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TECHNICAL REPORT WA/87/46
Geology of the Trough of Bowland area (SD 65 SW). Part of 1:50,000 Sheets 59 (Lancaster) and 67 (Garstang).

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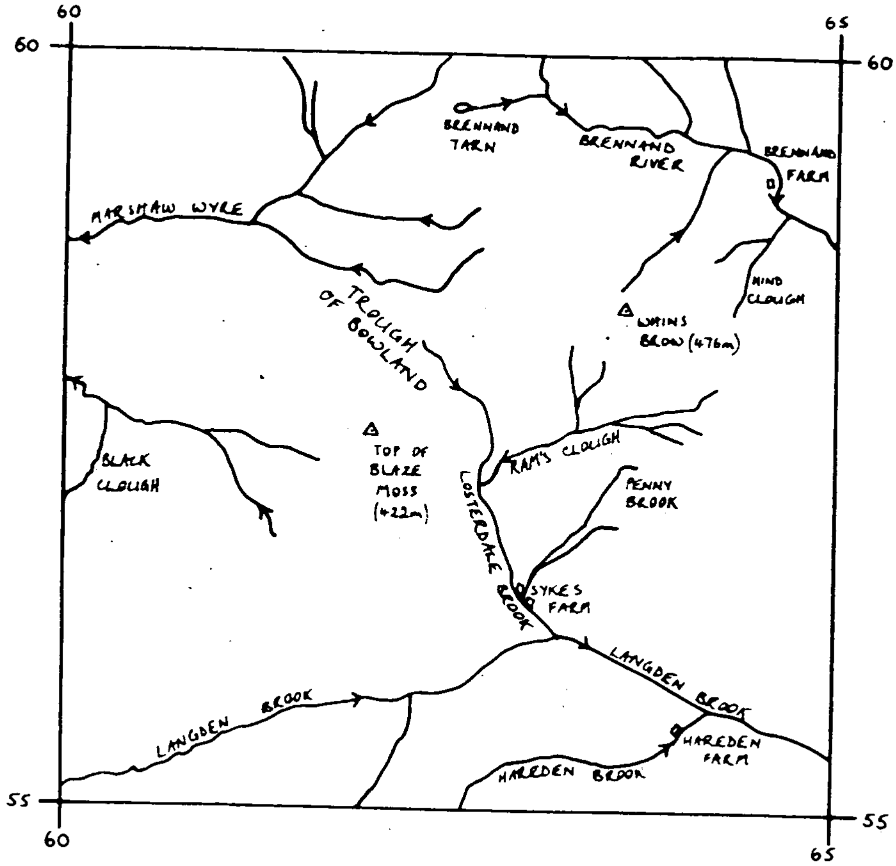

FIGURE 1: MAIN SECTIONS MENTIONED IN TEXT

1. INTRODUCTION

This report describes the geology of the 1:10 000 sheet SD 65 SW (Trough of Bowland), part of the 1:50 000 sheets 67 (Garstang) and 59 (Lancaster). The original geological survey was carried out on a scale of 1:10 560 by R. C. Tiddemann, and published as part of the Primary Series Sheets 91NE (1884: New Series Sheet 59) and 91SE (1883: New Series Sheet 67). The present survey was carried out by R. A. Hughes during 1985-86, under the direction of Dr A.J. Wadge, Regional Geologist. The ground to the north of the Miller's House Fault in the extreme northwest of the map was surveyed by Dr A. Brandon in 1984.

Most of the area consists of high, open moorland covered by peat bog and heather. Whins Brow [6363 5329] is the highest point at 476m (see Figure 1). The lowest areas are the Brennand and Langden valleys. The Trough of Bowland leads to the major watershed of the Bowland Fells at the Grey Stone of Trough (295m) [6225 5305]. To the north of the watershed is the drainage system of the River Wyre, to the south the River Hodder.

Apart from some conifer forestation, farming is entirely pastoral. Sheep graze the poor quality moorland and steep valley sides, while the marginally better pasture of the valley floors supports stock cattle. This is an important water catchment area for the North West Water Authority, supplying the industrial towns of north Lancashire.

Structurally the area is dominated by the Sykes and Brennand periclines which are part of the Ribblesdale Fold Belt. Though these structures have long been referred to as anticlines they are are more accurately described as periclines. Both have an ENE - WSW axial trace, and both have Dinantian rocks exposed in their cores. All the higher ground of the area is made up largely of Namurian sandstones. The "South-western part of the Sykes Anticline" was the subject of a paper by Moseley (1962), in which the succession and structure were described in detail.

2. GEOLOGICAL SUCCESSION

DRIFT

QUATERNARY

- Landslip
- Alluvial fan deposits
- River terrace deposits and alluvium
- Peat
- Head
- Till

SOLID

NAMURIAN

- Delph Beck Sandstone
- Brennand Grit Formation
- Pendle Grit Formation
- Upper Bowland Shale Formation

DINANTIAN

- Lower Bowland Shale Formation (including Pendleside Sandstones, and Ravensholme Limestone Member)
- Pendleside Limestone Formation
- Hodderense Limestone Formation
- Worston Shales
- Thornton Limestone

3. DINANTIAN

3.1 Introduction

The most complete surface sections through the Dinantian succession are in Ram's Clough [6279 5216 to 6215 5259] and in the Sykes Quarries [628 519]. The best section is in the western part of Ram's Clough [from 6279 5216 to 6318 5237]. The exposures on the eastern limb of the fold in Ram's Clough are rather discontinuous in the extreme east, and the field relationships above the Pendleside Limestone Formation are complicated. In the Sykes quarries the upper part of the Dinantian is not recognisable due to silicification, and is possibly absent on thickness grounds. In the Brennand pericline the Dinantian sequence is generally poorly exposed, with no continuous sections of any length. The sections in eastern and western Ram's Clough are graphically presented in Figures 2 and 3.

3.2 Thornton Limestone

Foraminiferan evidence confirms the oldest rocks exposed in the Sykes pericline to be of Chadian age. These rocks are present in the core of the pericline in Ram's Clough [6312 5232] and in Sykes quarries (see BGS Biostratigraphy Research Group reports PD86/98 and PD86/300 for full faunal lists). A correlation with the Thornton Limestone of sheet 60 (Clitheroe) is made on chronostratigraphic grounds (on the Clitheroe sheet the youngest Thornton Limestone is of mid-Chadian age). On thickness evidence it is probable that the sparites and biosparites exposed in the core of the fold at Sykes quarries [6282 5180] are older than the oldest rocks exposed in Ram's Clough. The oldest rocks in Ram's Clough are just 36 m below the Worston Shales, while in the Sykes quarries 80 m of biosparites and sparites are exposed with no sign of the overlying Worston Shales. There is insufficient precision in foraminiferan biostratigraphy in this part of the Dinantian to distinguish between the Chadian ages of the rocks at Sykes and in Ram's Clough. At the time of writing, further work is in progress to increase this precision.

