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Geology of the Bacup area (SD82SE)

E Hough

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1 Introduction

This report describes the geology of 1: 10 000 sheet SD82SE (Bacup). The area (hereafter referred to as 'the district') was first geologically surveyed on the 'old' county series (sheet 88NW) by E Hull, J C Ward Dakyns and C Fox Strangways, and published in 1870. D A Wray and W Lloyd subsequently remapped the district on the 'new' county sheets Lancashire 72 NE and SE, and 73 NW and SW. The one-inch geological sheet 76 (Rochdale) and the accompanying sheet memoir (Wright *et al.*,) were published in 1927. The area was resurveyed on the 1: 10 000-scale by E Hough in 1999.

The district encompasses the small market town of Bacup, and the industrial areas of Stacksteads and Shawforth. Two main areas of moorland lie within the district: Carr and Crags Moor to the north and Brandwood Higher End Moor to the south. Sandstone from the Millstone Grit has been extensively quarried in the area south of Bacup; Britannia-Whitworth quarry [8750 2010] is still active, although Greens [8535 2095], Greens Moor-Lee [8650 2100], Moss [8925 2000] and Facit [8855 2020] quarries are all disused. Coal has been mined by both deep and opencast methods in the area, although mining has today ceased. Rossendale Valley transects the south part of the district, along which the main Rawtenstall to Rochdale road (A671-A681) passes. The River Irwell flows through Old Meadows [8722 2500] in the north of the district, to Nun Hills [8500 2160] in the west.

The district is underlain by Upper Carboniferous rocks, which have a gentle, but variable dip. These were deposited in the Rossendale sub-basin of the Pennine Basin, which was created by late Devonian and early Carboniferous rifting. During the late Carboniferous, the basin underwent passive, thermal subsidence. The district forms part of the south Lancashire Coalfield, which is not currently worked.

The district was last glaciated during the Devensian. Quaternary deposits include glacial Till and Glaciofluvial Sand and Gravel. Post glacial deposits include Alluvium (associated with the River Irwell), Head and Hill Peat.

All National Grid references in this report lie within 100 km grid square SD, and are given as eight figure numbers. Grid references for the borehole and shaft sections referred to in the text are given in Appendix 1.

2 Geological sequence

The Carboniferous rocks proved beneath the area are from upper part of the Millstone Grit, and the lower part of the Lower Coal Measures, both of which are Langsettian (Westphalian A) in age.

The Quaternary deposits are grouped genetically on the accompanying 1:10 000 map in terms of process operating during their deposition. The sequence below gives a broad indication of their relative ages.

DRIFT

Flandrian	Head
	Alluvium
	Hill Peat
Pre-Flandrian	Glaciofluvial Sand and Gravel
	Till

SOLID

Silesian (Upper Carboniferous)	Lower Coal Measures
	Millstone Grit Group

3 Silesian (Upper Carboniferous)

Carboniferous rocks are known form outcrop studies, boreholes (Figure 3) and from workings for former collieries and opencast workings in the area. Borehole logs are held in the National Geosciences Record Centre (NGRC) at BGS. Details of coal workings are held by the Coal Authority, 200 Lichfield Lane, Mansfield, Nottinghamshire NG18 4RG.

3.1 MILLSTONE GRIT

The Millstone Grit consists predominantly of grey and brown sandstone and grey mudstone; rare coal beds are also present. Sandstone units are present throughout the sequence, and are typically coarse- to fine-grained and well-bedded. No marine bands have been proved within the Millstone Grit within the Bacup area. The group is present at surface or rockhead in the central and southern parts of the district. Figure 4 gives a generalised vertical section of the Millstone Grit proved in the district.

The presence of the Holcombe Brook Grit beneath the district has been inferred from the written record the Plantation Mill Borehole SD82SE 3. The basal 18.44 m of the borehole is described as 'Dark grey, white and hard rock'. These strata, lying under 9.75 m mudstone beneath the Haslingden Flags succession, are tentatively identified as the Holcombe Brook Grit. The unit is in the region of 8 m thick elsewhere in the Rochdale area, so it is highly likely that the succession proved in SD82SE 3 includes some strata from below the Holcombe Brook Grit. The Holcombe Brook Coal, which overlies the Holcombe Brook Grit elsewhere in the Rossendale Basin has not been proved within the district.

The **Lower Haslingden Flags** are in the region of 20 to 33 m thick in the Bacup district. The crop of the Lower Haslingden Flags is restricted to the Rossendale Valley, to south of Bacup and west of Whitworth. Although present at rockhead, the Lower Haslingden Flags are not exposed within the Bacup sheet area as they are mostly obscured by drift. The interval is typically described in borehole logs from the Bacup area (e.g., SD82SE/2 and 3) as 'Hard blue and grey rock, coarse-grained and jointed'.

The **Upper Haslingden Flags** are approximately 36 m thick in the Bacup area, and consist of fine and medium-grained sandstone with subordinate mudstone interbeds. The Upper Haslingden Flags are well exposed in the south of the region, in numerous quarries between Nun Hills and Whitworth. The flags are spilt into two leaves seperated by a mudstone-dominated interval on the northern slopes of Brandwood Higher End Moor.

In Greens Moor-Lee Quarries [8691 2102] (locations SD82SE 6 and 7), over 20 m from the upper part of the Upper Haslingden Flags are exposed. The lithology consists of green-grey silty sandstone, which is medium-grained (rarely fine- and coarse-grained), moderately-sorted and rarely micaceous. The Upper Haslingden Flags are well-bedded, ordered into co-sets composed of silt-draped ripple-laminated sandstone; sub-parallel set-bounding surfaces are typically 0.5 m apart. The lower part of the Upper Haslingden Flags are exposed in a disused quarry 700 m south of Nun Hills [8549 2080]. Here, the Flags are represented by a medium-grained sandstone which is current-ripple and planar laminated. At Bardon Aggregate's Whitworth Quarry [c. 8680 2025] (named on the 1:10 000 map as 'Britanna Quarries'), the sandstone is fine-grained, with subordinate siltstone beds. In all quarries, the major bedding surfaces dip in the region of 2 degrees to the north, with the azimuth of minor bedding surfaces varying from north to south.

The Upper Haslingden Flags are part of the 'Green Facies' of Chisholm (1990). The Upper Haslingden Flags are a broadly upwards-coarsening sequence (Bristow, 1988) that has been interpreted as distributory channel bar-finger sands from a delta-front (Collinson and Banks, 1975). Maynard (1992) considers the Haslingden Flags to be a highstand delta system. In this

environment, sandbodies are typically non-erosive. This agrees with the outcrop evidence from the Bacup district, where there is little evidence of channelling, and sub-parallel bedding is the dominant bedform. However, scouring at the base of sandbodies is up to 1 m (Collinson and Banks, 1975).

Water depth during deposition was generally very shallow, as indicated by current ripples and trace fossils. The presence of silty drapes on the surface of many ripples indicates that water flow waned periodically. Ichnofossils within the Upper Haslingden Flags at Whitworth Quarry were identified as Xiphosurid traces (Chisholm, 1983). These were produced by an animal walking on the sediment surface, or swimming in shallow water just above the sediment surface, which may have been sub-aerially exposed at times. However, Xiphosurid traces have also been described from facies of varying origins, some of moderate water depth.

The mudstone unit between the Upper Haslingden Flags and the Rough Rock is extremely variable in thickness. This is probably due to downcutting by the aggressive basal sandstone unit of the overlying Rough Rock. At Lee Quarry [8690 2102], the mudstone unit is 1.2 m thick; the Beech Mill Borehole (SD82SE 2) [c. 8724 2320] proves the mudstone to be 12.19 m thick. The interval is composed of approximately 40% silty sandstone and 60% mudstone in a quarry 700 m to the south of Nun Hills [8549 2080].

The **Rough Rock** is a brown-yellow pebbly sandstone with rare mudstone and coal beds. It is in the region of 16-22 m thick, and is generally massive or trough cross-bedded. The Rough Rock is well exposed in quarries to the south of Bacup.

