystalline calcite with some interstitial iron staining. No organic material visible.

(199) Main Limestone from the River Greta.

A fossiliferous limestone composed mainly of crystalline and organic calcite but with some clay matter. The larger fossil fragments are partially silicified.

(198) Main Chert from Rovegill.

A massive calcareous chert with alternate dark and light bands. In a groundmass of cryptocrystalline silica and microcrystalline calcite there are numerous carbonate rhombohedra which are particularly abundant in some bands of the rock. The dominant carbonate is dolomite with some ankerite. A few organic fragments can be seen which include sponge spicules, mainly composed of recrystallized silica, besides some calcareous organisms. Thin veins of chalcedony and calcite penetrate the rock.

(46) Lower Coal Sill from Borrowdale Beck.

A coarse grit consisting of rounded grains of quartz with a grain size ranging from 0.01 to 2 mm. Some pegmatitic quartz is present but mainly the grains show undulose extinction. The feldspars include orthoclase grains the margins of which are altered to kaolinite. Perthite and a little plagioclase also occur. There is a very little muscovite and some biotite.

(125) Top Marine Band in the Coal Sills Group from Lunedale.

Calcareous shelly sandstone consisting of up to 75% of angular, unsorted quartz grains mainly between 0.1 and 0.2 mm. in diameter but with a few larger grains. A little plagioclase feldspar, muscovite and organic calcite are also present. The grains are cemented by calcite and magnetite and pyrite is scattered through the rock.

(126) Little Limestone from Lunedale.

A calcareous sandstone consisting of about 50% of rounded and subangular quartz with a grain size ranging from 0.1 to 0.5 mm. There are some grains of zircon and muscovite and one of plagioclase feldspar. Organic fragments are seen and there is one foraminifera probably Endothyra. The cement is of calcite.

(76) Ten Fathom Grit from Ravock.

A slightly micaceous quartzoze, feldspathic grit consisting mainly of rounded grains of quartz showing undulose extinction with an average grain size of 0.25 mm. Andesine, orthoclase, hydrobiotite muscovite and zircon also occur. There is a little interstitial kaolinite and much limonite throughout the rock.

(183) Crow Limestone from No Name Beck.

A dark calcareous mudstone formed of finely divided mud and calcite with carbonate rhombohedra which may be ankerite. Tiny angular quartz grains crystalline calcite and phosphatic material are also present.

(140) Crow Limestone from Borrowdale Beck.

A hard dark ferruginous mudstone with calcite veins. The rock is a homogeneous mass of equigranular, brown carbonate, mainly siderite with some ankerite and a few tiny quartz grains.

(122) Above Crow Limestone from Shields Beck.

Sandy micaceous shale consisting of about 60% of angular quartz with a grain size varying from 0.1 to 0.05 mm. and 10% muscovite, cemented by dark clay matter and interstitial calcite.

(49) Lower Stonesdale Limestone from Borrowdale Beck.

A very hard dark siliceous mudstone composed mainly of cryptocrystalline silica and clay with a little microcrystalline calcite. Irregular, elongated pale bodies, probably worm burrows, occur which are filled by a calcitic clay which has been almost entirely altered to dolomite, rhombohedra of which can be seen in the pale bodies as well as in the groundmass of the rock.

(172) Lower Stonesdale Limestone from Borrowdale Beck.

A muddy limestone composed mainly of equigranular calcite which is slightly dolomitized. Shell fragments, preserved in calcite, and tiny quartz grains are seen in the matrix. Elongated ferruginous patches which contain some siderite rhombohedra also occur, and there are carbonaceous streaks along the bedding plane.

(210) Rookhope Shell Beds from Wester Beck.

A calcareous grit containing unsorted, rounded pebbles, ranging in size from 0.5 mm. to over 2 mm. They are mainly of quartz showing strain shadows, but some of the quartz is derived from quartzite. Pebbles of brown chert and phosphate also appear. The matrix is composed of calcite, mainly crystalline, and small angular quartz grains (c. 0.05 mm.). Clay matter is also present and calcite veins are seen to penetrate both pebbles and matrix.

(220) Rookhope Shell Beds from No Name Beck.

A siderite mudstone containing 30% of subangular quartz grains (c. 0.2 mm.) and chamosite ooliths set in a matrix of muddy siderite. The ooliths are composed of chamosite rings, with crystalline centres and are partially altered externally to a carbonate which is probably ankerite. Small fossil fragments preserved in calcite are also present.