The rocks of the Sykes quarries consist of argillaceous sparites and biosparites, with thin (<0.03m) shaly mudstone interbeds. Fossil material is abundant at some horizons, with numerous crinoids, bryozoa, and brachiopods. Corals are extremely abundant, with large Syringopora colonies and solitary rugose corals. Fossils have not been found in growth positions. Units occur up to 1.3 m thick, and are poorly bedded. Soft sediment slumping is common throughout the quarry faces. Clemmey and Gawthorpe (1985) recognised and described a number of soft sediment slumps at this locality. Some beds appear to have been reworked. In the higher parts of the quarry section beds become thinner and cherts appear as discrete units. Relict sedimentary features such as crinoid bioclasts clearly demonstrate the replacement nature of the silica. Thinner, laminated limestones here are dolomitised. Within individual beds, laminae are parallel at the base and become more wavy upwards. Mineralisation in the Sykes quarries is discussed in section 7 below.

The rocks from the Ram's Clough section which yield Chadian age foraminifera (e.g from the stream bed just to the east of the conifer plantation [6313 5236]) are lithologically different to those with similar faunas in Sykes quarries. They consist of more thinly bedded (0.8 m or less) sparites and biosparites with limestone turbidites up to 0.55 m thick, and thin shaly mudstones. Many individual bioclastic beds are completely silicified and chert nodules are common, but silicification is not as extensive as in the Sykes quarries.

3.3 Worston Shales

The Worston Shales, of Chadian to Holkerian age, consist of generally well laminated grey to black mudstones, often calcareous. Limestones in the form of turbidites or debris flows are present, but are thin and sparsely distributed. However, in drift covered ground and stream sections the limestones are often the only exposed part of the Worston Shales sequence. Exposures in the western part of Ram's Clough are poor, but in the stream bed south of the western end of the conifer plantation [6307 5234], four thin (<0.15 m) graded biosparites in black mudstones are exposed, and 10 m above here is 0.7 m of calcilutite. It is possible that the thickness of the Worston Shales (39 m) is affected by faulting near here, but exposure is too poor to be confident.

In the eastern part of the Ram's Clough section some 55 m of Worston Shales of similar lithology are intermittently exposed between the point at which a northerly flowing tributary joins Ram's Clough [6325 5239] and the point where Ram's Clough is joined by a southerly flowing drain [6330 5243].

In the Brennand valley both Hind Clough [645 534] and Swine Clough [640 537] contain sporadic exposures of bioclastic limestones belonging to the Worston Shales. In Hind Clough near to the confluence of an easterly flowing tributary

[6465 5375] are exposures of bioclastic debris flows. These are interpreted as being part of the Worston Shales because of their relationships with the younger succession upstream. A few metres to the west of the bridge over the river north of Brennand Farm [6446 5430], blue micrites, calcilutites, with occasional limestone turbidites near to the core of the Brennand pericline have yielded foraminifera of late Arundian age (see Biostratigraphy Research Group report PD86/300). These are interpreted as belonging to the Worston Shales on chronostratigraphic evidence.

There are significant differences between the Dinantian successions in the eastern and western parts of Ram's Clough. In the eastern Ram's Clough section (see Figure 2) parts of the Thornton Limestone are replaced by cherts. To the east of the point at which Ram's Clough is joined by a northerly flowing tributary [6318 5231] these replaced bioclastic limestones have undergone soft sediment deformation to produce a series of large scale slumps. The cherts are overlain by a major debris flow at least 12 m thick [6323 5238] in the lower part of the Worston shales, with clasts of bioclastic limestone, chert, and black mudstone up to 1 m across in a matrix of black mudstone. 29 m of Worston Shales are present here above the debris flow, exposed to the east of the confluence with the northerly flowing tributary [6325 5240]. They are lithologically similar to the Worston Shales of the western section in Ram's Clough (Figure 3), with thin graded biosparites and calcilutites in grey-black mudstones.

3.4 Hodderense Limestone Formation and Pendleside Limestone Formation

The Worston Shales are succeeded by the Hodderense Limestone Formation. The formation is of late Holkerian to late Asbian age. The formation is exposed in western Ram's Clough at the eastern end of the conifer plantation [6305 5233], and the succeeding Pendleside Limestone Formation immediately to the west of here. Both the Hodderense Limestone Formation and the Pendleside Limestone Formation are micrites with interbedded calcilutites, distinctive by virtue of their creamy caramel colour and extensive bioturbation. The Hodderense Limestone Formation, which in the western part of Ram's Clough is 4.8 m thick, is distinguished by its characteristic blue-grey mottling. It is not known whether this feature is of detrital or diagenetic origin, but the former seems more likely from examination of polished core slices. The goniatite *B. hodderense* is itself rare. The bioturbation of the Pendleside Limestone Formation is extensive, with vertical and ramifying burrow systems: the ichnogenera *Chondrites*, *Planolites*, *Thalassinoides*, and *Rhizocorallium* have been identified in the field. The lateral impersistence of laminae gives the impression of comprehensively reworked sediment. The upper boundary of the Pendleside Limestone Formation is drawn at the disappearance of the intense bioturbation.

The Hodderense Limestone Formation in eastern Ram's Clough is 8 m thick, and is exposed in a series of small waterfalls [6332 5243]. The Pendleside Limestone Formation is 17.5 m thick, and is exposed to the east of here. Lithologies are similar to those in the western Ram's Clough section, but the Pendleside Limestone Formation is thickened here by debris flows, and has undergone extensive dolomitisation.

The lowest exposures of the Pendleside Limestone Formation in Penny Brook [6307 5151] are 6 m of intensely bioturbated cream micrites and calcilutites overlying the Hodderense Limestone Formation. Only the very highest part of the latter is exposed here, in the bed of the stream. Upstream the Pendleside Limestone Formation is thrown down to the south-west by a fault. Loose blocks of Hodderense Limestone Formation lithology have been found in the southerly flowing unnamed tributary of Penny Brook [6313 5165]. Bioclastic debris flows, poorly exposed further upstream [6328 5174], are thought to be Ravensholme Limestone, and upstream of here are interbedded shales and calcilutites of the Lower Bowland Shales.

3.5 Lower Bowland Shale Formation

The Lower Bowland Shale Formation is best exposed in the eastern Ram's Clough section. Here the formation, including the Ravensholme Limestone Member and the Pendleside Sandstone, is 140 m thick. The dominant lithology of the Lower Bowland Shales is a dark grey shaly mudstone, often with bivalves, but grey calcareous mudstones up to 0.4 m thick are common in the lower part. The lowest shaly mudstones of the formation are seen interbedded with the limestone turbidites and debris flows of the Ravensholme Limestone Member.
In the Brennand Valley the best exposures of the Lower Bowland Shale Formation are in Swine Clough and Hind Clough. The Lyrogoniatites georgiensis Marine Band (P2c) is exposed in Hind Clough [6445 5340] (see Biostratigraphy research group internal report PD 86/305 for faunal lists).

3.5.1 Ravensholme Limestone Member

In western Ram's Clough 16.5 m of interbedded sparites, shaly mudstones, and massive debris flows belonging to the Ravensholme Limestone Member are exposed south of the conifer plantation [6298 5231]. The debris flows are bio- and lithoclastic, often with erosive bases, and are up to 1.2 m thick. In eastern Ram's Clough thicknesses are difficult to estimate due to poor exposure and folding, but at least 20 m of interbedded debris flows, sparites and shaly mudstones are present. Concordance of dips within the debris flows here, but discordance between these dips and those in the enclosing sediments suggests the possibility of an olistolith, but field relationships once more make this difficult to prove. The variation between the two sections on opposing limbs of the fold in Ram's Clough is an indication of the extreme lateral variation in sediment types at this level. The Ravensholme Limestone Member has not been recognised in the Brennand Valley.