The base of the Rough Rock is exposed in Moss Quarry [8925 2006] (location SD82SE 2) and in the south face of Greens Moor-Lee Quarries (locations SD82SE 6 and 7), where it is erosional, downcutting into the underlying mudstone-dominated unit. The bedforms exposed are dominantly large-scale trough cross-beding, with sets generally over 1 m thick. Thin mudstone interbeds are exposed from the mid-part of the Rough Rock at the Britannia railway cutting [8792 2151] (location 8), (Figure 5). At this location, beneath the Sand Rock Coal, the mudstone is blocky, and about a metre thick. Beneath this, the preserved mudstone units are no more than 0.24 m and planar laminated, with the upper parts of mudstone units eroded away by succeeding sandstone units.

The base of the **Sand Rock Coal** lies between 9.8 and 14.9 m above the base of the Rough Rock. It is between 0.1 and 0.6 m thick, and overlies either sandstone or between 0.5 and c. 1 m mudstone. At Whitworth Quarry, the base of the coal is almost flat, and overlies a 0.2 m thick mudstone with *Sigillaria* sp. (Bristow, 1993). The Sand Rock Coal has been extensively worked throughout the district. It has been adit and crop-worked on a small scale on Brandwood Higher End Moor and to the east of Bacup. The Sand Rock Coal has been opencast during the early 1990s at Facit Quarry opencast site, in preparation for the extraction of the underlying Rough Rock and Upper Haslingden Flags. The Sand Rock Coal was split into two leaves at the Facit Quarry site. The lower leaf (termed the 'Rider') is 0.13 m, and the upper leaf is 0.46 m thick. There is a 0.22 m parting between the seams. The Sand Rock Coal is exposed at the Britannia railway cutting exposure [8792 2151] (Figure 5). The coal is 0.25 m thick, and well-bedded. The sequence as a whole dips gently to the south.

At Moss Quarry [8925 2006], the Rough Rock is a pale buff, moderately-sorted quartz-feldspathic sandstone. Grains are angular, and pebbles are very rare. The sandstone is tangentially cross-bedded and lateral accretion barforms are common. Overlying the Sand Rock Coal, at the northern side of the Britannia railway cutting [8792 2151], the Rough Rock is a clast-supported breccia, which is crudely trough cross-stratified. Pebbles are up to 25 mm, well rounded and composed of quartz. In Greens Moor-Lee Quarry [8615 2065], the Rough Rock is a pale orange trough cross-bedded sandstone which is coarse-grained, with rare granules and small pebbles. Grains are mostly angular, and composed predominantly of quartz. A similar lithology is exposed in Whitworth Quarry [c. 8675 2025]. The lithology present in most of the Bacup area

is similar to 'Facies 1-3' of Bristow and Myers (1989), which are characterised by coarse sand to small pebble grain-size, and large-scale cross-stratification.

The **Six-Inch Coal** overlies the Rough Rock. It was formerly exposed at [8545 2255], 200 m north of Mitchell Field Nook, where the seam was 15 cm thick.

The Rough Rock is as a multi-story sheet sandstone. It is part of the 'Micaceous Facies' of Chisholm (1990). It has been interpreted both as a highstand systems tract (Read, 1991), and also as the onshore expression of the lowstand wedge systems tract (Maynard, 1992). The lowstand model is thought by the majority of workers to be best applicable to the Rough Rock. A lowstand systems tract is, in the simplest form, where a relative low sea level results in an increased accommodation space, and aggressive fluvial action is prevalent. Hampson (1995) has interpreted the base of the Rough Rock as a sequence boundary. The sandstone is interpreted as an incised valley fill (Hampson *et al.*, 1996), and as delta fronts (Hampson, 1995), deposited within a braided river system on a delta top (Bristow, 1988). Mudstone beds within the sequence have been interpreted as prodelta deposits and channel abandonment features, related to large and small-scale channel-switching and avulsion. Development of the Sand Rock Coal suggests the abandoned channels were filled to emergence (Hampson *et al.*, 1996); these probably developed in transgressive systems tracts, the upper parts of which have been removed in the Bacup area by the succeeding sandstone beds. The Sand Rock Coal itself is interpreted as an overbank swamp deposit (Bristow, 1993). Hampson (1995) suggests that the bases of the Sand Rock and Six-Inch coals may be taken as initial flooding surface correlatives. This is partly based on the presence of marine bands above the coals in other parts of the Rossendale sub-basin (the *Anthracoceras* Marine Band above the Sand Rock Coal, and the *Gastrioceras subcrenatum* Marine Band above the Six-Inch Coal), and assumptions regarding base-level and sediment supply. The preservation of the Sand Rock Coal within a coarse-grained, aggressive sandstone sequence may be in part due to rapid subsidence (Bristow, 1988). The preservation potential would have been increased as the peat that formed the Sand Rock Coal would have been a smooth mat, which would have resisted rip-up by fluvial action. Hampson (1995) interprets a mudstone interval present on the Sand Rock Coal elsewhere in the South Pennine Basin as a highstand systems tract; this is not present within the Bacup district, probably due to erosion by the succeeding sandstone. Palaeocurrent data indicates the source for the Rough Rock was to the north and east of the Bacup area (Bristow, 1988). Bristow and Myers (1989) estimate the river that deposited the Rough Rock in the Elland area (approximately 20 kilometres to the east of the Bacup area) was at least 6.5 m deep and about 1 km wide.

3.2 LOWER COAL MEASURES

The Lower Coal Measures consist predominantly of grey mudstones and siltstones. Sandstones are present throughout the sequence, mainly as fine- to medium-grained sheets. Thin beds of coal and ironstone are also present. Thick packets of sandstone occur throughout the Lower Coal Measures; the main sandstones have been named, in ascending order, the Woodhead Hill Rock, Gannister Rock, Great Arc Sandstone, Inch Rock, Helpet Edge Rock, Darwen Flags, Milnrow Sandstone, Dyneley Knoll Flags and the Old Larwence Rock. Seven coals have been proved within the district (see Figure 6); most of these have been mined at some scale by either deep or opencast methods, or crop-working.

A mudstone-dominated sequence lies between the Six-Inch Coal and the Woodhead Hill Rock. There is one unnamed sandstone up to approximately 6 m thick within this interval in the Bacup-Nun Hills area.

Mapping suggests that the Woodhead Hill Rock, which is not exposed, and is not proved by boreholes, is between 10 and 18 m thick. In the Cliviger area (SD82NE), to the north of Bacup, the Woodhead Hill Rock is a yellow, medium-grained, rarely pebbly sandstone that is cross-

bedded. The Woodhead Hill Rock forms an excellent feature where it is not covered by glacial drift.

The **Bassy Coal** rests on the Woodhead Hill Rock. The coal is not proved by boreholes in the district, although was described in a stream section of Broad Clough [8641 2393] which was logged during the previous survey. The coal was 0.15 m thick, which compares well to the 0.2 m proved elsewhere in the Burnley Coalfield. There is no evidence to indicate that the Bassy Coal has been worked in the district.

A thin, impersistent sandstone is present between the Bassy Coal and Lower Foot Coal to the north-east of Bacup. It is between 0 and approximately 8 m thick.

The **Lower Foot (Little) Coal** is developed across the area. The coal is typically 0.2 m thick, and has in the past been crop worked in the valley sides at Trough Gate, for example at [8868 2182], in the south-east of the district.

The **Gannister (Lower Foot) Rock** forms a fairly good feature across the district. It varies in thickness from 0 to approximately 3 m. The base of the Gannister Rock is commonly marked by a spring line. Exposure in the Gannister Rock is restricted to the back of a small sandstone quarry, to the east of Bacup [8800 2253] (location SD82SE 1 and 3). The sandstone is bright orange-yellow, and siliceous. The sandstone is cross-bedded, with foresets indicating a northerly depositional palaeoflow. Upright lithified tree trunks are preserved, and coalified plant fragments are common within the sandstone exposure.

