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Reference sections in the Lower Coal Measures at Elland, West Yorkshire

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Summary

Three former quarries and a working quarry near Elland (West Yorkshire) have recently provided a complete section through 136 m of Lower Coal Measures. Exposure extends from 11 m below the Soft Bed Coal to the lower beds of the Elland Flags. There has been an unique opportunity to record the Atlas Quarry section when it was enlarged immediately prior to landfill.

There are eight marine bands, four of which are new records for the immediate area. Details of faunal and lithological zonation within the bands are given. Numerous mussel bands include one below the Hard Bed Coal which is new to the area.

The sections are located in 1:50 000 Sheet 77 (Huddersfield) and straddle the boundary between 1:10 000 Sheets SE 11 NW and SE 12 SW.

1 Introduction

The quarries in the Elland area (Figures 1, 2) have recently provided a complete section through 136 m of Lower Coal Measures. One section, Atlas Quarry, was greatly enlarged in 1997–1998 to provide space for landfill. The period 1995–1998 was an uniquely good one to record these sections before they became obscured.

The sections lie in the basal part of the Lower Coal Measures, in the Lenisulcata and Communis zones, the lowest non-marine bivalve zones in the Langsettian Stage of the Westphalian (Figure 3). This part of the succession forms a recognisable unit, which throughout the Pennine region includes common marine faunal bands and palaeosols (Eden, 1954; Calver, 1968a, 1969).

The main lithologies follow one another in a cyclical pattern. At the base of each cycle a bed of mudstone (with or without a marine band) rests sharply on the palaeosol of the underlying cycle and is overlain by siltstone and sandstone. At the top of the cycle lies the palaeosol (or seatearth), which can include leached lithologies known as ganister and fireclay. Coal, if present, may lie within the seatearth or on top of it.

Depositional environments of these beds have been interpreted by Chisholm (1990) and Chisholm *et al*. (1996). All accumulated in large lakes which extended over the whole Pennine region, and which were linked to the sea at times of marine highstand (Calver, 1968a). Prograding river systems introduced clastic sediments, sandstones and siltstones being the proximal deposits formed in delta mouthbars and distributary channels, and mudstones the distal deposits that built up on the lake floor. Sandstones are thin in the Elland sections, showing that the area was relatively remote from the main points of fluvial input to the basin.

The cyclical nature of deposition in the Upper Carboniferous is commonly attributed to cyclical changes in world sea level produced by climatic variations, these being linked to regular changes in the earth's orbit (review by Leeder, 1988). In the beds described here, the marine bands represent highstands of global sea level and the seatearth palaeosols are taken to represent lowstands.

The marine band names used in the present account are those standardised by Ramsbottom *et al*. (1978), and the names of sandstones and coal seams are those used in the Bradford area by Waters *et al*. (1996, fig.3); synonyms used locally in earlier accounts are included in Figure 3. The distinctive nature of these beds was recognised in the name 'Ganister Coal Group' (or 'Series') formerly applied to the strata between the base of the Coal Measures and the 80 Yard Coal (e.g. Phillips, 1832; Wray *et al*., 1930).

Mudstones of the Lower Coal Measures escarpment in the Elland district were worked firstly near Blackley for pottery clay in the early 18th century (Walton, 1938). Later, in the 19th century there was much demand for glazed pipes and bricks, whilst during the 20th century bricks have become the dominant product. Now only the large Calder Quarry is still active, operated by Hanson Brick. Fifty two years ago when one of us (AAW) first examined the area, the firm of Samuel Wilkinson, founded in 1882, dominated the extractive industry with active workings at the Woodman, Atlas, Blackley and Hollins Hey quarries south of Elland (Figure 1). On the Ainleys, east of Elland, Sharratts worked the Storth and Holbeck quarries, with associated adits into thin seams of refractory clay, and Hawkyards worked the Victoria Quarry. Nowadays all these are closed down. The Calder works existed as a small pit but was not visited at that time. Part of the Storth Quarry is still exposed as a picturesque cliff next to the Elland Bypass road, and is a designated RIGS site. The Atlas Quarry is currently being operated as a containment landfill by Park Pit Landfill. Woodman Quarry, Blackley and Hollins Hey have already been infilled.

D A Wray made the first detailed six-inch scale Geological Survey map in 1924–1925. Wray *et al*. (1930) located the Listeri Marine Band at Atlas Quarry and described three other quarry sections from the area. These were working refractory clays associated with the Hard Bed Band and 36 Yard coals for manufacture of pipes, firebricks and seggars. Wray and Trueman (1934) described Jarmain's Minerva Works boring (Figure 1) at Kirkheaton, 7 km southeast of Elland, where four marine bands were identified in the sequence of strata covered by the present work. The earliest local records of the Meadow Farm and Amaliae marine bands were included. Non-marine bivalve faunas were also noted.

In 1949–1950 one of us (AAW) as a young student measured up sections in workings at Hollins Hey, Blackley, Woodman and Atlas. Eagar (1952, plate 1) recorded a section with non-marine bivalves in the mudstones above the Soft Bed Coal at Woodman Quarry. He noted the existence of two paper-shale beds corresponding to the Holbrook and Springwood marine bands but did not find marine faunas. In 1962 a field trip was led (by AAW) for the Leeds Geological Association, on which the Listeri Marine Band and certain other dark shale bands were collected for fossils. Dr M A Calver, who was on this trip, organised further collecting and then led an excursion to Elland for the 6th International Congress of Carboniferous Stratigraphy (Calver and Ramsbottom, in Francis, 1967). The Honley, Listeri and Lower Parkhouse marine bands were identified in the Woodman and Atlas pits. Eagar (1974a, 1974b) recorded a non-marine bivalve fauna below the Stanningley Rock at Woodman Quarry, another below the 48 Yard Rock at Sharrats (Storth) Quarry and a third, the Norton Mussel Band, below the 80 Yard Rock at Storth. The existence of the Amaliae (Tonge's) Marine Band below the Norton Mussel Band was also recognised but the coal 3.65 m below the marine band was wrongly named the 36 Yard Coal. It is in fact the 48 Yard Coal (Figure 2). The Storth section was recorded by Turner (in Scrutton, 1994) but the Amaliae band was omitted and the 80 Yard Rock was shown as Elland Flags. The 80 Yard Rock was shown correctly in a revised edition (Scrutton, 1996).

In 1995 the present authors independently of each other measured the Storth section and noted the existence of the Amaliae Marine Band. This led to work in Calder, Atlas and Woodman quarries. The highest portion at the Atlas Quarry was revealed late in 1997 as the pit was extended to accommodate more landfill.

The present account details the findings from the 1995–1998 exposures, together with additional information from the now infilled Blackley and Hollins Hey quarries seen in 1949–1950. Faunas collected during the present work were identified by Dr N J Riley (British Geological Survey). The map (Figure 1) is based on BGS revision mapping carried out by one of us (JIC) in 1995–1998. National Grid references are given in square brackets.

