British Upper Carboniferous Stratigraphy

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Chapter 12

Scottish Basin

This chapter deals with the area of Late Carboniferous deposition that lay between the Southern Uplands Massif to the south and the Caledonian Highlands to the north (Figure 12.1). In terms of present-day geography, it mostly occupies the area known as the Midland Valley. This is the belt of relatively flat topography that extends between Glasgow and Edinburgh, and which has been the home of most of Scotland's traditional heavy industry (the recent growth of the oil industry in northern Scotland has now changed this balance, somewhat).

Geologically, the area was subject to complex basement control, with numerous fault-bounded basins and blocks, probably resulting from a combination of strike-slip movement and thermal subsidence (Read, 1988). The thickest development is in Fife, where some 280 m of mainly arenaceous strata known as the Passage Group, are overlain by 830 m of Coal Measures. The overall pattern of sedimentation differs somewhat from that of the Pennine Basin to the south, being more condensed and showing a different relationship between the predominantly arenaceous Namurian deposits and the predominantly argillaceous Westphalian strata. There is a further complication in that the majority of the marine bands, that have played such a significant role in establishing detailed correlations in the Pennines, are nowhere near as well developed in Scotland. As a consequence, other biostratigraphical means have had to be employed, particularly non-marine bivalves (e.g. Weir and Leitch, 1936; Brand, 1983) and palynology (e.g. Knox, 1942, 1946). It has also meant that Upper Carboniferous stratigraphical nomenclature has tended to follow a different path from that in the rest of Britain (Macgregor, 1960).

Today, coal is still a relatively important economic resource in the area, with an annual productivity of over 2 million tons (British Coal Corporation Annual Report 1990/91). Modern production is exclusively from the Coal Measures, but in the past coals from the Lower Carboniferous Lower Limestone Coal Group were more significant. In fact, prior to the mid-19th century the Limestone Coal Group was the source of practically all of the coal in this area, and the early records of mining, which extend back to the 12th century, refer to these Lower Carboniferous coals (Macgregor and Macgregor, 1948). In the 1850s, Hull (1861) gives the annual Scottish coal production as nearly 9 million tons, but it is impossible to extract from this which is Upper Carboniferous. The same problem exists in interpreting the figures given by Bone and Himus (1936) for the mid-20th century productivity.

Other important economic resources in the Upper Carboniferous of Scotland include iron ores and refractory clays. In the Namurian of Ayrshire, there are also the bauxitic clays resulting from contemporaneous decomposition of lavas, that have been used as a source of alum, as well as for special types of refractory ware. Further comments on the economic geology of this part of Scotland can be found in Macgregor and Macgregor (1948).

History of research

The Geological Survey started work in earnest in the Scottish coalfields in the mid-19th century. As well as publishing a number of maps, there were also a number of sheet memoirs (e.g. Etheridge, 1873, 1879; Geikie, 1900). During the First World War, the potential economic significance of the Scottish coalfields became evident and the Survey started a comprehensive re-surveying programme. In addition to the maps, a series of memoirs were produced under the titles 'Economic geology of the . . . Coalfield' (Central Coalfield, Ayrshire Coalfields, Stirling and Clackmannan Coalfield, Fife Coalfield). Between 1917 and 1961, 19 memoirs of this type were produced, a full list of which can be found in Macgregor and Macgregor (1961). The drawback of these memoirs is that, being concerned principally with economic geology, they deal mostly with underground workings and temporary exposures. However, there were also published a number of more normal sheet memoirs covering parts of the Scottish coalfields (e.g. Richey *et al.*, 1930; Francis *et al.*, 1970; Forsyth and Chisholm, 1977), as well as a number of extensive papers dealing with the field geology of selected areas (e.g. Lumsden and Calver, 1965; Mykura, 1967; Davies, 1970).

The group of fossils in the Upper Carboniferous of Scotland that has attracted most biostratigraphical attention are the non-marine bivalves. The earliest record appears to be in Ure (1793), which is also claimed by Weir and Leitch (1936) to be the earliest record of such fossils from anywhere in Britain. In the 19th century, there were records by Brown (1843, 1849), Skipsey (1866), Grossart (1868) and Young and Armstrong (1871). The studies by Skipsey and Grossart are particularly significant as they demonstrate that certain species have restricted stratigraphical distributions and are thus of biostratigraphical potential. Towards the