The **Lower Mountain (Little) Coal** generally comprises a single coal. The coal is 0.9 m thick in the Freeholds Colliery shaft section (SD82SE 10), Laws New Pit, Greave New Colliery shaft section (SD82SE 4) and the Hogshead Colliery shaft section (SD82SE 7). The coal is exposed in a quarry to the east of Bacup [8803 2255] (location 1), where it is approximately 0.5 m thick.

The **Great Arc Sandstone (Bullion Rock)** is a fine-to medium-grained, well-bedded sandstone. The sandstone is present beneath the Upper Foot Coal, i.e., in the southern and western parts of the district; it is not present under the Union Coal. It forms good features within the district, such as at Jam Hill [8840 2090].

The **Upper Foot (Bullion) Coal** has been identified in most boreholes penetrating this part of the sequence. It is between 0.2 and 0.3 m thick There is no evidence to suggest widespread workings within the seam in the Bacup district.

The amalgamation of the Upper Foot and Lower Mountain coals forms the **Union Coal**. The coal is between 1.2 and 1.6 m thick, and is present in the extreme east of the area, to the east of Todmorden Moor [8990 2370] and Tooter Hill [8927 2381]. The actual union of the Upper Foot and Lower Mountain coals is shown to trend south-east north-west, 'passing under Tooter Hill on the north side of Reaps Moss, and thence a little west of Sharneyford and across Stake Moss' (Wright *et al.*, 1927). The Union Coal has been bell-pitted to the east of Todmorden Moor.

The **Listeri Marine Band** lies above the Upper Foot and Union Coals. The marine band was sampled and described from west of South Grain Farm [8929 2382] during the previous survey. A thin bed of *Posidoniella* was observed overlying the Upper Foot Coal in Whittaker Clough, also during the previous survey. In the Worsthorne district (Hough, 2004) (e.g. borehole SD83SE/50), the marine band is represented by black and grey fissile musdtone with lingula and goniatite impressions.

The **Inch Rock** is present at crop on the slopes of the Irwell Valley, to the north of Bacup. The sandstone is laterally impersistent, attaining a maximum thickness of about 4 m. The sandstone forms a slight feature that is often difficult to trace due to the presence of restored opencast operations on the slopes above its crop, in the Upper Mountain Coal. The sandstone is medium-grained.

The **Inch Coal** is 0.07 m thick in a shaft section from the Freeholds Colliery (SD82SE 10), and 0.05 m thick in a section recorded during the previous survey in Broad Clough [8639 2363]. The Inch Coal has not been mined within the district.

The **Helpet Edge Rock** is composed of grey-brown sandstone, which is coarse-grained and typically massive. Its maximum recorded thickness is 24 m, from Greave Colliery, at Reaps Moss (SD82SE 6). The sandstone is not recorded in many borehole and shaft sections, perhaps indicating it is absent under parts of the district.

The **Upper Mountain (Hogards) Coal** is present in all sections penetrating this part of the sequence. The seam has been heavily mined by deep methods in the east of the area. Beneath Reaps Moss, shaft sections from Greave Colliery (SD82SE 6) and Hogshead Colliery (SD82SE 7) prove the seam to be 0.40m thick. The seam comes to crop to the north of Bacup. Around Small Shaw Height the seam has been worked by opencast methods in the Higher Deerplay site, where it is 0.51 m thick. Around Stake Moss the seam is 0.58 m thick, and has been worked in the Flowers Farm opencast site.

The **Darwen Flags (Trough Edge End Sandstone)** are present at crop in the northern parts of the district. The Darwen Flags is a fine-grained micaceous sandstone which is cross-bedded. Complete sequences of the Darwen Flags are not available; the maximum thickness proved is 7.3 m from Laws New Pit at Greave New Colliery (SD82SE 4). The Darwen Flags are exposed in a small quarry on Reaps Moss [8898 2271] (location 5). The exposure shows a series of units composed of medium-grained, planar-laminated sandstone topped by fine-grained, ripple-laminated silty sandstone. Four such units are present, from 0.15 to 0.36 m thick.

The **Milnrow Sandstone** forms good features to the north and east of Bacup. The hills of Brex Height [8570 2419], Stake Moss[8785 2445], Tooter Hill [8885 2365] and Hogshead Law Hill [8915 2225] are all capped by Milnrow Sandstone. The Milnrow Sandstone is estimated to be in the region of 20 m thick. The sandstone is exposed in several small quarries within the district, at Brex Height, Tooter Hill and Todmorden Moor. At Brex Height [8565 2419] (location 4), less than 2 m of well-bedded, medium-grained, micaceous, ocherous-coloured sandstone is exposed at the back of a small active quarry. Strata in the lower part of the quarry are planar and low-angle cross-bedded, with major bounding surfaces semi-parallel to laminae. The upper strata exposed are tangentially cross-bedded. Foreset dip azimuth is to 018.

Although the **Cemetery Coal** has not been proved in the district, it is likely to be present under at least some of the north-eastern part of the district, based on borehole and outcrop evidence from the Cliviger district (SD82NE). The Cemetery Coal lies within the Milnrow Sandstone, typically about 5 m below the top of the sandstone, and no more than 0.1 m thick.

The **Dyneley Knoll Flags** are present at crop to the north and east of Little Tooter Hill. Their thickness, based on mapping and correlation from adjacent districts, varies between 7.2 and 19 m. The flags are not exposed in the district; in adjacent districts, the lithology is sandstone, greenish-grey, micaceous, well bedded and rarely cross-bedded. The Dyneley Knoll Flags form good features, including Slate Pit Hill [8900 2470]. They have, in the past, been extracted from shallow quarries, now backfilled, to the west and south of Slate Pit Hill.

The **Old Lawrence Rock** is present in the extreme north of the area, from Little Tooter Hill [8880 2430] to Mean Hey [8850 2500]. It is typically composed of grey-green well-bedded sandstone. The sandstone forms a strong feature, and is estimated to be no more than 10 m thick in the sheet area. The sandstone has been quarried [8875 2450]; this excavation is now partly backfilled.

The Lower Coal Measures are composed of a series of stacked cyclothems. A complete cyclothem is typically composed of a fossiliferous black shale horizon (marine band), marine-freshwater mudstone, fluvio-deltaic sandstone and coal with seatearth. It should be noted that not all cyclothems within the Bacup area are complete; in particular, the coals and marine bands are commonly absent. A single cyclothem can be explained in sequence stratigraphic terms; this can

be applied to the whole of the Lower Coal Measures. The bases of major sandstone bodies commonly equate to the sequence boundary. The base of a coal bed has been interpreted as the landward correlative of the initial flooding surface. Marine bands equate to maximum flooding surfaces, and represent the most sedimentation in the Pennine Basin at the time (Flint *et al.*, 1995).

Most of the sandstone units within the Lower Col Measures fall into the 'Green Facies' of Chisholm (1990). The main exception to this is the Dyneley Knoll Flags, which are part of Chisholm's 'Micaceous Facies'. The environment of deposition for the Lower Coal Measures was broadly deltaic. Guion and Fielding (1988) state the lower part of the Lower Coal Measures was formed within lower delta plain/shallow-water delta environments, in which marine incursions alternated with deltaic advances. Trees and vegitation in swamps, marshes and mires form coal beds. Palaeosols formed on emergent interfluves, or fully abandoned channels. Chisholm (1990) details some facies within the Dyneley Knoll-Old Larwence Rock interval. Major mudstone units are suggested to have formed as delta slopes and within abandoned channels. Environments such as distributary mouth bars, crevasse splays and fluvial channels are envisaged for the main sandstone units. Swift sedimentation rates in the Gannister Rock are indicated by the preservation of upright tree trunks. It is possible the trees grew on emergent interfluves that were flooded by a subsequent powerful fluvial event. The presence of ripple-topped planar-laminated sandstone units in the Darwen Flags indicates repeated shallowing-upwards fluvial events.