3.5.2 Pendleside Sandstones

Above the Ravensholme Limestone are up to 54 m (in the eastern Ram's Clough section) of interbedded black shaly mudstones and calcareous mudstones before the lowest of the Pendleside Sandstones, exposed to the north-east of Turner Hill [6399 5259]. The calcareous mudstones scattered throughout the Lower Bowland Shale Formation are up to 0.4 m thick and unfossiliferous.

Goniatites have not been found, but bivalves are present in the shaly mudstones of this interval. In the eastern Ram's Clough section [640 526] several sandstones up to 0.8 m thick are present throughout a 25 m interval.

In the western Ram's Clough section 19.5 m of interbedded sandstones and shaly mudstones are exposed in the stream banks at the western end of the conifer plantation [6290 5229]. The sandstones are dark grey, medium-grained, with flute casts and prod marks. The presence of grading, load structures, and sole markings produced by traction currents suggests a turbidite origin.

In the Brennand valley 3.5 m of interbedded sandstones and shaly mudstones in Hind Clough [6448 5355] are stratigraphically 177 m below the base of the Pendle Grit Formation. In Swine Clough [6380 5358] the Pendleside Sandstones consist of four sandstone beds, the thickest of which is 0.08 m, within 2 m of interbedded shaly mudstones and sandstones. In the easterly flowing tributary of Swine Clough [6402 5403] is a 2 m medium-grained sandstone.

Sandstones are present throughout the Lower Bowland Shales sequence above the Ravensholme Limestone Member. To the west of Bracken Hill [6233 5173] 1 m of sandstone interbedded with black shaly mudstones and calcareous mudstones is present 109 m below the base of the Pendle Grit. In nearby Swine Clough [6239 5188] sandstones are present throughout the upper 18 m of a poorly exposed stream section, some 210 m below the base of the Pendle Grit. The thickness of rock between the sandstones at the western end of Ram's Clough and the base of the Pendle Grit is indeterminable due to the folding within the Lower Bowland Shales around Parrack Clough [627 524].

The Pendleside Sandstone is also present in two of the BP minerals boreholes. In SD65SW/24 (an inclined hole on the north bank of the Brennand river [6410 5441]) 25 m of interbedded sandstones and shaly mudstones are present, while in SD65SW/21 on the western slopes of Middle Knoll [6497 5435] 15.77 m of interbedded sandstones and shales are present. In both these cases there is no surface indication of the sandstones.

The lithologies of the sandstones vary little throughout the present area. They are dominantly coarse-grained, micaceous, and grey, often with abundant plant remains. Feldspars and micas indicate mineralogical immaturity. Mudstone intraclasts are common, and sometimes concentrated in the upper parts of beds. Sedimentary structures in the sandstones are those normally associated with turbidites. Beds are rarely graded, but often have irregular bases and tops. Sole markings are common, and corrected palaeocurrents indicate a source from the north to north-east. Convolute lamination is present, and the interbedded shales are wavy and parallel bedded.

4. NAMURIAN

The base of the Namurian Series, by definition the base of the Pendleian Stage (E1), is recognised by the *Cravenoceras leion* Marine Band, exposed at numerous localities within the area. This boundary also divides the Lower from the Upper Bowland Shale formations.

4.1 Upper Bowland Shale Formation, including Hind Sandstone Member

The lower part of the Upper Bowland Shale Formation consists almost entirely of dark grey shaly mudstones, with occasional thin calcareous mudstones and siltstones. Towards the top of the formation, thinly laminated calcareous siltstones become more common, representing the encroachment of distal turbidites into the basin from the advancing delta front to the north.

The thickness of the Upper Bowland Shale Formation within the area varies between 140 m on the north-west facing slopes of Staple Oak Fell [6384 5212] to 79 m on the south-east facing slopes of Whin's Brow [6403 5281]. The C. leion Marine Band has not been found in the 160 m thickness of well exposed rock beneath the Pendle Grit Formation in the Trough of Bowland section. It is therefore likely that the *C. leion* Marine Band is at least 160 m below the base of the Pendle Grit Formation here.

The Upper Bowland Shales on the southern side of the Sykes Pericline are exposed in a number of gullies on the north-western facing slopes of Staple Oak Fell (for example at [6385 5215]). Here the *C. leion* Marine Band is present in two leaves, some 4 m apart; the overlying E2a *Cravenoceras brandoni* Marine Band is 60 m above the *C. leion* Band in the same section. The higher marine bands of the Upper Bowland Shales are not exposed here.

The best-exposed section through the upper part of the formation is the Trough of Bowland section [625 588], where the unit is at least 160 m thick (see Figure 4). The lower part of the section consists of interbedded shales, mudstones, calcareous mudstones and occasional calcareous siltstones with parallel laminated bases. Siderite concretions are present at a few horizons. Calcareous siltstones, up to 0.35 m thick, become more abundant towards the top of the section up to the base of the Pendle Grit Formation.

The *Eumorphoceras pseudobilingue* Marine Band, exposed on the western bank of the stream [6253 5282], is 42 metres below the base of the Pendle Grit Formation. At 22 m below the base of the Pendle Grit on the western side of the road are two sandstones, the lower 0.13-0.20 m thick, the upper 0.6 m, separated by 0.5 m of mudstone and siltstone. On the eastern side of the road [6252 5285] these sandstones amalgamate to form a single bed up to 1.27 m thick. This is the Hind Sandstone of Moseley (1962) (named after Hind Clough in the Brennand Valley - see below) here named the Hind Sandstone Member. It is a coarse-grained, massive, ungraded, micaceous and felspathic sandstone with rare mudstone intraclasts. Comminuted plant remains are abundant, and crinoid ossicle external moulds are rare. Because of its precise stratigraphic position between the two marine bands, the Hind Sandstone Member has been traced over a wide area throughout the Bowland basin, but nowhere is it of sufficient thickness to produce a topographic feature at the surface. The sandstone is not present in the section along the Brennand river north-west of Brennand Farm [638 544] where both the *E. pseudobilingue* and the *Cravenoceras malhamense* Marine Bands, together with the intervening rocks, are fully exposed.

4.6 m above the Hind Sandstone in the Trough of Bowland section is the *C. malhamense* Marine Band, which on the western bank of the stream [6249 5284] is 2.4 m thick. Its base is 14 m below the base of the Pendle Grit Formation here. Above the marine band are some 14 metres of shaly mudstones and calcareous mudstones below the earliest sandstone turbidites of the Pendle Grit.