(224) Lower Felltop Limestone from No Name Beck.

An ankerite mudstone containing 25% of subangular quartz and glauconite (c. 0.2 mm.) with a little organic calcite in a matrix composed of a carbonate which is mainly ankerite. The clastic matter occurs in layers.

(347) Mirk Fell Ironstone from Mickle Gill.

A fine-grained fossiliferous mudstone, composed mainly of cryptocrystalline calcite with some rhombohedra of dolomite and a few of siderite. There are occasional angular quartz grains about 0.05 mm. across and shell fragments of calcite are scattered throughout the rock. There are also circular brownish-green aggregates composed mainly of cryptocrystalline silica, but with a surrounding ring of calcite and with carbonate rhombohedra in the centre. Pyrite is disseminated throughout the rock which is penetrated by thin veins of calcite.

(22) <u>Mirk Fell Ironstone from Rowantree Beck</u>.

A calcite mudstone containing microcrystalline calcite and rhombohedra of ankerite with a few small angular quartz grains and organic fragments.

(535) <u>Transgression Beds Grit from Balder River</u>.

A coarse quartzose, feldspathic grit consisting of subangular quartz with a grain size varying from 0.1 mm. to 2 mm. Most grains show undulose extinction and have sutured edges. Pegmatitic quartz and quartzite pebbles are also present. Feldspars include orthoclase which is cloudy and sometimes altered to sericite, perthite and oligoclase to andesine plagioclases. All gradations of biotite altered to hydrobiotite can be seen. The rock is well cemented by kaolinite, some of which is the decomposition product of orthoclase. Magnetite and zircon also occur.

(606) <u>Transgression Beds Grit from Crag Pond</u>.

A medium-grained quartzose, feldspathic grit consisting of moderately well graded, subangular to rounded quartz grains with an average grain size of about 0.5 mm. Orthoclase, microcline and plagioclase feldspars are present and muscovite can be seen as well as biotite and hydrobiotite. The rock is well cemented by small quartz grains and kaolinite.

(364) Base of Coalcleugh Marine Beds from Coal Gill.

A chamosite mudstone consisting of c. 15% angular quartz (0.1 - 0.3 mm.) organic and phosphatic fragments in a matrix of microcrystalline carbonate which is mainly calcite, with a little ankerite. Chamosite ooliths have their margins replaced by a carbonate which is probably ankerite. Some of the fossil fragments have been altered to pyrite which is disseminated throughout the rock.

(365) Coalcleugh Marine Beds from Coal Gill.

A chamosite mudstone consisting of brown-green chamosite ooliths, superficially altered to carbonate, and phosphatic nodules in a matrix of microcrystalline ankerite and calcite. A few angular quartz and green glauconite grains are present, besides large organic fragments and streaks of pyrite.

(391) Coalcleugh Marine Beds from Mewmon Sike.

Sandy mudstone consisting of 45% subangular quartz with an average grain size of 0.2 mm. and glauconite in a matrix of muddy calcite and dolomite. Phosphatic fragments and chamosite ooliths are also present.

(379) Coalcleugh Marine Beds from Hunder Beck.

A chamosite mudstone consisting of glauconite, subangular quartz grains and chamosite ooliths in a matrix of fine-grained calcite and ankerite.

(442) Upper Felltop Limestone from West Carni Gill.

A muddy limestone consisting of fossil fragments of crystalline calcite in a matrix of mud and microcrystalline calcite, with some dolomite and a little ankerite. Some pyrite is also present.

(109) Upper Felltop Limestone from Howgill.

A dolomitized muddy limestone consisting of a few quartz grains and many calcareous fossil fragments some of which have been partially replaced by pyrite in a matrix of mud and microcrystalline dolomite.

Botany Grit.

Many rock slices were examined from the Botany Grit. They showed that it is a coarse quartzose feldspathic grit, loosely cemented and containing three types of quartz: rounded to subangular grains derived from pegmatitic quartz, quartzite and sandstone are present; grains from the latter show undulose extinction and the finer grains are frequently surrounded by secondary silica. The grain size varies from 0.1 to 2 mm. but some grains are considerably larger. Plagioclase feldspar is usually oligoclase or andesine and cloudy, sericitized or perthitic orthoclase is present. Microcline was present in about half the rocks examined. Muscovite is rare, but biotite and its decomposition product, hydrobiotite, are common. Pyrite, zircon, rutile, apatite, garnet and tourmaline have been found. Some interstitial kaolinite occurs but most of the cementing material is lost in grinding.