4 QUATERNARY

4.1 HEAD

Small patches of marshy Head are present: west of Maden Recreation Ground [8603 2280], 250 m north-west of Parrock Farm [8824 2398] and 300 m south of Pasture Bottom Farm [8826 2288]. A thin ribbon of scree is present immediately to the east of Greens Clough [8581 2089].

4.2 ALLUVIUM

A tract of Alluvium up to 200 m wide, passes from Nun Hills to the centre of Bacup. The Alluvium is associated with the Irwell, and estimated to be no more than 4 m thick. A small patch of Alluvium is has been mapped at the northern margin of the district. The Alluvium, which is also associated with the River Irwell, is probably no more than 2 m thick.

4.3 HILL PEAT

Hill Peat is typically composed of wet, dark brown, partially decomposed vegetation with interbeds of silt and sand. Hill Peat in the district is estimated to be no more than 4 m thick. It is present on the higher ground in the area, principally Brex Height [8575 2400] and Small Shaw Height [8600 2500] in the north-west, Brandwood Lower End Moor [8500 2000] to Jam Hill [8840 2095] in the south, and Reaps Moss [8910 2290], Tooter Hill [8885 2395], Maden Pasture [8995 2325], Todmorden Moor [8940 2480] and Mean Hey [8825 2490] in the north-east of the district.

4.4 GLACIOFLUVIAL SAND AND GRAVEL

A patch of Glaciofluvial Sand and Gravel has been identified between Britannia [8765 2210] and Nun Hills [8500 2175], along the Irwell Valley. The western part of the deposit has been proved by a series of boreholes (SD82SE 36-40) for a residential development. These prove the deposit to be a brown silty-sand interbedded with common layers of grey pebbly clay (possibly pods of Till within the sand and gravel). Boreholes indicate the Glaciofluvial Sand and Gravel is in the region of 5 m thick.

4.5 TILL

Glacial Till is present along much of the Rossendale and Irwell valleys, from Nun Hills [8500 2145] to Trough Gate [8870 2150], and north from Bacup, along the Irwell Valley to Old Meadows [8710 2500]. Till in the area is typically composed of dark grey silty, sandy clay with mudstone and sandstone fragments. Trial pits SD82SE 26-35 indicate that pods of sand and gravel may be present within the Till sequence. The thickest proving of Till is 5.5 m, proved by site investigation borehole SD82SE 36, located on the south-eastern fringe of Bacup.

5 STRUCTURE

The Bacup district lies within the south-eastern part of the Burnley Coalfield, part of the South Lancashire Coalfield. The dip of strata in the district is typically low, ranging from horizontal (e.g. east of Shawforth), to shallow, no more than 4 degrees in rocks unaffected by faulting. The dip azimuth varies widely, with the beds rolling and flexing. Strata to the south of Bacup generally dip to the north and north-east, and strata to the north of Bacup generally dip to the south and west.

The strata in the Bacup district are affected by a number of faults of varying magnitude. The major faults trend north-west south-east, and throw to the north. A major subparallel fault set is present from Shawforth [8925 2045] in the south-east of the district, trending north-westwards. A single, unnamed fault passes beneath Cowm [8892 2019], and has a throw of approximately 60 m to the north, throwing the Upper Haslingden Flags in the south against the Woodhead Hill Rock to the north. At Jam Hill 8829 2086], the fault splays. The northern splay dies out to the west of Pennine Road [8721 2260]. The southern splay continues to the New Line Road, throwing Upper Haslingden Flags to the south against the Rough Rock to the north. The fault splays again, at [8755 2165]. The southern splay is mapped slightly to the north of East Hile [8525 2300], where it has a throw of 15 m to the north (as proved in underground workings in the Lower Mountain Coal). The northern splay continues north-westwards, passing beneath Windy Gate [8526 2440], where it has a throw of no more than 10 m to the north.

The Deerplay Fault transects the north-eastern part of the district. The fault has a throw of approximately 100 m to the north-east, throwing the Darwen Flags to the south against the Old Larwence Rock to the north. The Deerplay Fault is a synsedimentary structure that was active during the deposition of the Union Coal-Upper Foot Coal sequence (Broadhurst and Simpson, 1983). The split of the Union Seam southwards into the Lower Mountain and Upper Foot coals suggests the fault originally had a throw down to the south-west. The distribution of 'Rigs' (sediment bodies formed in ponds of water on the peat surface prior to coal formation) in the upper part of the Union and Lower Mountain seams supports the assumption that the Deerplay Fault originally threw down to the south-west. Subsequent reactivation of the fault with movement down to the north east explains the current north-easterly throw.

Several smaller faults have been mapped between the Deerplay Fault and major faults in the south of the area; none of these have throws exceeding 20 m.

6 ECONOMIC GEOLOGY

Figure 7 shows the areas of surface mineral extraction (opencast coal, fireclay and sandstone) within the district.

6.1 COAL

Coal is one of the main resources of the area, and although not presently worked, it has been extensively worked in the past, with practically all the seams in the area having been mined at one time or another. Workings have been concentrated in the thicker seams, the Upper and Lower Mountain coals, and the Union Coal. The Sand Rock Coal has been extensively worked south of Bacup. Extraction prior to the 1950s was by crop working and shaft and adit mining. After this, opencast methods became dominant (see Table 1).

BGS Ref. No.	Site name	Coal worked	Year ceased	Restoration
SD82SE 16/ SD82NE 33	Higher Deerplay	Upper Mountain	1954	Full
SD82SE 17/ SD82NE/34	Flowers Farm and Extension	Upper Mountain	1958	Full
KP 823	Facit Quarry	Sand Rock	1991	None; site worked in preparation for quarrying sandstone form the Millstone Grit

Table 1: Details of opencast coal sites within the district.

6.2 FIRECLAY

Fireclay has been worked by both deep and opencast methods in the north-east of the district, to the north of Midgelden Brook [8992 2381]. The mudstone unit between the Great Arc Sandstone and the Helpet Edge Rock was dug at [8986 2403] and this pit is now backfilled. The fireclay beneath the Lower Mountain Coal at Oaken Clough [c. 8821 2295] was extracted up to the 1950s by deep mining methods.

6.3 SANDSTONE

The **Lower Haslingden Flags** have been quarried on a small scale south of Nun Hills, between [8500 2115] and [8536 2124]. These quarries are now backfilled. The Lower Haslingden Flags were used as a building and paving stone.

The **Upper Haslingden Flags** are the main worked sandstone resource within the district. They have been extensively quarried in the area south of Bacup. Barden Aggregate's Whitworth Quarry [8750 2030] is the only working quarry within the Upper Haslingden Flags in the district. Most of the stone quarried today is crushed and used as a general aggregate, although a small proportion of the stone is as building stone, and used mostly in renovation work.

The **Rough Rock** has been extracted from Greens Moor-Lee [8650 2100], Whitworth [8750 2010], Facit [8855 2020] and Moss [8925 2000] quarries. It has historically been used as a building stone, but is mostly used now as crushed rock aggregate, and after acid leaching, as a high quality quartz sand for glass making (Bristow, 1993).

The **Gannister Rock** is currently being extracted from a small quarry 200 m north of Causeway House Farm [8800 2251] (location SD82SE 1 and 3). The sandstone is used as a crushed rock aggregate.

The **Darwen Flags** have been quarried at Reaps Moss [8898 2271]. The quarry is now disused, and partly backfilled.

The **Milnrow Sandstone** has been extracted from a quarry at Todmorden Moor [8950 2430], and on a smaller scale from quarries at Brex Height [8566 2420] (still active at the time of survey), [8581 2400] and [8575 2418] and Tooter Hill [8883 2365], [8903 2346] and [8890 2342]. It was probably used as a local building stone.

The **Old Larwence Rock** has been quarried on the northern flank of Little Tooter Hill [8877 2447]. The quarry was disused at the time of survey.

7 MAN MADE DEPOSITS and WORKED GROUND

7.1 MADE GROUND

Made Ground comprising of quarry or opencast spoil is present at Holden Gate [8946 2393], Moss Quarry [8920 2022], Land Gate Quarry [8977 2004] and on Brex Height [8572 2402]. Numerous small areas of spoil associated with adit-mining of coal are present between Land Gate [8975 2011] and Hogshead Law Hill [8917 2218].