In the Brennand Valley good exposures of the Upper Bowland Shale Formation are present in Hind Clough and along the Brennand River. In Hind Clough there is an almost complete section through the Upper Bowland Shale Formation [644 533] in which the *Lyrogoniatites georgiensis*, the *C. leion*, the *E. pseudobilingue* and the *C. malhamense* Marine bands are exposed (see Biostratigraphy Research Group internal report PD86/305 for faunal lists). Exposures of the sequence above the Hind Sandstone Member are not as complete as those in the Trough of Bowland section. The Upper Bowland Shale succession here is similar to that exposed in the Trough of Bowland section, but the uppermost parts of the Hind Clough section are complicated by minor faulting and possible slumping of the lowest sandstones of the Pendle Grit Formation. The Hind Sandstone Member consists of 7 m of coarse-grained, poorly sorted sandstone. The *C. malhamense* Marine Band is approximately 9 m above the top of the Hind Sandstone Member, and approximately 20 m below the base of the Pendle Grit Formation.

4.2 Pendle Grit Formation

The precise thickness of the Pendle Grit Formation in the area is difficult to calculate because of folding. The section least likely to be structurally disturbed runs from Whins Brow [633 532] to Grainings [626 539]. The thickness of the Pendle Grit Formation here is calculated to be 345 m. This compares closely with figures of 355 m to the west on Beatrix Fell (T.P. Fletcher, personal communication) and 336 m in the Bowland Forest Tunnel (Earp, 1955).

The lowest 14 m of the Pendle Grit Formation in the Trough of Bowland section consists of sandstones up to 0.40 m thick interbedded with siltstones and shaly mudstones. The rocks show the typical sedimentary structures of turbidites, with sole structures, graded beds, wavy and parallel bedding, convolute lamination, and flame structures. In the Trough of Bowland section there is a 12 m gap in exposure, occupied by a negative topographical feature, between these lowest beds and the first massive, coarse, sandstones of the Pendle Grit Formation. This double feature at the base of the Pendle Grit is present throughout the area. In the Brennand valley the conspicuous double feature at the base of the Pendle Grit Formation is formed by the Hind Sandstone Member and the lowest sandstones of the Pendle Grit Formation.

The main part of the Pendle Grit Formation consists of massive, medium- to coarse-grained, felspathic, poorly bedded sandstones in units up to 1.5 m thick. Exposures are generally restricted to stream sections and steep hillsides, and by and large are discontinuous. Bedding within the sandstones is often indefinite, with apparent bedding planes merging with joints. Evidence of channelling has been seen at one locality on sheet SD 55 SE, adjacent to the west. Plant remains are common, particularly in the more finely bedded flaggy, micaceous beds. Interbedded with the massive coarse-grained sandstones are thicknesses of thinner sandstones with mudstones. These thinner sandstones are sometimes graded, with sole structures and current rippled tops suggesting a turbidite origin. The interbedded sandstones and mudstones are responsible for the laterally impersistent negative topographic features seen within the Pendle Grit.

4.3 Brennand Grit Formation

The highest massive sandstones of the Pendle Grit Formation are succeeded by approximately 20 m of siltstones and mudstones which generally are poorly exposed in this area. These strata produce a negative topographic feature by which the top of the Pendle Grit Formation is mapped. Small exposures are present in the tributaries of Threaphaw Clough to the south of Threaphaw Fell. Near the confluence of two tributaries of Threaphaw Clough [6238 5386] 8 m of siltstones and mudstones with two 0.30 m laterally impersistent flaggy, micaceous sandstones are exposed. There are other poor exposures in the upper parts of the Marshaw Wyre section [6113 5420], and in Tarn Clough [6282 5459].

These mudstones are overlain by the interbedded thick, coarse-grained sandstones and poorly exposed fine-grained sandstones and siltstones of the Brennand Grit Formation. In the White Moor area [54 60] the four major sandstone bodies and their interbedded sediments which comprise the Brennand Grit Formation are greater than 160 m thick. The top of the section is faulted out here by the Miller's House Fault, which throws down to the north-west. The Brennand Grits are lithologically distinct from the Pendle Grits, consisting of coarse-grained, pebbly sandstones, cross-bedded throughout. The pebbles are mainly of quartz, and are up to 0.02 m across. Cross-bedding is a particularly distinctive feature of the Brennand Grits. Wherever the rocks are seen in large outcrops, trough and planar cross-beds are always present, with cross-sets up to 1 m thick, and apparently bi-directional palaeocurrent directions. Individual sandstones within the Brennand Grit Formation reach up to 40 m in thickness, as at Tower Plantation [608 542].

Exposures of the sediments interbedded with the sandstones of the Brennand Grits are rarely seen, but consist mainly of siltstones, as in the unnamed stream to the east of High Tower Plantation [6150 5479].

4.4 Delph Beck Sandstones

The youngest rocks exposed in the area are the Delph Beck Sandstones (see Wilson *et al.*, 1985). These are poorly exposed in a downfaulted block in the extreme north-west of the area. Better exposures to the north on sheet SD 65 NE show that these rocks lie above the *Cravenoceras cowlingense* Marine Band.

The rocks are interbedded, medium-grained, parallel-laminated sandstones and siltstones with rippled bedding planes and groove casts. A thickness of approximately 4 m is present.

5. STRUCTURE

5.1 Folding

The geological map of the area is dominated by the Sykes and Brennand periclines. The axial traces of these folds trend approximately 055° and 047° respectively, and coincide with the other major folds of the Ribblesdale Fold Belt which have axial trends between north-east to south-west and ENE to WSW (see Arthurton, 1984). It is possible that the Brennand Ppericline axial trace splits into two in the south-west, but the evidence for this is slight. The major fold axis here runs north-east to south-west along Swine Clough. These major folds are flanked by complimentary synforms with similar axial traces, such as the Staple Oak Fell synform and the Hareden Nab synform.

The Sykes Pericline itself has a number of parasitic folds with axial trends similar to the main fold. The best exposed of these is in the tributary which flows south from Whins Brow past Trough House into Ram's Clough [633 528]. Another such fold is in the un-named tributary to the east [635 528]. Very limited exposures suggest another such fold east of Parrack Clough [628 524]. No major parasitic folds have been found in the Brennand Pericline, but exposure is very poor here. The minor folds in the Brennand river north of Brennand Farm [6445 5429] are seen in cross-section only, but their axial traces appear to be approximately north-east to south-west.

The degree of deformation within the folds varies greatly between the cores and the limbs. In the Sykes Pericline beds exposed in the core of the fold in Ram's Clough are overturned. The higher parts of the fold limbs in the Pendle Grit dip away from the axial area at dips of only 30°.

In the north-west part of the area, away from the influence of the local intense folding, the regional dip is to the north at less than 20°.

5.2 Faulting

The dominant fault direction is between NW-SE and WNW-ESE. The major fault runs north-west from Fog Hill [6382 5113] (where it can be seen throwing Bowland Shales against Pendle Grit) through Hareden Nab to Black Clough [603 523]. It may be traced from the Mellor Knoll area to the south on sheet SD 64 NW where it throws down 250 m to the north-east (A.S. Howard, in prep.): it is named the Mellor Knoll Fault. This fault is joined by the Langden Valley

Fault, which runs along Langden Valley and probably merges with the Mellor Knoll Fault on the high ground of Holdron Moss. The Langden Valley Fault throws down an unknown amount to the south-west, and is exposed as a highly disturbed zone at Langden intake [6313 5106]. Both these faults may be traced to the north-west on to sheet SD 55 SE, where they disappear beneath thick glacial drift cover. It is possible that they merge in this direction with the Marshaw fault system of the Abbeystead area (see Wilson et al., 1985). A series of six small faults on Sykes Nab [635 514] suggests a component of dextral transcurrent movement accompanying the major movement on the Mellor Knoll and Langden Valley faults.