APPENDIX III.

FAUNAL LISTS.

Iron Post Limestone.

Aviculopecten ?	Smeltmill Beck	
Sanguinolites plicatus (Portlock)	"	"
Zygopleura rugifera (Phillips)	"	"
Nautiloid indet.	"	"
Trilobite pygidia.	"	"

Great Limestone.

Aulophyllum fungites (Fleming)
Corwenia ?
Dibunophyllum bipartitum bipartitum (McCoy)
D. bipartitum Koninckii (Edwards and Haime)
Koninckophyllum magnificum (Thomson and Nicholson)

Shale above Main Limestone.

Lingula squamiformis Phillips	Sleightholme Beck.	
Sanguinolites sp.	"	"

Marine Band above Middle Coal Sill.

Chonetes hardrensis (Phillips) group	River Lune	
C. (Semenewia) sp.	"	"
Nuculana attenuata (Fleming)	"	"

Little Limestone.

Chonetes hardrensis (Phillips) group	Borrowdale Beck	
cf. Composita ambigua (J. Sowerby)	"	"
Derbyia sp.	"	"
Orthotetid	"	"
Productus (Avonia) sp.	"	"
P. (Avonia?)	"	"
P. (Eomarginifera) lobatus J. Sowerby	"	"
P. (Eomarginifera) cf. lobatus var. laqueatus Muir-Wood	"	"
P. (Eomarginifera) cf. longispinus J. Sowerby	"	"

Little Limestone (contd.)

P. (Eomarginifera) setosus Phillips	Borrowdale	Beck
P. (Eomarginifera) sp.	"	"
Smooth Spiriferid spp.	"	"
Spirifer sp.	"	"
Spirifer trigonalis (Martin) group	"	"
Aviculopecten sp.	"	"

Faraday House Marine Band

Camarotoechia pleurodon (Phillips)	Grassholme	Bridge
C. pleurodon var. triplex? (McCoy)	"	"
C. sp.	"	"
Chonetes hardrensis (Phillips) group	"	"
Productus (Buxtonia) sp.	"	"
P. (Dictyoclostus?) sp.	"	"
P. (Eomarginifera) aff. Tissingtonensis cambriensis Stubblefield	"	"
Smooth Spiriferid	"	"
Spirifer bisulcatus J. de C. Sowerby group	"	"
Spirifer (Spiriferellina?)	"	"
S. trigonalis (Martin) group.	"	"

Rookhope Shell Beds

Liroceras sp. cf. L. liratum (Girty)	Bink House

Lower Felltop Limestone

Chonetes (Tornquistia) cf. polita McCoy	Crawlaw	Gill
C. (Tornquistia) sp.	"	"
Orbiculoidea sp.	Hunder	Beck
Orthotetid	"	"
Productus (Eomarginifera) lobatus J. Sowerby	"	"
P. (Eomarginifera) setosus Phillips	"	"
P. aff. (Sinuatella) sinuatus de Koninck	"	"
Spirifer sp.	"	"
Nuculopsis gibbosa (Fleming)	Crawlaw	Gill
Posidonia sp.	"	"
"Pleurotomaria" sulcata Phillips	"	"
Straparolus (Euomphalus) carbonarius (J. de C. Sowerby)	"	"
Straparolus sl.	Hunder	Beck

Mirk Fell Ironstones

Chonetes (Plicochonetes) sp.	Rowantree	Beck
C. (Tornquistia) sp.	"	"

Mirk Fell Ironstones (contd.)