2 Description of sections

Beds below the Soft Bed Coal are confined to the northwest end of Woodman Quarry (Figure 2), where they have been exposed for at least 50 years. The lowest visible strata are 2 m of siltstone, very fine-grained sandstone and silty mudstone, lying an estimated 25 m above the base of the Coal Measures (Figure 3). These are overlain by 4 m of mudstone with two bands of siderite. Mussels, mostly *Curvirimula belgica*, occur in several beds. Siltstones and silty mudstones follow, with a number of sandstone bands at the top. The fine-grained sandstones are highly micaceous with irregular carbonaceous laminations and many roots. They are the attenuated representatives of the **Soft Bed Flags**, which thicken rapidly to the south, where they form a plateau at Lindley and Marsh, about 2 km away (Wray *et al*., 1930; confirmed by recent BGS mapping). Seatearth mudstone underlies the **Soft Bed Coal**, which is currently exposed in the lowest level of Woodman Quarry [SE 1055 2004] with a thickness of 35 cm. In its roof are 22 cm of dark grey shaly mudstone with abundant fish scales 8 cm above the coal.

In 1950 measurement of **beds between the Soft Bed and Middle Band coals** at Woodman revealed two thin beds of carbonaceous shaly mudstone (see also Eagar, 1952). Further work (Calver and Ramsbottom, in Francis, 1967) showed that both beds contained fish remains. The present work (Figure 2) shows that marine faunas are present in both beds, confirming that they are the **Holbrook and Springwood marine bands** of the standard sequence of Ramsbottom *et al.* (1978). The lower bed, the Holbrook Marine Band, has two exposures in Woodman Quarry, one at the western end [SE 1034 2011], where *Lingula mytilloides, Spirorbis, Elonichthys, Rhadinichthys* and coprolites are recorded, and another in the lowest face [SE 1058 2002] where the best section is seen, as follows:

	m
Mudstone, dark grey, friable; jarosite	0.17
Mudstone, very dark grey, shaly, with fish bones, spines, coprolites and *Lingula mytilloides*	0.05
Mudstone, dark grey, silty; jarosite; fish scales, *Carbonita* sp. and *Curvirimula* near top; *L. mytilloides* near middle; very silty towards base with 4 mm-wide burrows, *Curvirimula* cf. *subovata* and *Elonichthys* sp.	0.17
Mudstone, dark grey, friable; jarosite	0.16
Siltstone	--

The first definite record of the Holbrook Marine Band in the area was 4 km to the south, at Springwood railway cutting [SE 1377 1637], where Eagar (1947, p.15) noted *Lingula* and *Orbiculoidea* in paper shale 4.26 m above the Soft Bed Coal.

At the western end of the quarry [SE 1034 2008] the higher bed, the Springwood Marine Band, shows the following section:

	m
Mudstone, dark grey; mussels	--
Mudstone, dark grey, shaly; jarosite; finely striated plant, *Lingula, Spirorbis, Rhadinichthys* and gill raker of fish	0.03
Mudstone, dark grey, friable; jarosite; palaeoniscid scales, *Curvirimula belgica, Carbonita* sp. and *Spirorbis*	0.06
Mudstone, dark grey, silty, ferruginous; jarosite	0.09
Mudstone, dark grey, ferruginous	--

At a nearby exposure in the lower cliff [SE 1060 2001], beds are more weathered, but include fish spines, coprolites and *Lingula* spat.

The type section of the marine band is in the Springwood railway cutting [SE 1377 1637], some 4 km to the south, where Eagar (1947, p.14) recorded *Lingula* in paper shale 7.3 m above the Soft Bed Coal.

Between the Soft Bed Coal and the Holbrook Marine Band are some 4 m of mudstones, coarsening upwards into silty mudstones and siltstones. Fish scales occur abundantly in 22 cm of dark grey shaly mudstone 8 cm above the coal. Mussels occur at several levels higher in this sequence in both mudstone and siderite; they include *Anthraconaia* sp., *Carbonicola* sp., *C. fallax*, *C.* cf. *limax, C rectilinearis* and *Curvirimula* sp. [at SE 1055 2003]. Calver and Ramsbottom (in Francis, 1967) recorded *C. fallax, C. protea* and *C. rectilinearis* in this interval.

Some 5 m of beds between the Holbrook and Springwood marine bands are mudstones with siderite nodules, coarsening upwards into siltstone. Mussels occur at many levels in both mudstone and siderite, including *Carbonicola* sp., *C. fallax* and *C. rectilinearis*. The ostracod *Geisina arcuata* is also present [SE 1058 2002]. Ramsbottom and Calver (in Francis, 1967) recorded *C. haberghamensis* and *C. discus* at this level.

Beds between the Springwood Marine Band and the Middle Band Rock are dark grey mudstones with some siderite nodules, with mussels in the lower half of the sequence preserved in both mudstone and siderite. The fauna includes *Carbonicola* sp., *C.* cf. *protea, Curvirimula belgica, Geisina arcuata* and *Spirorbis* [SE 1060 2001]. Calver and Ramsbottom (in Francis, 1967) recorded *C. limax* and *C. declinata.* The uppermost mudstone beds contain sparse rootlets.

The **Middle Band Coal**, 29 cm in thickness, overlies a 1 m-thick very fine-grained seatearth sandstone with stigmarian roots and attached numerous rootlets. This yellow weathering sandstone is an attenuated representative of the **Middle Band Rock**, which makes the dip slope on which much of central Huddersfield, 4 km to the south, is founded.

The **Honley Marine Band** above the coal was examined at the western end [SE 1033 2007] and centre [SE 1043 2002] of Woodman Quarry.

A combined section is as follows:

	m
Mudstone, dark grey, shaly, friable; jarosite	0.14
Mudstone, dark grey, shaly; selenite crystals. Abundant pectinoid bivalves, mainly *Posidonia*, near top; also coprolites, *Calamites*	0.10
Mudstone, dark grey, tough; scattered 1mm pyrite spherulites	0.06
Mudstone, dark grey, shaly; fish scales and coprolites; a ?conodont 5 cm above coal	0.50
Mudstone, dark grey, shaly; coaly laminae	0.03
Middle Band Coal	0.29

The first 47 cm above the Middle Band Coal were examined in detail in a large fallen block which included the top part of the coal [SE 1033 2007]. There was no trace here of the *Posidonia-Lingula* fauna noted in the Woodman Quarry by Calver and Ramsbottom (in Francis, 1967) 'in the immediate roof of the coal'. Such a band undoubtedly exists in some places, because at the Minerva Works boring [SE 1745 1730] a 25-mm band rich in *Lingula* was located immediately above the coal, and at the type locality in Honley railway cutting [SE 1448 1262], some 8 km to the south, Bromehead *et al*. (1933, p.87) recorded:

	m
Mudstone, dark, with bands of ironstone nodules	6.10
Shale, black, with *Lingula* and fish scales	0.23
Coal	0.25

It may be, therefore, that the Honley Marine Band at Woodman Quarry includes two marine faunal horizons, the lower one only sporadically developed and perhaps represented in our sections by the ?conodont noted above. A comparable sequence has been described in Lancashire (Magraw, 1957, p.26).