The other significant fault in the area is the Miller's House Fault in the north around White Moor [607 546]. The fault has an arcuate east-west trend and downthrows to the north, bringing the higher leaves of the Brennand Grit Formation into juxtaposition with the Delph Beck Sandstones. To the east of here around Threaphaw Fell is a number of small faults which displace the topographic features formed by the major sandstones of the Brennand Grit Formation.

Field evidence suggests that the folding predates the faulting. To the north-east of Holdron Moss [608 519] the dip of the Pendle Grit is quite different on opposite sides of the Mellor Knoll Fault. To the south-west of the fault the rocks dip at up to 60° to the north-west, but on the north-eastern side of the fault the rocks dip at 20° to the south-east. A north-easterly trending anticlinal structure whose axis probably runs along the watershed of Holdron Moss is here truncated to the north-east by the Mellor Knoll Fault. (It is worthy of note that if dextral transcurrent movement has indeed occurred, then this may be the offset south-western extremity of the Sykes pericline).

5.3 Discussion

Field evidence from the present area strongly supports Arthurton's (1984) thesis that the Ribblesdale Fold Belt is the expression in the Carboniferous cover rocks of dextral shear in the Lower Palaeozoic basement. Clay box model experiments (Wilcox, Harding, and Seely, 1972) predict the major products of dextral shear to be en echelon folds with synthetic and antithetic shears, these structures being repeated in a regular geometrical pattern.

Within the present area the Langden Valley Fault and the Mellor Knoll Fault trend at approximately 110° and 120° respectively. The geometrical relationship of these trends with respect to the axial traces of the Sykes, Brennand and Whitendale periclines (approximately 055°, 047°, and 044° respectively) is consistent with them being synthetic shears within a dextral shear regime. The six small faults on Sykes Nab [635 514] add further evidence to this thesis. Synthetic fractures are commonly less well developed than antithetic fractures within strike-slip regimes because of rotational movements in the cover rocks.

Taking into account the empirical evidence of Wilcox, Harding and Seely (op. cit) and the fold and fault trends in the present area, the basement fracture is predicted to have a trend of between 074 and 085.

6. QUATERNARY

6.1 Landslip

Landslip is common on all steep valley sides in the Namurian of the area. The major landslips which involve movement of the solid rocks are of the rotational type. Some landslips are areally extensive, such as those at Brennand Stones [640 535], Langden Castle [610 505], and Mellor Knoll [645 500]. Slips are particularly common at or near to the base of the Pendle Grit. This is probably due to the downward moving pore waters of the Pendle Grit meeting the relatively impervious Bowland Shales below. Bedding planes within the upper parts of the Bowland Shales are lubricated to produce slip planes.

Small scale, non-rotational slips are common in the steep banks of till in the north of the area. Many of these are too small to be mapped. Minor non-rotational slips in the extensive head deposits are common and active at the present day. A minor slip in head occurred on the south side of Langden Valley [6340 5070] on September 21st, 1985, following torrential rain.

6.2 Head

Head covers the lower parts of all the steeper slopes. It is the product of locally derived weathered bedrock moving downslope under the influence of gravity, perhaps initially in periglacial conditions. In this area it consists almost entirely of unsorted sandstone fragments of all sizes, with varying amounts of sand and sandy clay. In the steep sided Langden Valley head reaches a vertical thickness of 4 m. Here the head once formed a much more extensive deposit which probably covered the valley floor, but today it is being actively eroded by Langden Brook.

6.3 Till

Till occurs extensively only on the ground to the north of the Trough of Bowland and in the col between the Brennand and Whitendale valleys. To the north of the Trough of Bowland [6005 5366] the till reaches a thickness of 8 m, and consists of locally and distally derived clasts set in a matrix of dense grey clay. Some of the erratics are of volcanic and igneous origin, and a Lake District source area is likely. There is a small area of till to the east of Hareden Farm [639 503], and another area, mostly concealed beneath the river alluvium of Langden Brook due east of Langden Farm [6447 5051]. In this last locality are patches of intensely disrupted laminated clays with rootlets, which may be more extensive beneath the adjacent landslip. The disruption was caused either by the overburden of ice or by the overriding of local landslips. The laminated clays here suggest the former presence of a body of water in which varved sediments were able to accumulate.

The banks of Trough Brook [617 536] are made up of a material consisting entirely of locally derived clasts, some with ice striae, in a dense matrix of sandy clay. The compact nature of the matrix suggests a till, but the absence of erratics suggests a local origin. The deposit is quite unlike the head of other valley slopes, and a thick head deposit is unlikely in this position: it is interpreted as an ablation till.

There are two possible glacial drainage channels in the area. The Trough of Bowland is the lowest point on the main watershed of the Bowland Fells at 295 m, and is a deep incision in the Pendle Grit escarpment. The second drainage channel is at Brennand Tarn [626 546], and lies along the line of a strike fault. It is a deeply incised gully which is the lowest point on the watershed between the drainage of the Marshaw Wyre and the Brennand rivers.

6.4 River terrace deposits and alluvium

Alluvium is present in the valleys of the Marshaw Wyre, Langden Brook, and the lower parts of Losterdale Brook. It is most extensive in Langden Brook, where three terraces have been mapped. At least 8 m of alluvium are present in boreholes in the upper parts of Langden Brook [625 508]. In the lowest part of Langden Brook on this sheet [6499 5035] a borehole (SD65SSW/16) revealed 15 m of river alluvium overlying till to a depth of 30 m. The alluvium consists of interbedded clays, sands and gravels.

6.5 Alluvial fan deposits

Tributaries of the main valley rivers which join from the steeper fell sides in many cases produce small alluvial fans of coarse sands and gravels, with cobbles and boulders. Little Hareden Clough for example has produced an alluvial fan where it meets Langden Brook [6235 5070].

Harvey and Renwick (1987) used carbon dating techniques to demonstrate two major periods of alluvial fan development during the Holocene in the Bowland Fells area. The earliest was after 5400y BP but before 1900y BP, the second around 900y BP.

6.6 Peat

Peat covers much of the upland area of the map, reaching a maximum thickness of 3.2 m in the area between Threaphaw Fell and the headwaters of the Marshaw Wyre [624 546]. In all areas the peat is being actively eroded. On the slopes of Blaze Moss [611 528], Staple Oak Fell [645 517], and the northern slopes of Whin's Brow [635 537] for example, a once continuous peat cover now consists of a highly dissected group of hags, up to 2 m high.

7. ECONOMIC GEOLOGY

7.1 Metalliferous mineralisation and silicification

The history of metalliferous ore mining in the area has been described by Raistrick (1973), and by Gill (1987). It suffices to say that galena and sphalerite have been intermittently extracted from the Dinantian limestones in the cores of the Sykes and Brennand periclines since the sixteenth century. The most intensive period of extraction was between 1866 and 1871. Chalcopyrite, malachite, silver, fluorite, and baryte have also been extracted, but are of comparatively minor importance.