C. sp.	Balder River
cf. Composita ambigua (J. Sowerby)	Mickle Gill
Derbyia sp.	Balder River
Orbiculoidea sp.	Rowantree Beck
Productus (Eomarginifera) cf. lobatus J. Sowerby	" "
Spirifer bisulcatus J. de C. Sowerby group	Mickle Gill
S. trigonalis (Martin) group	Balder River
Posidonia sp.	Rowantree Beck
Gasteropod indet.	" "
Trilobite pygidium	" "

Coalcleugh Marine Beds

Athyrid ?	Soulgill or Rowantree Beck
Brachythyris pinquis (J. Sowerby)	" " " "
Chonetes (Tornquistia) sp.	" " " "
Cleiothyridina sp.	" " " "
Productus (Eomarginifera) longispinus J. Sowerby	" " " "
Rhipidomella sp.	" " " "
Spirifer bisulcatus J. de C. Sowerby group	" " " "
Cypricardella sp.	" " " "
Edmondia aff. pentonensis (Hind)	" " " "
Edmondia sp.	" " " "
Nuculana attenuata (Fleming)	" " " "
Nuculopsis cf. gibbosa (Fleming)	" " " "
Palaeoneilo undulata (Phillips)	
Euphemites urei (Fleming) mut. ardenensis (Weir)	" " " "
Straparolus (Euomphalus) carbonarius (J. de C. Sowerby)	" " " "
Worthenia gairensis (Grey Thomas)	" " " "
Coleolus aff. carbonarius Demanet	" " " "
Orthocone nautiloid spp.	" " " "
Stroboceras sp.	" " " "
Tylonautilus nodiferus (Armstrong)	" " " "

Upper Felltop Limestone.

Zaphrentid indet.
cf. Composita ambigua (J. Sowerby)
Productus sp.
Soleniscus sp.
Fish indet.
Poecilodus jonesi McCoy.

Botany Limestone.

Hyalostelia parallela (McCoy)	Botany	Ridge
Aulina rotiformis Smith	"	"
Dibunophyllum bipartitum craigianum (Thomson)	"	"
D. bipartitum konincki (Edwards and Haime)	"	"
Zaphrentis spp.	"	"
Lithostrotion junceum (Fleming)	"	"
cf. Composita ambigua (J. Sowerby)	"	"
Leiorhynchus spp.	"	"
Martinia sp.	"	"
Phricodothyris sp.	"	"
Productus (Avonia) sp.	"	"
P. (Buxtonia) spp.	"	"
P. (Dictyoclostus) cf. antiquatus Phillips	"	"
P. (Dictyoclostus) griffithianus de Koninck	"	"
P. (Dictyoclostus) cf. muricatus Phillips	"	"
P. (Dictyoclostus) semireticulatus (Martin)	"	"
P. (Dictyoclostus) spp.	"	"
P. (Cancrinella) undatus Defrance	"	"
P. (Echinoconchus) cf. elegans McCoy	"	"
P. (Echinoconchus) punctatus J. Sowerby	"	"
P. (Eomarginifera) aff. derbiensis Muir-Wood	"	"
P. (Eomarginifera) cf. longispinus J. Sowerby	"	"
P. (Eomarginifera) setosus Phillips	"	"
P. (Jurazania) sp.	"	"
P. (Krotavia) cf. aculeata J. Sowerby	"	"
P. (Linoproductus) sp.	"	"
P. (Productus) concinnus J. Sowerby	"	"
P. (Pustula?)	"	"
P. (Sinuatella) sinuatus de Koninck	"	"
Reticularia ?	"	"
Schellweinella sp.	"	"
Schizophoria resupinata (Martin)	"	"
Smooth Spiriferid	"	"
Spirifer bisulcatus J. de C. Sowerby group	"	"
Fenestella aff. plebeia (McCoy)	"	"
Penniretepora sp.	"	"
Edmondia sp.	"	"
Lamellibranch indet.	"	"
Limipecten dissimilis (Fleming)	"	"
Paralledon sp.	"	"
Pecten s.l.	"	"
Shansiella cf. globosa (Grey Thomas)	"	"
Stroboceras cf. subsulcatus (Phillips)		