An ill-defined patch of Made Ground associated with surface-landfill is present at Nun Hills [8515 2132].

The alluvial tract of the Irwell at Bacup has largely been covered with Made Ground, which has acted as a foundation for many of the mills in the area.

7.2 WORKED GROUND

The largest areas of Worked Ground are to the south of Bacup, and are associated with sandstone quarrying in the Upper Haslingden Flags. Smaller areas of Worked Ground are present in the north of the district, also associated with sandstone quarrying. Worked Ground is also associated with the Britannia railway cutting [8789 2150] and the reservoir north of Rochdale Road [8773 2200].

7.3 INFILLED GROUND

The main areas of Infilled Ground are associated with backfilled opencast sites, sandstone and fireclay quarries. The nature of fill is largely unknown, except for a quarry at Nun Hills [8505 2120], which is backfilled with domestic refuse.

7.4 LANDSCAPED GROUND

Bacup Golf Course [8630 2300] is the largest area of landscaped Ground in the district. It consists of ill-defined patches of shallow made and worked ground.

8 GEOLOGICAL HAZARDS

8.1 UNCONSOLIDATED DEPOSITS

Unconsolidated deposits in the Bacup area include **Till, Glaciofluvial Sand and Gravel, Hill Peat, Alluvium and Head, and Made and Infilled Ground.** Unconsolidated deposits are internally heterogeneous, and can be highly compressible compared with other drift deposits or bedrock, and may give rise to excessive or differential settlement of superposed structures. For this reason particular care should be taken in the siting of any construction on such deposits. The presence of relatively impermeable till beneath sand may cause the presence of a perched water table. Running conditions may be encountered in such unconsolidated deposits if encountered below the water table.

8.2 LANDSLIP

Steep slopes consistng of interbedded sandstone and mudstone (such as those formed by parts of the Lower Coal Measures) may be susceptible to slope instability and failure. Two small areas of landslip has been identified, 100 m north of Dury Lane [8924 2153] and 150 m east of Coal Pit Field [8880 2212]. These are probably shallow rotational slips.

8.3 MAN MADE DEPOSITS

Man Made Deposits represent a hazard in three main ways:

1. Areas of backfill (see 'Infilled Ground', above) may have been poorly compacted when emplaced or may contain materials likely to rot or corrode. The composition of the fill material can vary from site to site, and within short distances on a single site. This may lead to unpredictable bearing capacity and uneaven settlement. Additionally, the backfill material may be partly water-soluble and the slow dissolution by water over time may result in the formation of voids and unpredictable ground conditions. If the spoil is dumped on a slope, any buried soil/organic layer may form a plane of weakness and therefore might form a potential failure surface. Poorly managed groundwater flow in embankments and spoil heaps may allow pore pressures to build up in these deposits, resulting in slope failure.
2. Toxic residues, either as a primary component of a Man Made Deposit or generated secondarily by chemical or biological reactions, can migrate both within a deposit itself, and into adjacent permeable strata. The presence of partially backfilled quarries in this area may provide a source of such a hazard.
3. Toxic or explosive gases, particularly methane, can be generated within waste tips and landfill sites. Such gases migrate (sometimes through adjacent permeable strata) and accumulate within buildings or excavations either nearby or some distance away (Aitkenhead and Williams, 1991; Hooker and Bannon, 1993). As with toxic residues, the presence of backfilled quarries may provide a potential hazard.

The possible problems presented by Man Made Deposits in various geological contexts should be addressed by appropriate geotechnical investigations. It must always be borne in mind that, in an area of past and active opencast mining and quarrying, Man Made Deposits are common. Those shown on 1:10 000 Geological Sheet SD82SE (Bacup) were delineated principally by recognition in the field and the examination of documentary sources. As such, only the more

obvious Man Made Deposits can be mapped by this method, and the boundaries shown may contain inaccuracies

8.4 COAL MINING SUBSIDENCE

Much of the area has been undermined, often at many levels under any one site, and from surface to potentially considerable depths. Deep mining ceased in the 1950s and any subsidence affects are likely to have long ceased. A detailed picture of the mining history and possible effects that may be related to mining can be obtained from the Coal Authority, Mining Reports, 200 Lichfield Lane, Mansfield, Nottinghamshire NG18 4RG.

8.5 MINEWATER POLLUTION

Minewater pollution has been a problem since the cessation of deep mining in the region. Polluted minewater (locally termed 'race') has escaped into the local waterways from numerous collieries in the region. After the mine-pumps are turned off, rising groundwater can exit the mine void through shafts and adits. The Coal Authority has undertaken remediation at numerous sites in recent years (for example, at the site of the former Old Meadows Colliery [8680 2400]) in order to alleviate the problem.

Appendix 1

Grid references of borehole and shaft sections, and opencast sites referred to in text.

BGS Ref. No.	Borehole/Shaft/Opencast Name	Grid Reference
SD82SE 2	Beach Mill	8723 2320
SD82SE 3	Plantation Mill	8684 2253
SD82SE 4	Laws New Pit, Greaves New Colliery	8856 2346
SD82SE 6	Greave Colliery	8926 2287
SD82SE 7	Hogshead Colliery	8932 2225
SD82SE 10	Freeholds Colliery	c. 892 207
SD82SE 16 SD82NE 33	Higher Deerplay Opencast Site	876 250 – 880 240; extends northwards
SD82SE 17 SD82NE 34	Flowers Farm Opencast Site	853 249 – 866 245; extends northwards
SD82SE 26-35	Residential development, west of Stack Lane (Trial Pits)	Area around 875 219
SD82SE 36	Residential development, west of Stack Lane (Borehole)	c. 875 219
KP 823	Facit Quarry Opencast Site	Area around 880 204

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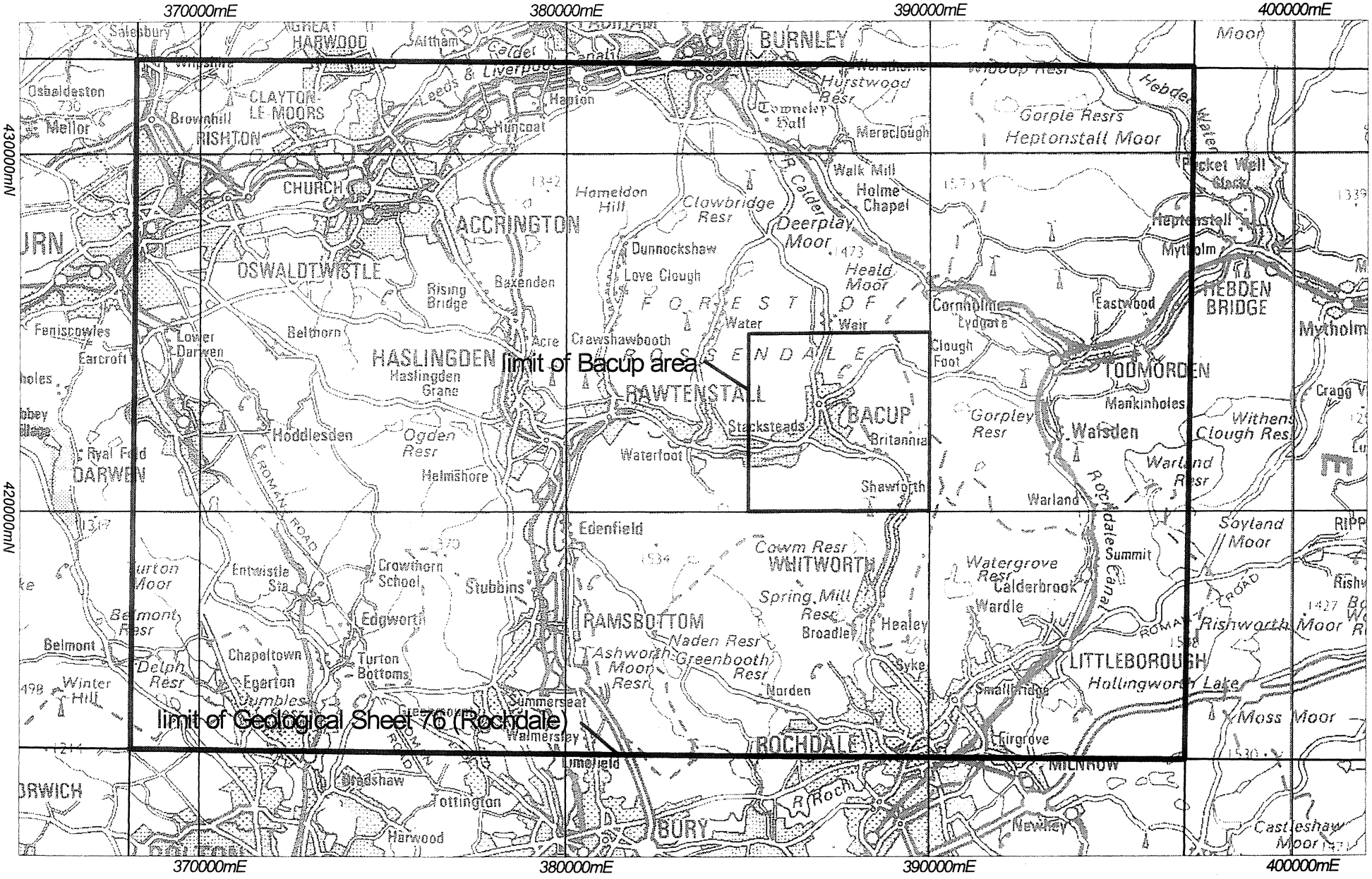