Adits on both the east and west sides of Losterdale Brook in the Sykes Quarries [6281 5186 and 6273 5186] testify to the existence of former workings. Galena, barytes and copper staining are common in the waste tips here, but according to Raistrick, the amounts extracted were never great. In the upper part of the western quarry face is a barytes vein up to 1m wide at outcrop. Building stone from the Sykes quarries has also been used locally.

During the present survey a previously unrecorded small anastomosing vein with galena, chalcopyrite, and barytes was found on the western side of the Trough of Bowland [6251 5273]. Probably the same vein may be seen again in an unnamed tributary on the eastern side of the Trough of Bowland [6271 5283]. Further to the east, among the screes [632 531], there are abundant loose blocks of mineralised breccia. It seems that the vein follows an ENE to WSW trend.

Ore deposits in the Brennand valley are on a much larger scale. Evidence of mineralisation is widespread throughout the Dinantian limestones at outcrop in the form of quartz veins with sphalerite and galena. Mineralisation is most pervasive in the area around the adit on the eastern side of the Brennand river [6461 5429]. The nature and extent of mineralisation here have been recently investigated in some detail both by the BGS and by BP Minerals. As part of the Craven Basin Mineral Reconnaissance Programme (see Wadge et al., 1983) the BGS undertook detailed sulphide mineralisation investigations using VLF and IP surveying techniques. The results of these surveys are published in Wadge et al. (op. cit.), but no major new mineral finds were made.

Stimulated by the BGS reconnaissance exercise, BP Minerals in 1983 began a programme of drilling and geochemical surveying in the Sykes-Brennand-Whitendale area. Eight boreholes, up to 266.7m deep, and twelve shallow "Winkie" holes were sunk in the area of SD 65 SW. (Further holes were drilled on SD 65 NE and SD 65 SE). Details of the BHD9 (Bowland Higher Diamond) borehole may be found in report number PD86/131 of the BGS Biostratigraphy Group, by Dr N. J. Riley. Details of the other boreholes may be found in the boreholes section of this report.

The BP drilling programme revealed that the greatest mineral concentrations occur in the area which has been most intensively mined, that is from the area of the Brennand Level adit north eastwards to Whitendale. The cores reveal the elements Pb and Zn (with minor Cu) to be distributed throughout the Dinantian rocks from Asbian to ?Chadian age. They are not stratabound, but are more abundant in the limestones, in particular the lithoclastic and bioclastic limestones which have large pore spaces and voids. The Worston Shales and Bowland Shales contain minerals in small amounts. The mineral ores in which the metals occur, galena, sphalerite, and chalcopyrite, are in both vein and disseminated forms.

Regardless of the host rock, mineralisation is always associated with silicification. Limestones are often partly or completely dolomitised. It is not known whether the widespread silicification of the limestones exposed in the Sykes Pericline was synchronous with the mineralisation. Though the cherts (silicified ?Thornton Limestones) in the western Sykes quarry are in a mineralised area, the massive cherts exposed in the core of the pericline in Ram's Clough [632 523] are not associated with metalliferous mineralisation. Silica (quartz) veins containing metalliferous minerals frequently brecciate the host rock upon emplacement, implying high pressures at that time. The distribution of the cherts is not stratigraphically limited.

Dunham and Wilson (1985, p. 104) made a detailed comparison between the mineralisation of the North Pennine Orefield and the Mississippi Valley type of mineralisation of the United States. There are many similarities between the ore deposits of the Pennines and the present area, and it seems reasonable to extend this model to the mineralisation of the Ribblesdale Fold Belt.

7.2 Dolomitisation

The dolomitisation of the limestones in both the Sykes and Brennand periclines may also be associated with metalliferous mineralisation. The dolomitisation is stratigraphically limited to the Pendleside Limestone Formation within the Dinantian. Gawthorpe (1985) showed this dolomitisation to be a late stage diagenetic event post-dating several generations of calcite cement.

7.3 Hydrocarbons

Though no oil seeps have been seen, the Thornton Limestones of the Sykes Anticline are rich in hydrocarbons. Fresh rock surfaces give off a pungent smell of oil. In the BP minerals boreholes hydrocarbon staining was seen around drusy cavities in the Thornton Limestones.

8. BOREHOLE DATA

In 1982 BP Minerals undertook a programme of drilling in the Bowland area in order to ascertain the economic value of the sulphide minerals described here in the economic geology section. In the area of SD 65 SW six boreholes were sunk, the details of which are tabulated below. An asterisk after the hole number signifies the cores held in the National Geosciences Data Centre at Keyworth.

HOLE NUMBER	BGS NUMBER	TOTAL DEPTH (m)	NGR	BGS NUMBER AND LOCATION
BHD 3*	SD65SW/19	122.77	6519 5491	Close to axis of Brennand Pericline.
BHD 4	SD65SW/20	113.95	6495 5464	Middle Knoll, Brennand Pericline.
BHD 5	SD65SW/21	156.61	6497 5434	Middle Knoll, Brennand Pericline.
BHD 9*	SD65SW/22	220.78	6372 5233	Turner Hill, Sykes Pericline.
BHD 10	SD65SW/23	129.35	6329 5192	Higher Barn, Sykes Pericline.
BHD 11*	SD65SW/24	188.47	6416 5441	Brennand River.
BHD 12*	SD65SW/25	266.70	6414 5368	Brennand Stones, Brennand Pericline.
BHD 13	SD65SW/26	180.50	6418 5395	Swine Clough, Brennand Pericline.

Borehole logs prepared by the BP geologists are in the records of the BGS, and SD65SW/22 has been reported on by Dr N.J. Riley (Biostratigraphy research group report PD 86/131). I have examined the cores from holes BHD 3 and 12 and summary logs are presented below.

SD65SW/19

DEPTH (m)	LITHOLOGY
0-15.3	Coarse-grained limestone debris flows and turbidites. Dominantly bioclastic, with abundant crinoidal material and some corals. Wackestone lithoclasts. Laminated shaly mudstones at 14.72-15.3m.
to 54.9	Intense bioturbation *(Chondrites, Planolites)* in caramel coloured calcareous mudstones below 15.3m. "Wispy" darker mudstones in lighter wackestones. Sequence punctuated by limestone turbidites and debris flows up to 2 m thick. "Background" lithology is typical of the Pendleside Limestone.
to 57.15	Debris flows with reworked lithoclasts up to 0.25 m across of Hodderense limestone Formation with characteristic blue-grey mottling. Hodderense Limestone Formation not seen in situ in core.)
to 58.8	Laminated, ungraded, calcareous packstones/grainstones.
to 98.5	Predominantly calcareous mudstones, with some wackestones. Bioturbated throughout, but dark grey colour distinguishes these from the Pendleside Limestone bioturbated calcareous mudstones above.
to 122.7	Well-bedded, laminated calcareous mudstones, with subordinate thin, coarse bioclastic limestones (?turbidites). Bioturbation increasingly uncommon, but abundant soft sediment deformation present.