Beds overlying the Honley Marine Band are well exposed near the centre of Woodman Quarry. The lowest 7.6 m consist of dark grey shaly mudstone, with numerous bands and nodules of siderite varying between 4 and 10 cm in thickness. A petrol-like sheen was seen on the middle beds. About two thirds of the way up the mudstone sequence is a fauna comprising *Carbonicola* cf. *extenuata?, Curvirimula belgica, C. trapeziforma, Naiadites* sp., *Geisina arcuata* and *Spirorbis,* with trace and plant fossils, in a 1m-thick set of mudstones with siderite nodules [SE 1043 2002]. Above the 7.6-m mudstone is a 2.5-m thick pale grey seatearth mudstone.

Above the pale seatearth the **Hard Bed Coal** is about 60 cm in thickness and much of it has been extracted from former underground workings. As made ground has been added in Woodman Quarry, sections have recently become accessible in the former high faces. The coal is preserved in two roof-support pillars [near SE 1050 1996].

The main part of the **Listeri Marine Band** directly overlies the Hard Bed Coal and is some 22 to 25 cm in thickness. It has been examined in detail at two exposures. The first exposure, seen in 1950 [close to SE 1082 1985], showed a tripartite division with dark grey shaly mudstone, rich in *Dunbarella,* lying between two ammonoid-rich beds. This site is now deeply buried under the made ground of the Atlas tip. The present exposure at the Woodman Quarry [SE 1050 1996] shows the Listeri Marine Band intact and 22 cm in thickness above unworked pillars in the Hard Bed Coal. As in the former exposure in the Atlas Quarry, there is a tripartite faunal division, the central unit being packed with *Dunbarella* on many of the bedding planes. The fauna includes *Gastrioceras listeri, G. carbonarium, Anthracoceras* or *Dimorphoceras,* an orthocone, *Caneyella multirugata, Posidonia gibsoni, Dunbarella papyracea* and fish debris. In both the former Atlas and current Woodman exposures, the main fossil band is separated from a higher bed 4 to 6 cm in thickness with *Gastrioceras* and bivalves by 46 to 48 cm of jarositic dark grey mudstone. This higher ammonoid band is in turn overlain by 80 cm of dark grey jarositic mudstone with rare marine bivalves and fish remains.

In 1949 a further poor exposure of the Listeri Marine Band, affected by slippage and weathering, was seen in the Holbeck brick and fireclay works [near SE 1155 2007]. Here large blocks rich in *Dunbarella* were seen in spoil, with other blocks rich in *G. listeri*, smooth ammonoids and bivalves, again suggesting a tripartite division of the main band.

Mudstones with siderite nodules which overlie the Listeri Marine Band include two more marine bands.The lower one, which lies about 5 m above the top of the Hard Bed Coal, was noted by Calver and Ramsbottom (in Francis, 1967); the marine nature of the higher bed is a new discovery. They are probably the Parkhouse marine bands of the standard Pennine sequence (Ramsbottom *et al*., 1978).

The **Lower Parkhouse Marine Band** was briefly exposed in 1986 at the very base of the Atlas Quarry during excavation before renewed tipping [SE 1086 1982]. A further but more weathered exposure is seen at the eastern end of the Woodman Quarry [SE 1055 1993]. At each exposure the marine band contains a tough 3 to 4 cm-thick sideritic mudstone with scattered small bivalves, and there is a distinctive 2 cm-thick grey clay just above. The average sequence, based on the two sections, is as follows:

	m
Mudstone, dark grey, shaly; uneven parting; jarosite	0.40
Clay, grey	0.02
Mudstone, dark grey, shaly, friable; jarosite	0.07
Mudstone, dark grey, sideritic, very tough; scattered small bivalves including *Caneyella* sp.	0.04
Mudstone, dark grey, highly fissile; bivalves including *Caneyella multirugata* and *Posidonia?* abundant on one lamina	0.03
Mudstone, dark grey, shaly; uneven parting; pyritised burrows, *Caneyella* or *Posidonia* and fish fragments 25 cm below top	0.44

Between the two marine bands are 3.2 m of mudstone with siderite nodules. The overlying **Upper Parkhouse Marine Band** has been seen in the Atlas [SE 1089 1982] and Woodman [SE 1060 1995] quarries. It yielded only fish debris to Calver and Ramsbottom (in Francis, 1967). During the present study it was seen to be a platy very dark grey jarositic mudstone 30 to 50 cm in thickness, with *Lingula mytilloides, Curvirimula belgica,* fish scales and pyritised burrow traces. Above the marine band, **measures up to the base of the Stanningley Rock** are mudstones about 13 m thick, with many siderite bands 3 to 12 cm thick, overlain by about 70 cm of siltstone. They are best seen in Atlas Quarry, and more difficult to access at Woodman Quarry, in the high face.

A 30-cm band of mudstone with scattered mussels (*Curvirimula* sp. and *Naiadites* sp.) and *Spirorbis* is present in Atlas Quarry 1.8 m below the base of the sandstone. This bed is part of a 2 m-thick non-marine faunal band recorded by Eagar (1974a, pp.225–226) at Woodman Quarry,

just below the Stanningley Rock. His list comprised *Curvirimula belgica, Carbonicola lenisulcata, C.* aff. *bellula* and *C. extenuata,* with bivalve escape traces (*Pelecypodichnus*) in the basal 90 cm of the Stanningley Rock. A mussel band noted by Wray and Melmore (1931, p.45) in mudstone 21 m above the Hard Bed Coal at the Mold Green Borehole [SE 156 162] in Huddersfield is clearly the same bed.

The **Stanningley Rock** has been exposed recently in a cliff-top exposure across the full 200 m width of Atlas Quarry, with a thickness of about 2.6 m. It consists of fine-grained well bedded light grey sandstone with planes rich in carbonaceous debris and mica. Sideritic concretions occur sporadically within the lower half of the sandstone, and sparse roots are present near the top. The sandstone is overlain by some 3 m of pale grey seatearth mudstone below the Hard Bed Band Coal. The heavy mineral suite in the sandstone is consistent with northern provenance (Hallsworth and Chisholm, 2000; sample ZA 4114A).

The Stanningley Rock is also seen at the base of the Calder Quarry section [near SE 1243 2155] where the visible portion is a fine-grained seatearth sandstone 1.3 m in thickness overlain and underlain by seatearth mudstone. In 1950 exposure in the Blackley Quarry [near SE 1045 1985] was only in the uppermost 30 cm of a seatearth sandstone, overlain by 2.3 m of seatearth mudstone. The seatearth mudstone immediately below the Hard Bed Band Coal has been widely used for pipe manufacture in the Elland district. It is only 30 cm thick at Calder Quarry, but thickens to 2.3 m in former exposures at Blackley Quarry, and to 3 m at Atlas Quarry (see above), where the section is:

	m
Coal (Hard Bed Band), basal 5 cm shaly with plants including *Sigillaria*	0.45
Seatearth mudstone, grey	0.65
Seatearth sandstone, very fine-grained, passing laterally into seatearth mudstone	0.60
Mudstone, dark grey; abundant plants including *Lepidodendron*	0.09
Seatearth mudstone, grey	0.20
Seatearth mudstone, dark grey, with plants	0.06
Seatearth mudstone, grey	1.40

The **Hard Bed Band Coal** is a variable seam containing some 11 to 45 cm of pure coal overlying 5 to 47 cm of inferior coal or coaly shale. In Blackley Quarry (in 1950) 47 cm of coaly mudstone rich in fossil plants were seen underlying 45 cm of clean coal. The coal is currently well exposed in the Calder pit.