Figure 1: limit of Rochdale Geological Sheet showing Bacup area explained in this report

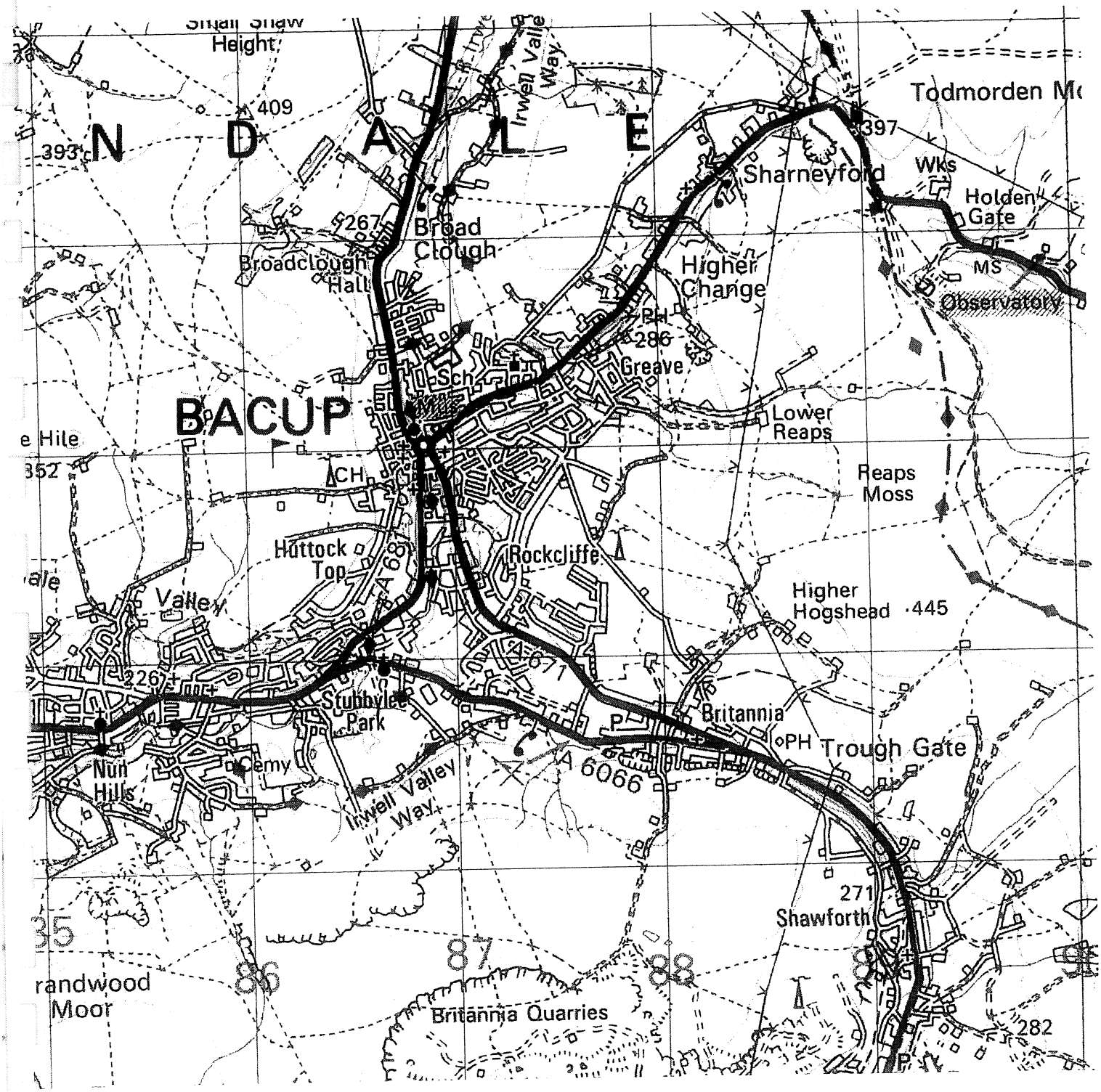


Figure 2: Map of the Bacup district

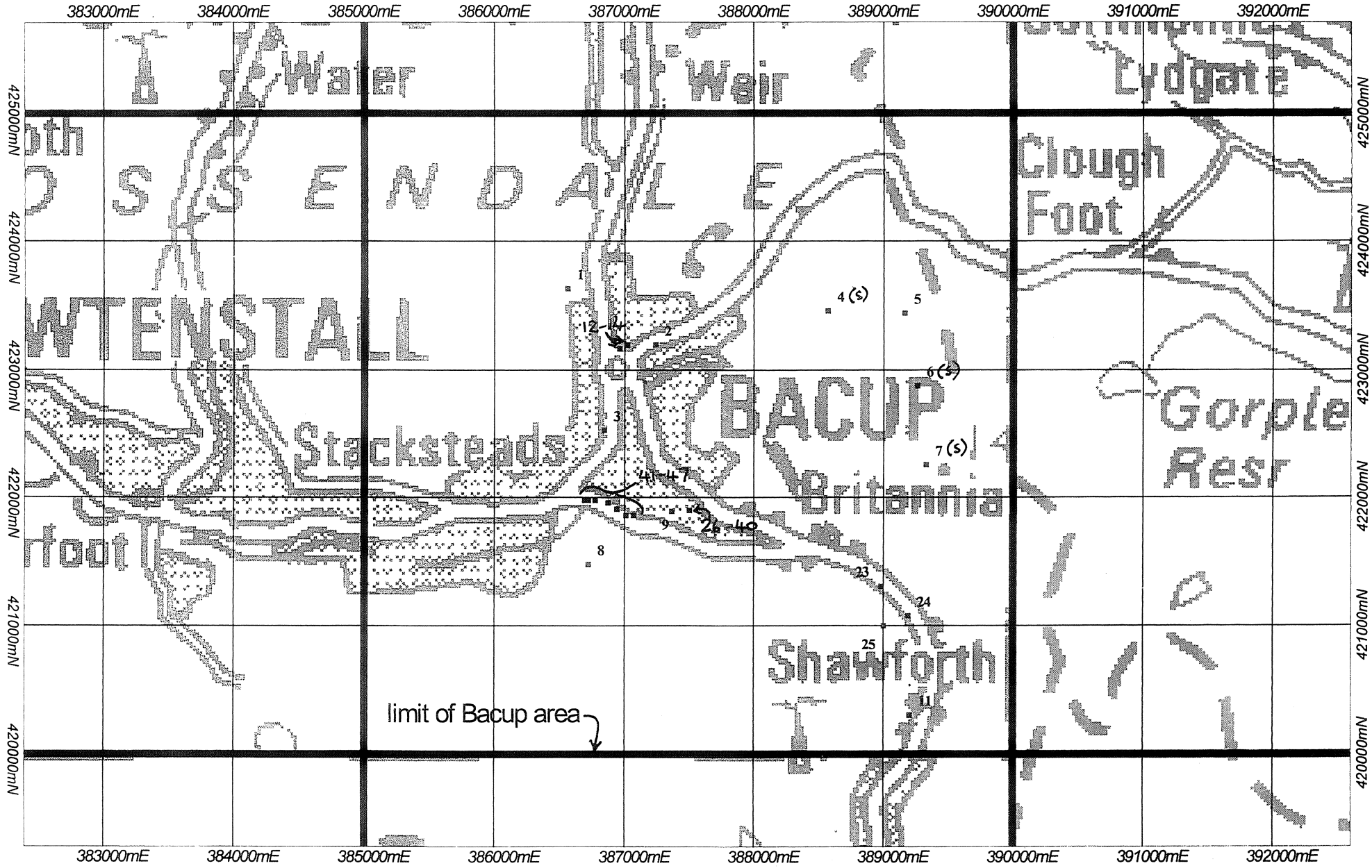


Figure 3: Location of boreholes and shafts (suffixed 's'). Numbers are those of the BGS record system, where they are preceded by SD82SE. Full details are given in Appendix 1.

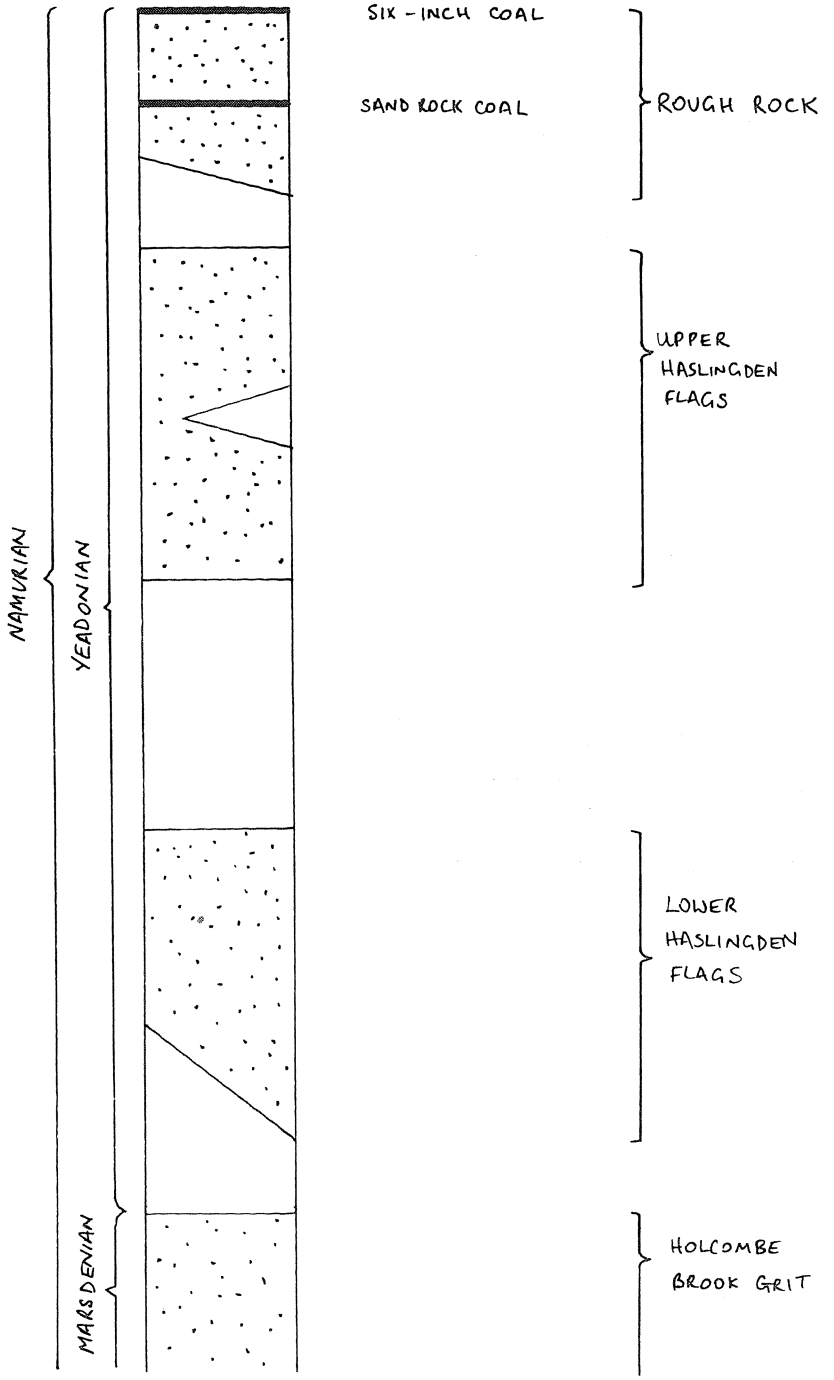
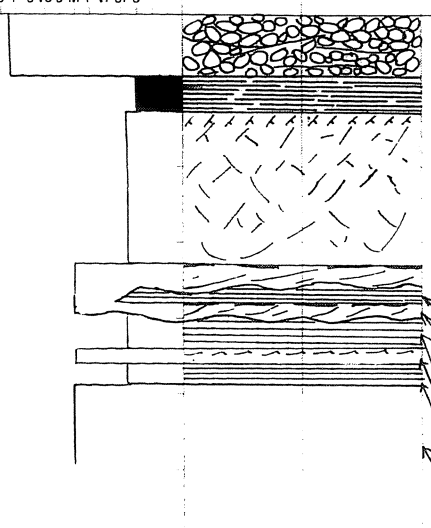


Figure 4: Generalized vertical section of the Millstone Grit proved within the Bacup district; chronostratigraphy on the left, lithostratigraphy on the right Scale approx. 1:800

BRITISH GEOLOGICAL SURVEY Sheet of

Borehole/Well No.	Location Disused railway cutting (N-side) BRITANNIA, ROCHDALE	NGR/Lat. & Long. (887920 421510)
Scale 1:50 (1cm : 50cm)	KB/Ground level	Logged by E HOUGH

Stratigraphy	Carbonates Calc. R Calc. A Calc. L Average grain size C P G V C C M F V F S I C	Sedimentary structures	Graphic lithology	Lithological description



0.4	Sandstone, very pebbly (pebbles: quartz, well-rounded, medium-large pebble size). Crudely stratified.
0.25	Coal, thinly-bedded
c.1.0	Mudstone, grey-orange, slickensided/brecciated. Suggestion of seatearth beneath coal.
0.19	Sandstone, low-angle cross-bedded, with lithified wood fragments on upper surface, (coalified)
0.10	Mudstone, planar-laminated; wedges out laterally
0.11	Sandstone, low-angle cross-bedded, with lithified wood fragments on upper surface; coalified
0.24	Mudstone, planar-laminated
0.1	Sandstone, massive, wave-ripple-laminated in upper part
0.12	Mudstone, planar-laminated
0.54	(Base not seen) Sandstone, massive

Figure 5: Log of the Sand Rock Coal, Britannia Railway Cutting [8792 2151]