SD65SW/25

DEPTH	LITHOLOGY
0-45.65 m	Laminated black shaly mudstones. Medium- to fine-grained sandstones up to 0.45 m distributed throughout. Sandstones with erosive bases.
to 45.67 m	Bioclastic/lithoclastic calcareous debris flow with erosive base.
to 51.60 m	Laminated black shaly mudstones.
to 53.00 m	Lithoclastic debris flow with clasts of Pendleside Limestone.
to 54.80 m	Slumped coarse bioclastic limestone.
to 70.25 m	Intensely bioturbated caramel coloured calcareous mudstones and wackestones. Some bio- and lithoclastic grainstones and debris flows. Large scale slumping.
to 81.20 m	Spectacular development of Hodderense Limestone mottling in cream coloured wackestones. Rare carbonate sand geopetal infills of cephalopod shells.
to 115 m	Caramel coloured calcareous mudstones and wackestones, becoming more argillaceous and grey with depth. *Dunbarella* Bed at 109.10 m?
to 142 m	Interbedded mudstones and siltstones with banded appearance. Slumping throughout. Erosive bases to some siltstone units: these up to 0.20 m thick. Sporadic litho- and bioclastic debris flows up to 0.10 m thick below 119 m.
to 151 m	Dark grey mudstones.
to 170 m	Wackestones/packstones, some graded, interbedded with thin mudstones to give banding. Limestone increases in proportion downwards.
to 240 m	Debris flows and coarse turbidites become more common in succession of grainstones, calcisiltites, and calcilutites. Thin mudstone partings. Bioturbation present and large bioclasts (e.g. *Syringopora* 0.15 m across at 219 m).
to 266.7 m	Calcisiltites with little bioclastic material. Turbidites and debris flows now largely absent. Extensive *Chondrites* bioturbation.

The remaining seventeen boreholes on the sheet serve only to demonstrate the thickness of drift deposits in the area, and give no detail of the solid geology. The most important of these are annotated on the margin of the map.

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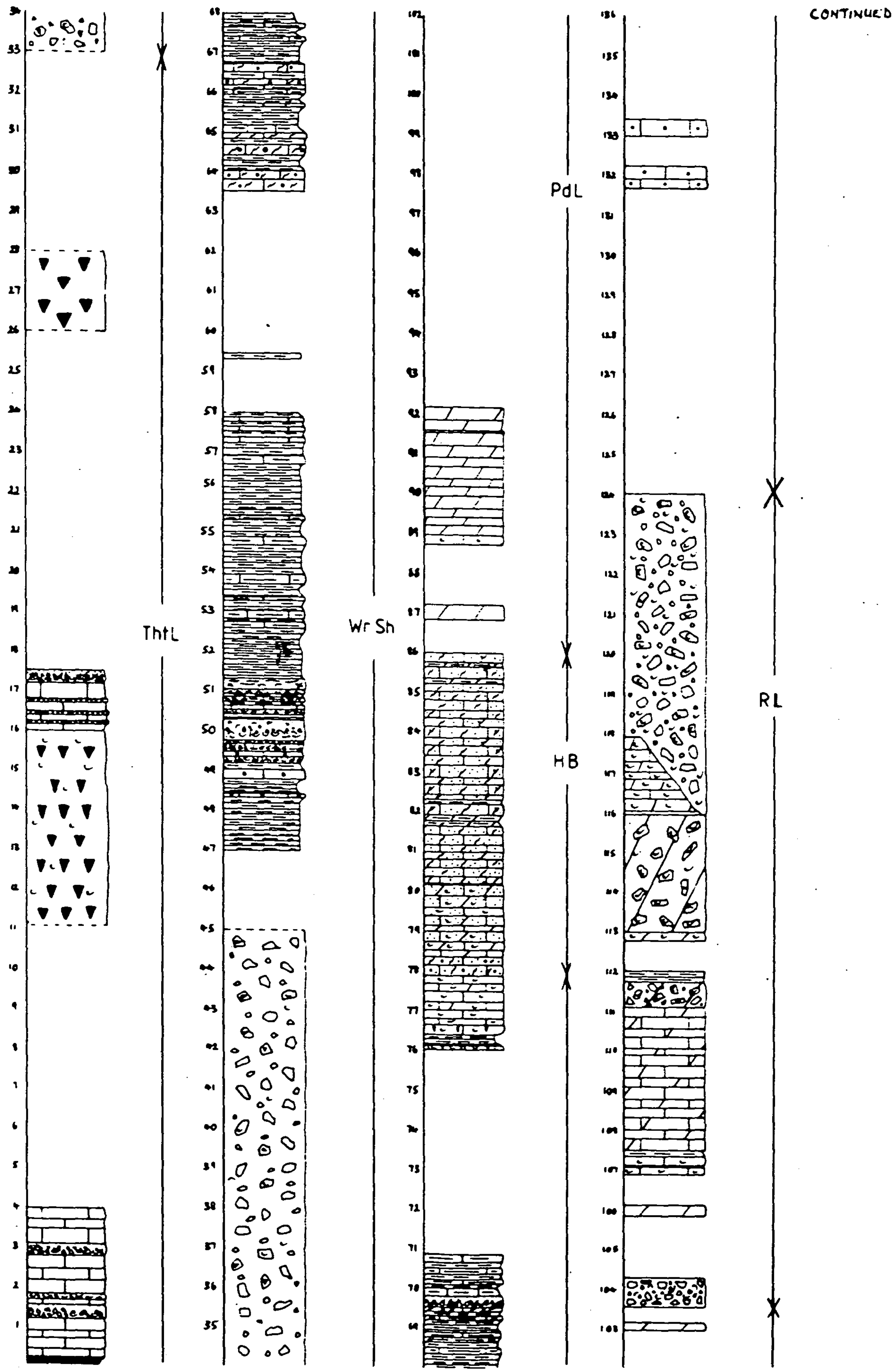
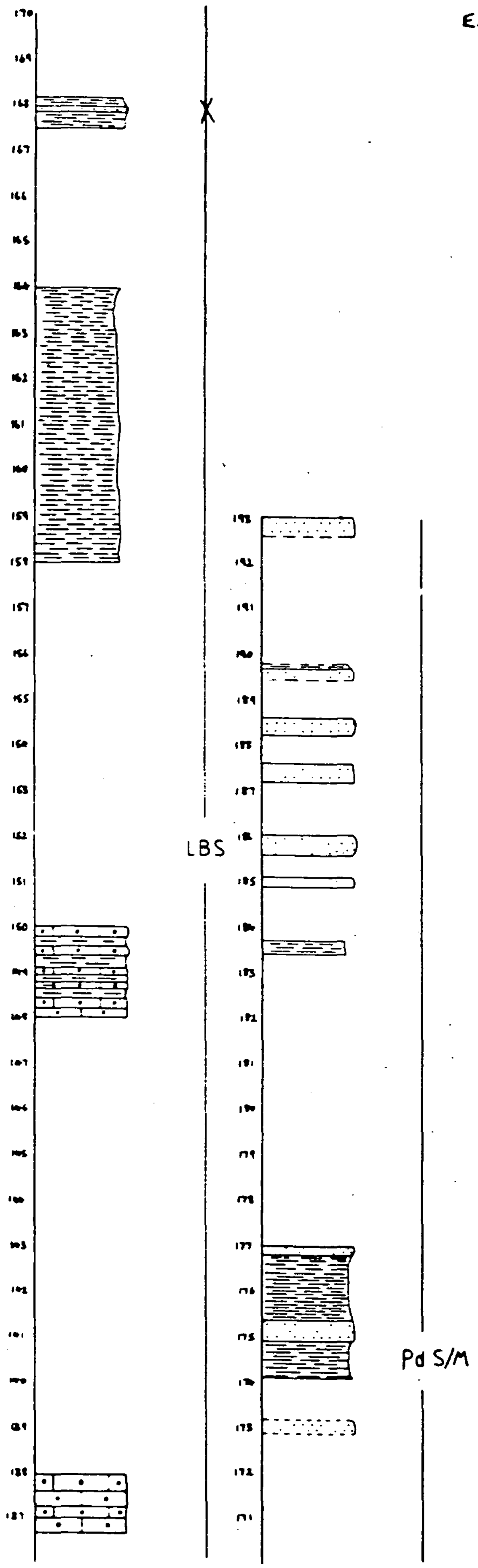
FIGURE 2