At Calder Quarry, **strata between the Hard Bed Band and 36 Yard coals** are all seatearth mudstone, some 1.35 m in thickness. These have been a source of clay for sink manufacture in the past. In new exposures in the Atlas Quarry 5 m of strata occur between the coals, mostly siltstones and fine-grained sandstones with seatearth horizons; plant remains are common. In the now infilled Hollins Hey Quarry [SE 1020 1940] similar interbedded strata about 5 m thick were seen in 1950, containing logs in the sandstones and plants (including pteridosperms) in mudstones. The strata were arranged in erosive-based wedges ranging up to about 3 m thick, with bedding inclined at up to 20°. Discontinuous rootlet horizons were noted.

The **36 Yard Coal** varies in thickness, being 5 cm at Atlas Quarry, up to 10 cm at Blackley Quarry and 14 cm at Calder Quarry.

The 36 Yard Coal is overlain by the sparsely fossiliferous **Meadow Farm Marine Band.** The section at Calder Quarry [SE 1248 2157] is as follows:

	m
Mudstone, dark grey, with pyritic spherulites and tubes; sporadic fish scales and coprolites; *Ammodiscus* and sponge spicules 13 cm above base; one band of 7 cm-thick siderite nodules	0.45
Mudstone, dark grey; pyritic spherulites and tubes at several levels; rare fish scales; cf. *Serpuloides stubblefieldi* near base	0.21
Mudstone, dark grey, with pyrite nodules to 2 mm; fish scales	0.02
Mudstone, dark grey, shaly, with common plant debris	0.02
36 Yard Coal	0.14

New excavation in 1998 at Atlas Quarry [SE 1101 1978] revealed a similar sequence of plant bed, fish bed, beds with pyritic spherulites and a further fish bed. Some 7 km to the southeast the Meadow Farm Marine Band was encountered in the Minerva Works borehole (Wray and Trueman, 1934). The faunal band was in paper shale 15 cm above the coal and contained *Dunbarella* and *Posidonia gibsoni*.

Beds from the Meadow Farm Marine Band up to the base of the 48 Yard Rock were well exposed at Calder and Atlas quarries and in 1950 in Blackley and Hollins Hey quarries, where they provided the raw material for brick making. In all these sections they consist of dark grey shaly mudstones with siderite nodules at many levels. Some fish remains were noted in Atlas Quarry and *Gulielmites* trace fossils occur in several sections. At Calder, Storth [SE 1185 2034], Atlas and Hollins Hey (in 1950) a mussel band was located near the top of the mudstone and locally in the bottom part of the overlying seatearth mudstone. At Atlas Quarry it contains *Carbonicola extenuata* and variants, with *Spirorbis?* This bed was noted at Storth Quarry first by Eagar (1974a, p.226; 1974b, pp.205–206) in rooted silty mudstone 0.55 to 2.16 m below a thin coal now identified as the 48 Yard seam (see below). He recorded *Carbonicola proxima, C. extenuata, C. pontifex* grading to *C.* aff. *declinata, C.* cf. *fallax, C*. aff. *artifex, C. crispa* and *Curvirimula* cf. *belgica*.

The **48 Yard Rock**, a persistent sandstone in the Bradford area, is not developed in Calder Quarry but comes in gradually further south, so that it is 26 cm thick in Storth Quarry and 1.15 m at the Atlas and former Blackley quarries. It is a fine-grained sandstone with rootlets in the upper part.

The **48 Yard Coal** rests directly on the 48 Yard Rock (where that is present) or on rooted mudstone and siltstone. It is 7 cm thick in Calder Quarry, 3 cm in Storth Quarry and only 5 mm of smut in Atlas Quarry. In all three sections, the coal is immediately overlain by about 20 cm of dark grey brittle shaly mudstone with fish remains (including *Rhadinichthys* sp. and *Elonichthys aitkeni*), followed by 3.0 to 3.45 m of shaly mudstones with siderite bands, up to the Amaliae Marine Band.

The **Amaliae Marine Band** is a distinctive bed formerly known in Lancashire as Tonge's Marine Band (Earp and Magraw, 1955). It was first found in the Elland area by Eagar (1974a,b), and its stratigraphical position was given as 3.65 m above the 36 Yard Coal. The status of the marine band is correct, but the coal under it is clearly the 48 Yard (Figure 2). As well as confirming its presence in Storth Quarry, our study shows that the marine band extends across the 200 m-long face of Calder Quarry. As in Lancashire the fossiliferous bed is remarkably thin, some 5 cm only, with abundant but poorly preserved ghost-like impressions of *Dunbarella*.

Details of the sections are:

	Storth [1180 2037] m	Calder [1262 2169] m
Layer of siderite nodules with mudstone matrix	0.12	0.08
Mudstone, dark grey, shaly; uneven parting; jarosite; pyritic pustules up to 1 mm across	0.16	0.29
Mudstone, very dark grey, platy, fissile, rich in jarosite and selenite; poorly preserved *Dunbarella papyracea, Posidonia* cf. *gibsoni*, anthracoceratid ammonoid, conodonts, plant stem	0.05	0.03
Mudstone, very dark grey; 1 mm-wide pyrite pustules	0.03	0.10
Mudstone, dark grey; uneven lamination, some jarosite and selenite	0.07	
Mudstone, dark grey, very ferruginous, with iridescent weathered surfaces	--	--

In the section at Atlas Quarry the Amaliae band is faulted out. The band was recorded in the Minerva Works borehole (Wray and Trueman, 1934), again with poorly preserved *Dunbarella papyracea.*

Mudstones above the Amaliae Marine Band up to the base of the 80 Yard Rock are about 21.5 m thick, partly faulted out at Atlas Quarry but well seen in Storth and Calder quarries. The lowest 12.5 m are dark grey, largely unfossiliferous mudstones with some siderite nodules; sparse *Planolites ophthalmoides* was found in the more shaly beds 0.75 m above the marine band. Some 4 m of dark grey mudstones with a few siderite nodules follow. These have yielded a mussel fauna with cf. *Naiadites hibernicus* and *Curvirimula subovata* (at Calder) and *Carbonicola fallax, C.* sp., *C.* aff. *extenuata* and *Curvirimula* sp. (at Storth). The bed was identified at Storth by Eagar (1974a, pp.226–227; 1974b, pp.206–208) as the **Norton Mussel Band**. He recorded eleven faunal bands in mudstone lying between 3.7 and 6.4 m below the base of the 80 Yard Rock, with faunas dominated alternately by *Curvirimula* and *Carbonicola* spp. His faunal list includes *Curvirimula belgica, C. subovata, C.* aff. *tesselata, Carbonicola extenuata, C.* aff. *fallax, C.* aff. *crispa, C.* aff. *extima, C. declinata, C.* cf. *communis, C.* cf. *bellula, C.* cf. *bipennis, C.* aff. *proxima;* and rare *Naiadites* and *Spirorbis.* The same mussel band has almost certainly been located on the downthrow side of the fault in Atlas Quarry [SE 1090 1972] where only the basal 50 cm of the band can be safely accessed. Above the Norton Mussel Band are some 5 m of largely unfossiliferous mudstone, with mussels seen just below the 80 Yard Rock in the Atlas section.