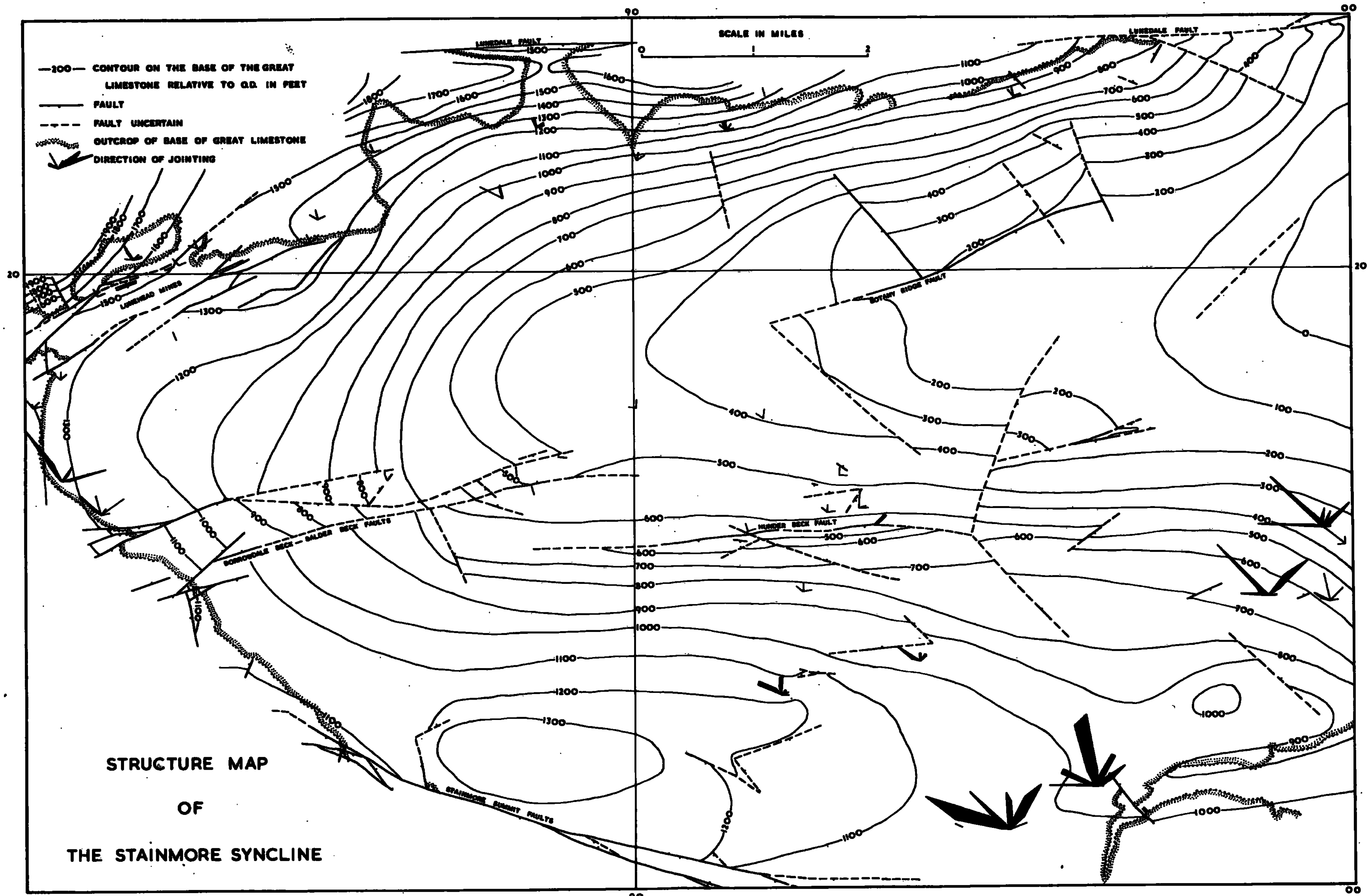
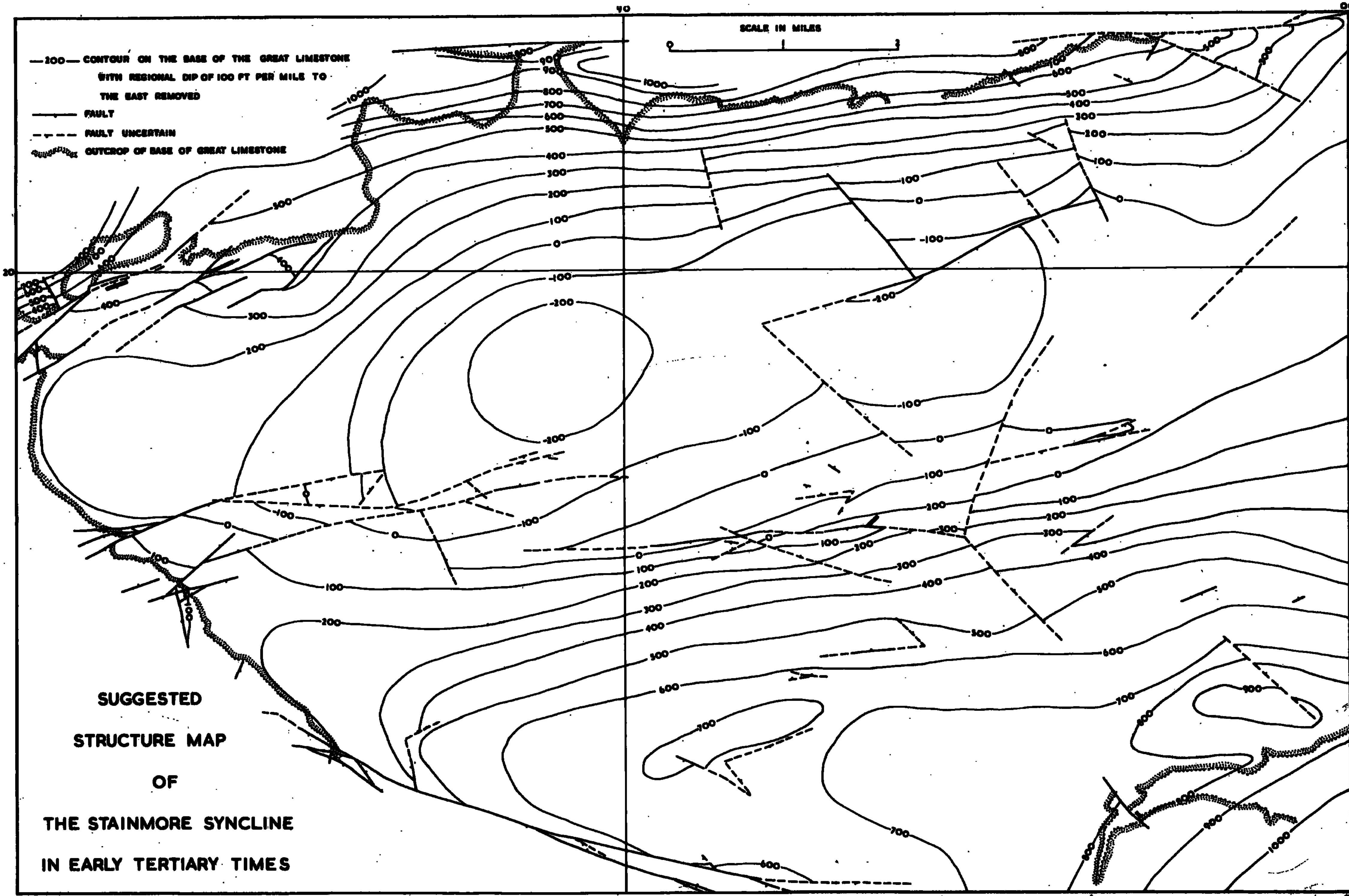