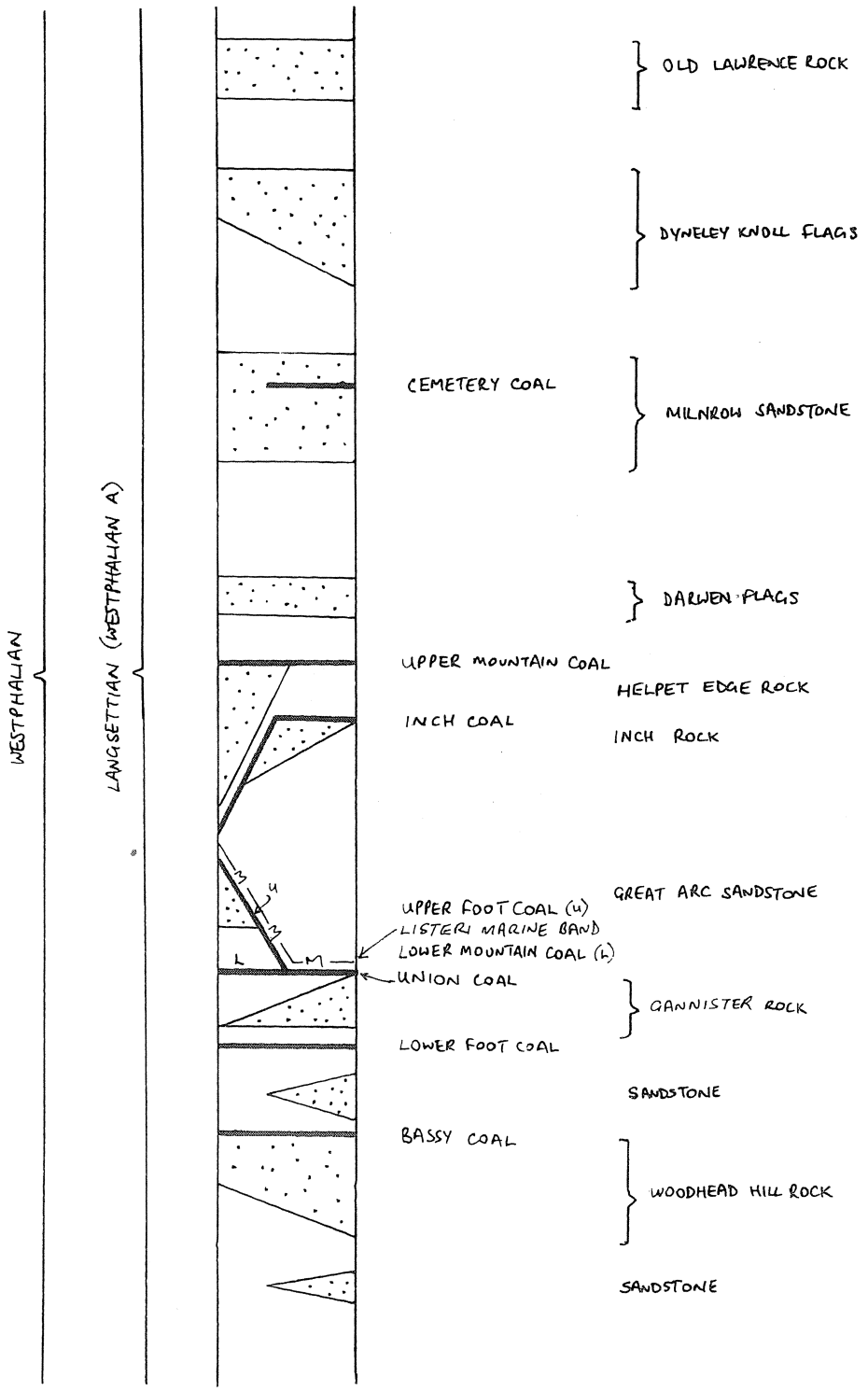
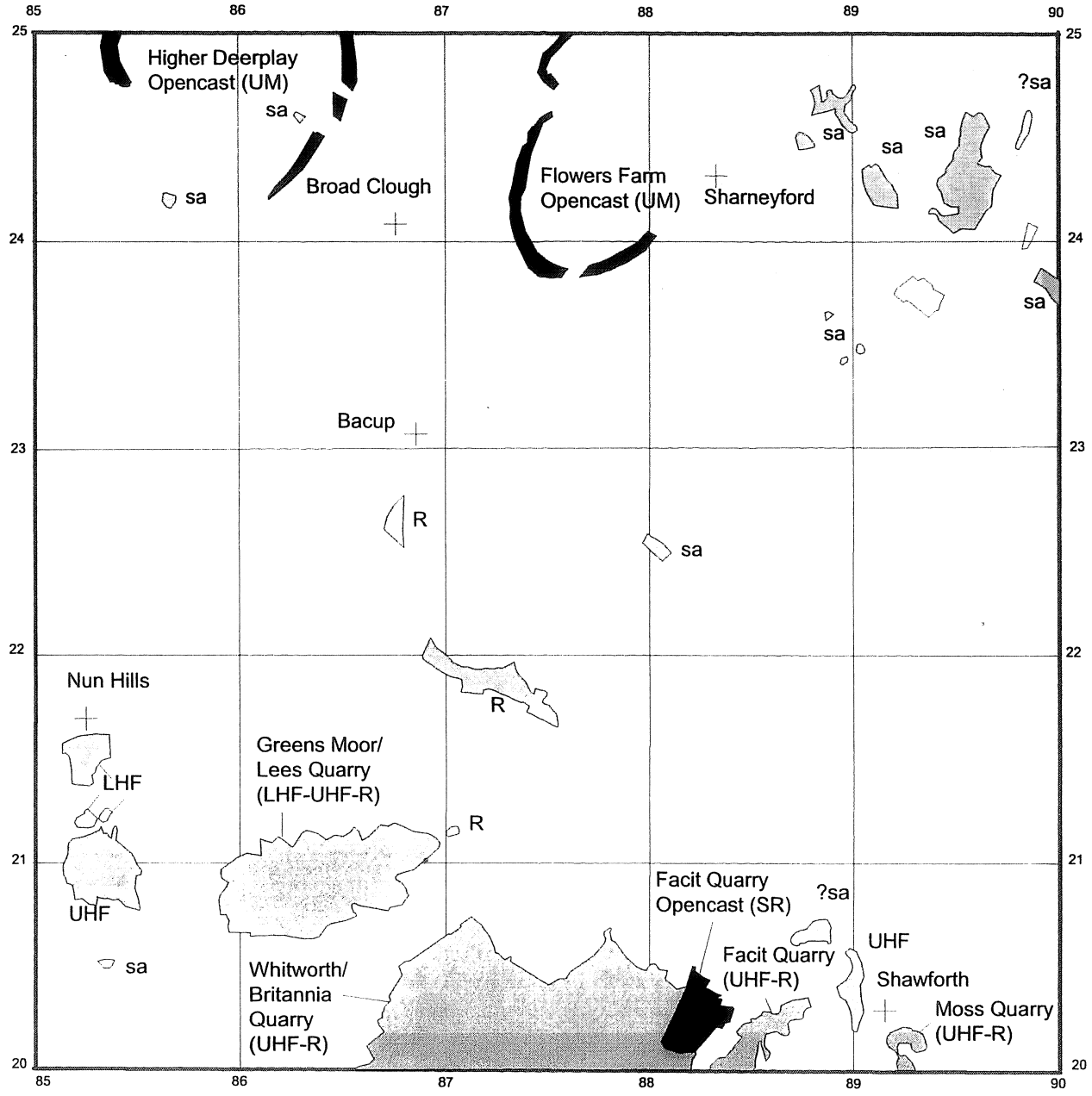


Figure 6: Generalized vertical section of the Lower Coal Measures proved within the Bacup district; chronostratigraphy on the left, lithostratigraphy to the right

Scale approx. 1:1250



Named opencast coal site, with coal worked (UM= Upper Mountain; SR= Sand Rock)

Sandstone, with sandstone worked (LHF= Lower Haslingden Flags; UHF= Upper Haslingden Flags; R= Rough Rock; sa= sandstone within Lower Coal Measures)

Fireclay

Figure 7: Main areas of surface mineral workings within the district