The **80 Yard Rock** is well defined in the Atlas, Storth and Calder quarries. Typically it is a fine-grained micaceous sandstone, in two or three leaves separated by variable siltstone bands and overlain by seatearth mudstones. In the southwest part of Calder Quarry these leaves amalgamate into a 4.2 m-thick sandstone which includes ripple-laminated, planar laminated and cross-bedded units, plus a convoluted bed. As noted by Hallsworth and Chisholm (2000), the cross-bedding here [SE 125 214] indicates local palaeocurrent flow towards the northwest, but garnet composition demonstrates provenance from the same northern source as that which supplied the Millstone Grits. Laterally, within about 100 m, the sandstone thins northeastwards to 10 cm among some 1.6 m of siltstone, overlain by 20 cm of seatearth mudstone. At Storth Quarry the 80 Yard Rock is at least 7 m thick, but only the lowest 2 m are accessible. The sandstone is fine- to medium-grained, micaceous, parallel and ripple-laminated, with some cross-bedding. Siltstone bands range up to 1.5 m thick. Current ripple-lamination in the lowest beds shows palaeocurrent flow towards the west (27 readings spread between 224 and 288°, circular mean 262°).

Bilobate burrows and associated resting marks are present as positive reliefs on the base of the sandstone. They are very similar to a set of positive hyporeliefs illustrated by Eagar *et al*. (1985, plate 11B) from the Milnrow Sandstone of Lancashire (the stratigraphical equivalent of the 80 Yard Rock) and attributed to the activity of limulid arthropods. The resting traces can be assigned to the ichnospecies *Selenichnites [Kouphichnium] rossendalensis* (Romano and Whyte, 1990), but the burrows are currently unnamed. They have affinities with the limulid burrow *Aulichnites? bradfordensis* (Chisholm, 1985) but the bilobate nature of the latter appears on the upper surface, whereas the 80 Yard Rock trace is bilobate on the underside. Eagar (1974a, p.226) noted other trace fossils here, with small *Pelecypodichnus, Planolites* and *Cochlichnus kochi* on the sandstone base and larger *Pelecypodichnus* 22 to 25 cm above.

The **80 Yard Coal** is a thin and variable seam, sometimes split, which occurs on and within the seatearth mudstone above the 80 Yard Rock. Details are included in the sections tabulated below. Overlying mudstones at the presumed level of the **Langley Marine Band** include a 3 to 6 cm-thick paper shale with jarosite, suggestive of a marine origin. No marine fauna was detected in this and and the adjacent beds, however, although indeterminate trace fossils were present. The beds are exposed in the Calder Quarry [SE 1269 2161] and on the downthrow side of the fault in Atlas Quarry [SE 1101 1972]. The sections are as follows:

		Calder m	Atlas m
Mudstone, dark grey, ferruginous; sparse fish remains at Calder		0.14	0.20
Mudstone, dark grey, very fissile (paper shale); jarosite, selenite, fish debris, worm burrows, *Calamites*		0.06	0.03
Mudstone, dark grey, ferruginous; worm burrows (some pyritic) at intervals; fish fragments including *Rhizodopsis* and *Rhadinichthys*		0.40	0.27
Coal, shaly	80 Yard Coal	0.03	0
Seatearth mudstone		1.10	0.35
Coal, clean		0.08	0.05
Mudstone, grey, with coaly layers		0.07	0
Coal, shaly		0.03	0

Beds above the jarositic mudstones are best seen at Calder Quarry. These are mudstones about 8 m thick with a few bands of siderite nodules and are apparently unfossiliferous. They pass up into about 8 m of siltstones, giving a gradational passage into the sandstones of the **Elland Flags**. The siltstones include beds showing parallel lamination with diffuse interlaminar contacts, a distinctive lithology which has been recognised elsewhere at the base of the Elland Flags (Chisholm, 1990, p.61). The lowest 12 m of this sequence are also seen in Atlas Quarry but, again, no fauna was found in the accessible portions. The Elland Flags thin markedly to the south of Elland, and pass laterally into siltstones of the type just described (Benomley Siltstones: Chisholm, 2000a,b); these then pass southwards into mudstone.

The basal 11 m of the Elland Flags are well seen in Calder Quarry but are just above the exposed section in Atlas Quarry. They are ripple- and planar-laminated fine-grained sandstones with partings rich in mica and comminuted plants. Beds of siltstone up to 2 m thick occur within the sandstone sequence. Palaeocurrent flow was to the southwest, based on current ripple-lamination (7 readings spread between 126 and 252°, circular mean 203°). This is compatible with the wider regional evidence of transport from the north (Chisholm, 1990).

3 Discussion

3.1 MARINE BANDS

All nine of the marine bands that are commonly present between the base of the Coal Measures and the 80 Yard Coal of the Pennine region (Ramsbottom *et al*., 1978, plate 2) have now been identified in the Huddersfield area (Figure 3). Only the basal Subcrenatum Marine Band has not been sampled during the present study. Two marine bands (Langley and Burton Joyce) that lie above the 80 Yard Coal have not so far been found in the Huddersfield area.

The Subcrenatum Marine Band was described by Wray *et al*. (1930, p.63) at the east end of Elland railway tunnel [SE 104 216] and a detailed section was given by Wray and Melmore (1931, p.42) from the Phoenix Mills borehole [SE 149 175] in Huddersfield. The marine band there was 40 cm thick and separated from the underlying Pot Clay Coal by 23 cm of mudstone with non-marine bivalves.

The faunas of all the marine bands conform closely to the distribution patterns worked out by Calver (1968a) for the region as a whole. The Subcrenatum Marine Band is an ammonoid-pectinoid bed, the Holbrook and Springwood bands contain sparse *Lingula*, the Honley Marine Band contains pectinoid bivalves, and the Listeri band is a rich pectinoid-ammonoid bed. The two Parkhouse marine bands (counted as a single band by Ramsbottom *et al*., 1978) have not previously been noted by name north of Sheffield (Calver, 1968a), perhaps because they have been regarded as leaves of the Listeri bed. Their faunas, of pectinoid bivalves and *Lingula*, are consistent with the records further south (Eden, 1954, p.94). The Meadow Farm Marine Band has so far yielded only foraminifera and sponge spicules at Elland, 38 cm above the 36 Yard Coal, whereas at Minerva Works borehole Wray and Trueman (1934, p.42) recorded a thin bed with pectinoid bivalves 15 cm above the coal. Calver (1968a, fig. 11) shows that a pectinoid fauna would be expected in this part of the region. The Amaliae Marine Band, with its fauna of 'ghost' *Dunbarella*, closely resembles its Lancashire development.