CONTOUR ON THE BASE OF THE GREAT LIMESTONE RELATIVE TO O.D. IN FEET
FAULT
FAULT UNCERTAIN
OUTCROP OF BASE OF GREAT LIMESTONE
DIRECTION OF JOINTING
SCALE IN MILES
0 1 2
LUNEDALE FAULT
LUNEHEAD MINES
BOTANY RIDGE FAULT
HUNDER BECK FAULT
BORROWDALE BECK - BALDER BECK FAULTS
STAINMORE SUMMIT FAULTS
STRUCTURE MAP
OF
THE STAINMORE SYNCLINE

PLATE II



SCALE IN MILES
0 1 2
—200— CONTOUR ON THE BASE OF THE GREAT LIMESTONE WITH REGIONAL DIP OF 100 FT PER MILE TO THE EAST REMOVED
FAULT
FAULT UNCERTAIN
OUTCROP OF BASE OF GREAT LIMESTONE
SUGGESTED STRUCTURE MAP OF THE STAINMORE SYNCLINE IN EARLY TERTIARY TIMES

PLATE III


GEOLOGICAL MAP
OF
THE STAINMORE SYNCLINE
H.G.R. 1953.
LUNEDALE
ROMALDKIRK
HUNDERTHWAITE
COTHERSTONE MOOR
LARTINGTON
BOWES MOOR
GILMONBY
STAINMORE COMMON
Slate Quarry Moss
White Hill
Redgill Moss
Beldoo Moss
The Old Moss
Lune Head Moss
Blindgill Moss