EASTERN LIMB OF SYKES PERICLINE IN RAM'S CLOUGH



EASTERN LIMB OF RAM'S CLOUGH
CONTINUED



Pd S/M – Pendleside sandstone with mudsto[ne]
LBS – Lower Bowland Shales
RL – Ravensholme Limestone
PdL – Pendleside Limestone
HB – B. hodderense Beds
WrSh – Worston Shales
ThL – Thornton Limestone.

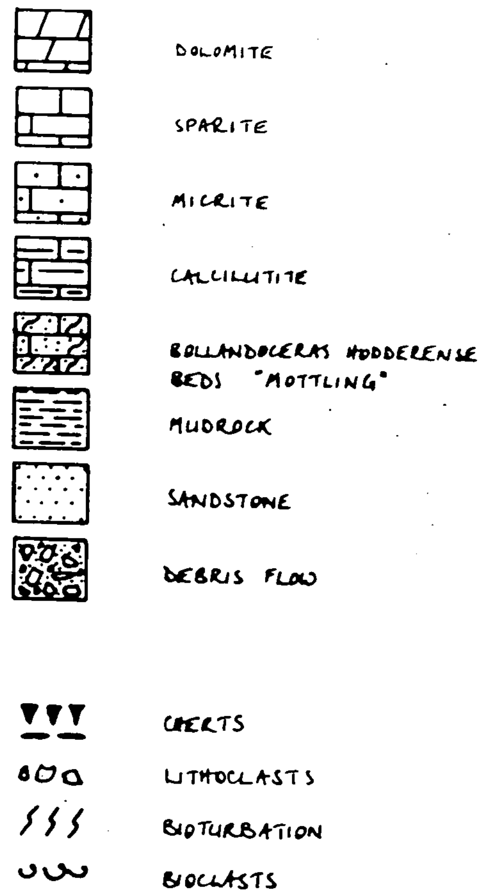


FIGURE 3.

WESTERN LIMB OF SYKES PERICLINE IN RAM'S CLOUGH

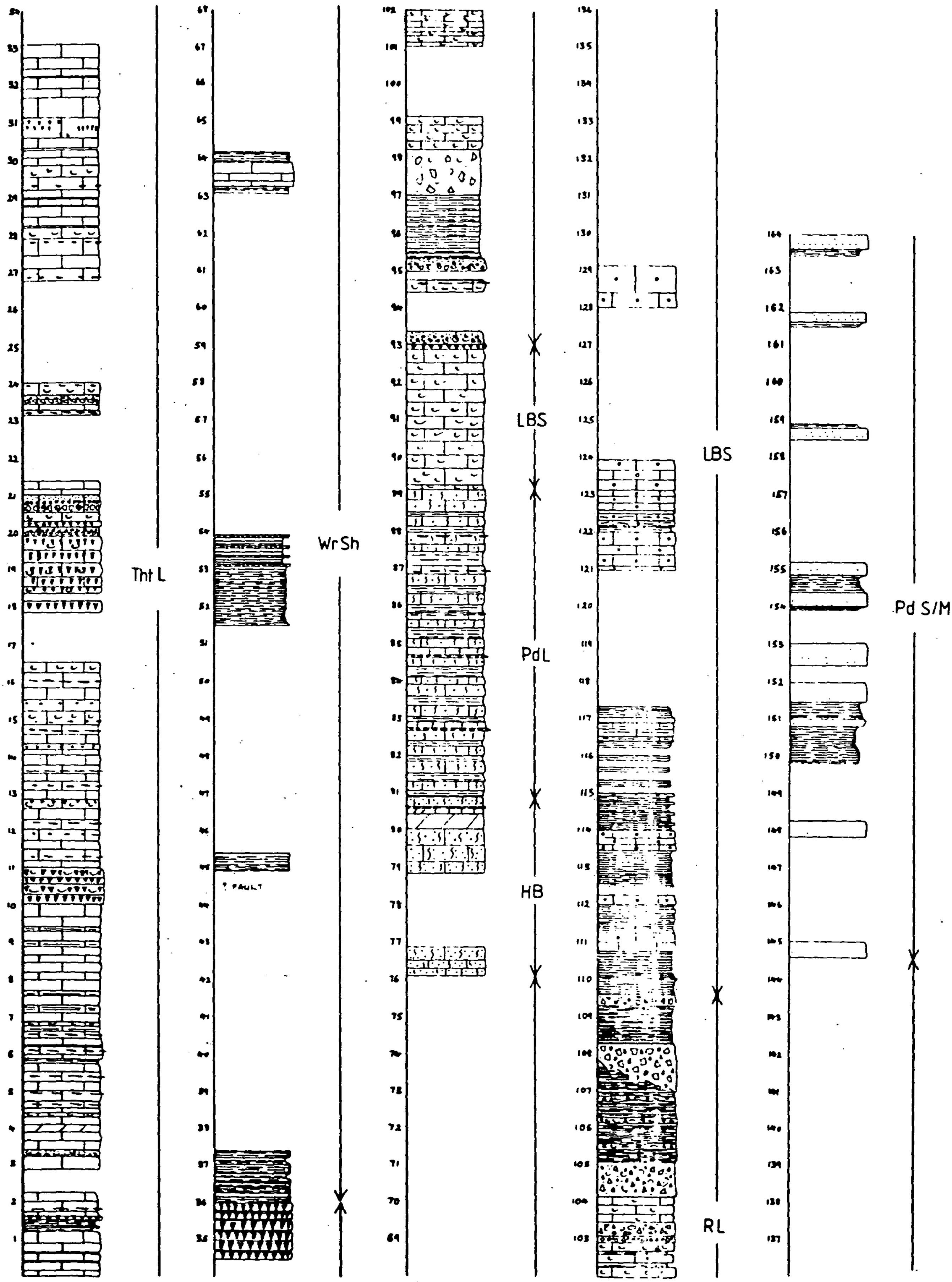


FIGURE 4.

TROUGH OF BOWLAND SECTION