The Langley and Burton Joyce marine bands are sporadically found in the mudstones above the equivalent of the 80 Yard Coal in areas to the south of Sheffield. The Langley lies 1.4 m above the coal (Frost and Smart, 1979, p.171), the Burton Joyce between 6 and 7 m above that seam (Eden, 1954, p.101; Smith *et al*., 1967, p.116). Both are thin microfaunal bands containing foraminifera and conodonts, locally accompanied by *Lingula* or pectinoid bivalves (Calver, 1968a, p.34; 1969, fig.6). Chisholm (1990, fig.2) has argued that the horizon of the Langley band in West Yorkshire lies close above the 80 Yard Coal and that the Burton Joyce horizon is most likely to be represented in mudstones that sharply overlie the sandstones of the Elland Flags. Extensive collecting in the mudstones above the 80 Yard Coal at Calder and Atlas Quarries has failed to identify any marine fauna, but a thin paper shale with jarosite, 27 to 40 cm above the coal, is considered the most likely candidate for the horizon of the Langley Marine Band. No evidence relating to the presence or absence of the Burton Joyce Marine Band has been obtained, because the sections did not extend to the top of the Elland Flags.

The marine faunas are commonly found in dark grey fissile mudstones with encrustations of powdery yellow jarosite, sometimes with selenite, both minerals being sulphates produced by the weathering of pyrite. Pyrite in the form of small spherulites and burrow fills is also found in barren beds close to the fossiliferous beds. All these fissile pyritic lithologies, whether fossiliferous or not, are likely to represent condensed sections deposited under anoxic conditions during periods of marine highstand (Calver, 1969, p.245, 7d; Martinsen *et al*., 1995). In five of the marine bands (Holbrook, Lower and Upper Parkhouse, Meadow Farm, Amaliae), and at the supposed horizon of the Langley Marine Band, the central part of each band is better laminated than the rest and tends to weather out. The over- and underlying beds are less well laminated, commonly with uneven or hackly fissility. The best fossils are usually in the well laminated central part, which probably represents the acme of marine incursion.

3.2 MUSSEL BANDS

Non-marine bivalve faunas were recognised in the Huddersfield area by Wray *et al*. (1930, pp.161, 189, 194) below the Soft Bed Flags, above the Soft Bed Coal, below the Stanningley Rock and below the 80 Yard Rock. One below the Subcrenatum Marine Band was described by Wray and Melmore (1931 p.42), and one below the 48 Yard Rock by Wray and Trueman (1934).

The bivalve fauna below the Subcrenatum Marine Band was described in its regional development by Eagar (1953) and referred to *Carbonicola* (now *Anthraconaia*) *?lenisulcata* and *C.* (now *A*.) aff. *bellula*.

Only the highest part of the interval between the Subcrenatum Marine Band and Soft Bed Coal was exposed in the Elland quarries, and sparse *Curvirimula* is the only bivalve recorded. Wray *et al*. (1930, p.194) recorded only *Carbonicola* at this level. However, in a cored borehole drilled not far away in 1965 (Elland Bypass No. 47 Bore [sited at SE 1160 2072]), C G Godwin recorded common non-marine bivalves in silty mudstones just below the Soft Bed Flags (between 4.12 and 5.18 m below the Soft Bed Coal). The composition of a fauna recorded from below the Soft Bed Flags 'in the Bradford, Halifax and Brighouse districts' by Wray and Trueman (1931, pp.72–73; 1934, p.39) is in doubt, because the faunal list includes material from a higher stratigraphical level (Wray and Melmore, 1931, p.45; Eagar, 1954, p.60). Godwin's collection therefore provides the only authenticated fauna from the beds below the Soft Bed Flags in the area.

The beds between the Soft Bed and Middle Band coals were called the Soft Bed-Bassy Mine Succession by Eagar (1947, 1952, 1956) and split into three parts, or cycles, recognisable throughout the Pennine area. The Lower Division, immediately above the Soft Bed Coal, consists of mudstones with bivalve faunas characterised by *Carbonicola fallax, C. protea* and *C. rectilinearis*; the Middle Division, which begins with the Holbrook Marine Band, comprises mudstone with *C. artifex, C. discus* and *C. haberghamensis*; while the Upper Division, with the Springwood Marine Band at the base, comprises mudstone with *C. limax, C. artifex* and *C. declinata*, overlain by the Middle Band Rock (Eagar, 1956, p.333). The faunas recovered in the present study and by Calver and Ramsbottom (in Francis, 1967) are consistent with these generalisations.

The non-marine fauna between the Honley Marine Band and Hard Bed Coal in Woodman Quarry appears to be a new record for the area, although in 1965 C G Godwin did record 'possible mussel fragments' and 'traces suggesting very poor mussels' at this level in Elland Bypass No. 60 Borehole [SE 1182 2009].

A bivalve fauna present between the Listeri and Lower Parkhouse marine bands in the area south of Sheffield (Eden, 1954, plate 2a), and characterised by *Carbonicola prisca* (Eagar, 1954, 1956, p.345), has not been detected in the Elland sections.

The bivalve fauna found during our study just below the Stanningley Rock at Atlas Quarry was first noted by Wray *et al*. (1930, p.161) in Harrow Clough, about 200 m west of Hollins Hey Quarry. The fauna was described in detail by Eagar, first (1956, p.346) in Harrow Clough [SE 099 193], and then (1974a, p.226–227) at Woodman Quarry. He noted the presence of a *Curvirimula* fauna at the base and a fauna characterised by *Carbonicola extenuata* above.

The mussel band found below the 48 Yard Rock in all the Elland sections has likewise been described in more detail by Eagar (1956, p.348; 1974a, p.226; 1974b, pp.205–206). He suggested that the fauna is intermediate between that of the band below and that of the Norton Mussel Band, above.

The widespread Norton Mussel Band, between the Amaliae Marine Band and the base of the 80 Yard Rock, contains bivalves of the *C. extenuata* and *C. crispa* groups, with a wide range of other species (Eagar, 1956, p.350; 1974a, pp.226–227; 1974b, pp.206–208). The band is present at Storth Quarry, where Eagar (1974a,b) noted a cyclical variation of faunas, with thin

Curvirimula beds alternating with thicker *Carbonicola* beds (see below). It is also present at Atlas Quarry. A bivalve fauna noted at a slightly higher level in Atlas Quarry, just below the 80 Yard Rock, has counterparts elsewhere in the region (Eagar, 1956, p.353).

No non-marine bivalve faunas were found above the 80 Yard Coal during the present study.

Eagar (1956, p.355), noting that non-marine bivalve faunas up to the level of the 80 Yard Coal belong to species groups characteristic of the Lenisulcata Zone, while faunas above this level are marked by the appearance of forms appropriate to the Communis Zone, recommended that the zonal boundary be redrawn at the level of the 80 Yard Coal. Calver (1956, fig.4) then placed it at the Burton Joyce Marine Band, but later (1969, fig.4) revised this to the level of the Langley Marine Band.

Non-marine bivalves tend to occur in dark grey mudstone with siderite bands, rather than the fissile pyritous lithology associated with marine faunas. The two types of mudstone are commonly interbedded, so there clearly was depositional continuity between them. The most likely environment for the non-marine bivalves was in large lakes created as falling sea level reduced the regional water level to the point where sea water had only limited access. The genus *Curvirimula* occurs with both marine and non-marine faunas (see above; also Calver, 1968b), so may have occupied intermediate habitats, when sea water was able to gain more frequent access to the lakes. The regular alternation of *Curvirimula* and *Carbonicola* faunas in thin and thick beds in the Norton Mussel Band would then be explained by cyclical rises and falls of sea level, giving thin deposition in deeper water brackish conditions, distant from the sources of clastic supply (for *Curvirimula*), and thicker, more proximal deposition in shallower, fresher water (for *Carbonicola*). Given that there are 5 such cycles in the Norton band, and that this bed accounts for only a small part of the cycle between the Amaliae and Langley marine bands, these minor fluctuations in base level could be an order of magnitude shorter than those responsible for the main marine bands.

3.3 PROVENANCE

Provenance of Upper Carboniferous sediments in Yorkshire has been linked to bulk lithology, sandstone petrography, heavy mineral content, palaeocurrent directions, and palynomorph assemblages (Chisholm, 1990; Chisholm *et al*., 1996; McLean and Chisholm, 1996; Hallsworth and Chisholm, 2000). These studies show that the lowest Coal Measures (the beds represented in the Elland sections) were derived from a northern source, probably the same as that which supplied the Millstone Grit, but that local palaeocurrent flows were variable in direction, with transport across the area from the east as well as from the north.

In the Elland sections the strongly micaceous lithologies characteristic of northern provenance predominate, and heavy mineral evidence from the Stanningley Rock and 80 Yard Rock also indicates a northern source. Limited palaeocurrent data for the 80 Yard Rock and Elland Flags are compatible with known regional trends.

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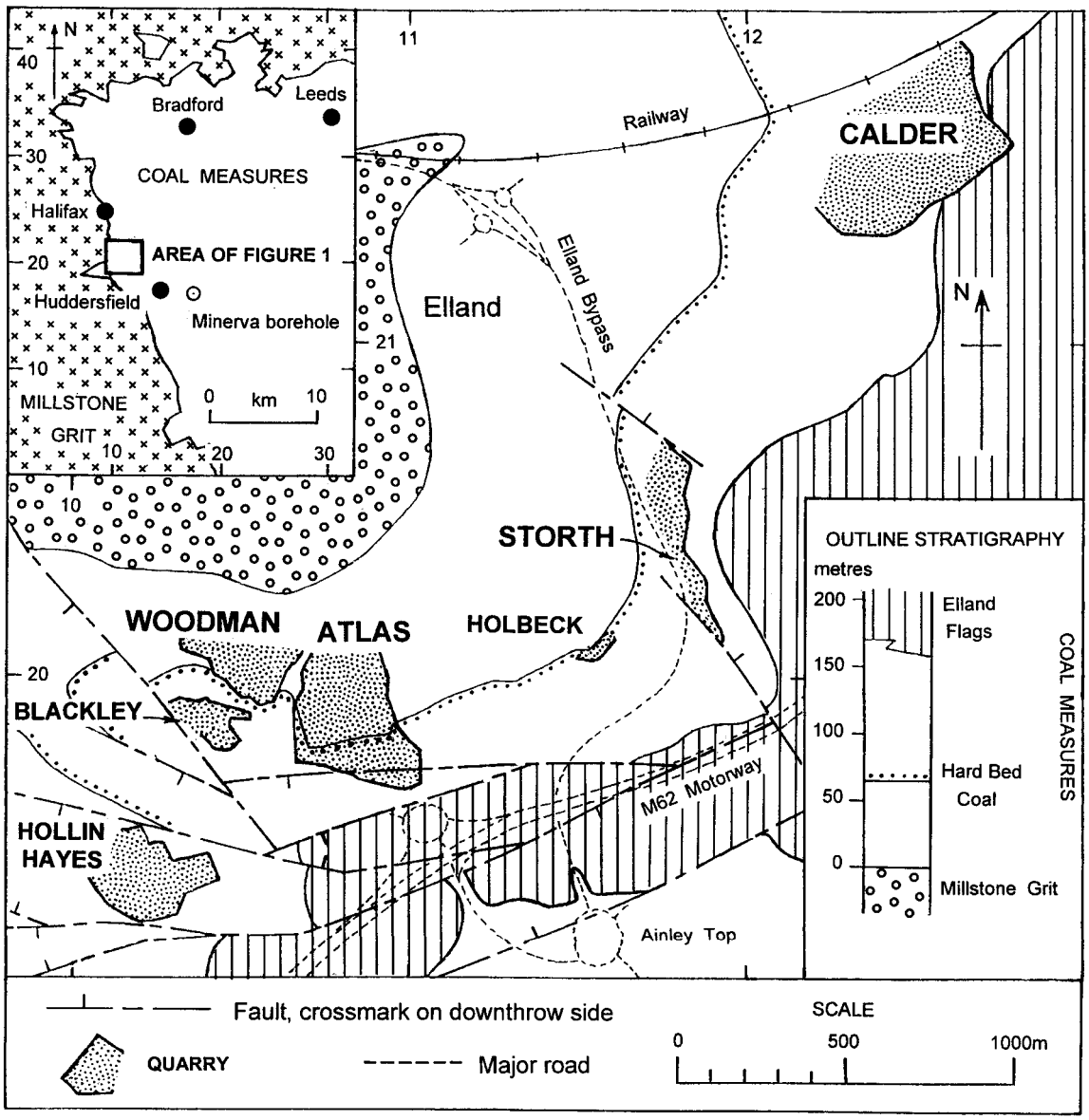

Figure 1. Location of sections and outline geology. Based on BGS 1:10 000 scale maps, sheets SE 11 NW and SE 12 SW.

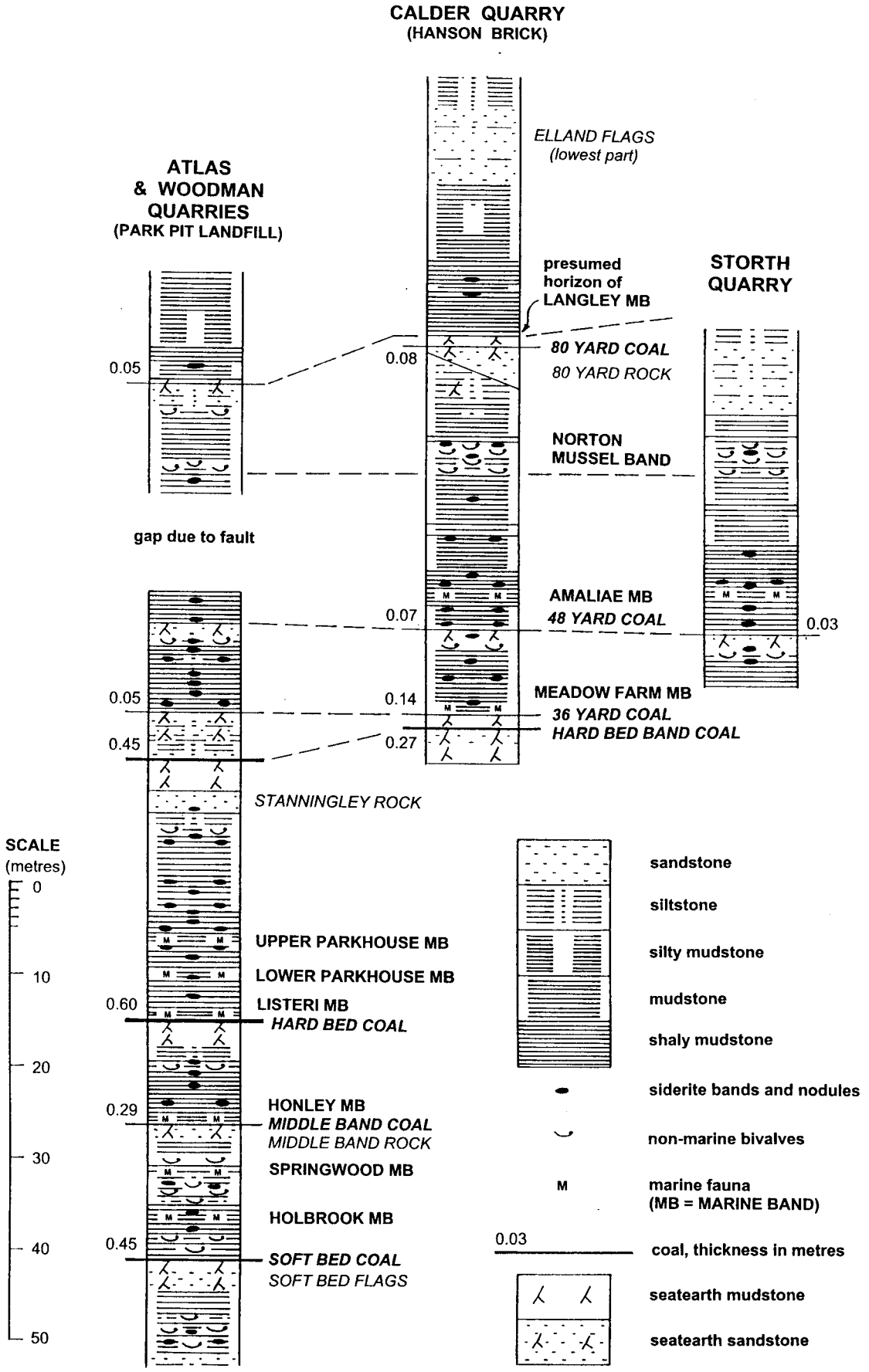

Figure 2 Detailed sections in the Elland quarries

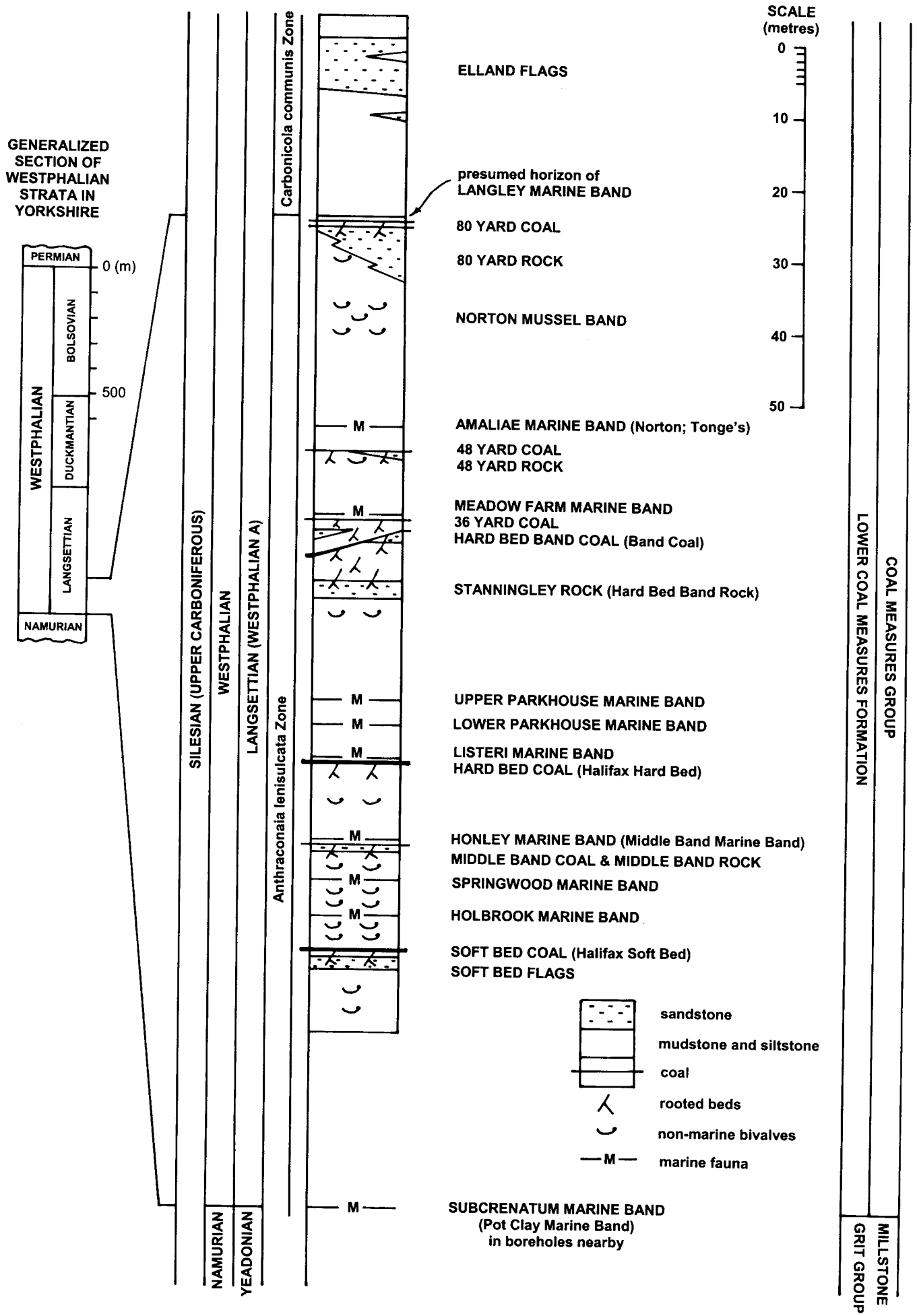

Figure 3. Generalized section of the Elland quarries, related to regional stratigraphy. Yorkshire Westphalian section from Ramsbottom *et al.* (1978). Former bed names are shown in brackets.