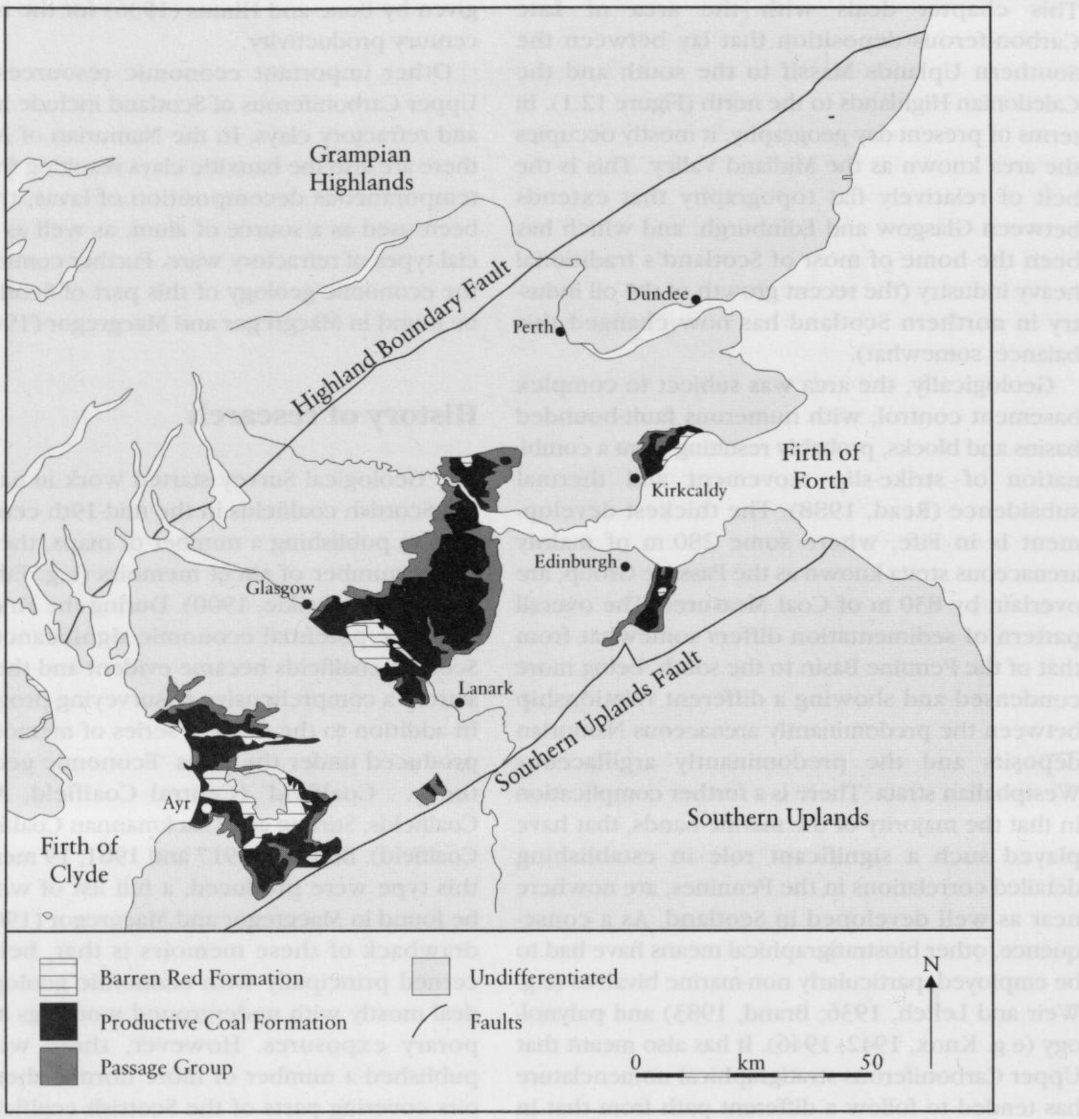

Figure 12.1 Upper Carboniferous outcrops in the Midland Valley of Scotland. Based on Macgregor and Macgregor (1961, pl. 8).

end of the 19th century, Hind's (1894-1896) monograph on these fossils included many Scottish specimens, albeit often with only vague stratigraphical localization.

In the 20th century, major contributions in the study of Scottish Upper Carboniferous non-marine bivalves were by Pringle and Manson (1929), MacLennan (1943, 1946) and Manson (1957), not to mention the numerous records produced in the Geological Survey memoirs mentioned above. Perhaps most significant, however, was the work by Leitch (1936, 1940, 1942), Leitch *et al.* (1937) and Weir and Leitch (1936), which brought together much of the then available information on the distribution of these bivalves in Scotland and enabled a detailed correlation with the sequences in England. Most recently, Brand (1983) has provided a detailed analysis of the non-marine bivalve biostratigraphy of the Ayrshire Coalfield.

As stated at the beginning of this chapter, restricted development of marine bands have meant that they have played a less significant role in Upper Carboniferous stratigraphy in Scotland than in England. Their existence in the Scottish successions was noted by Skipsey (1865) and Kirkby (1888), and detailed studies on two of the most significant bands (Skipsey's and Queenslie) have been given by Currie *et al.* (1937) and Brand (1977).

However, they have not been given the same prominence as the marine bands in England, especially in the Pennines (see Chapter 10).

Despite one of Britain's greatest proponents of plant biostratigraphy being a Scotsman (Robert Kidston), there has been relatively little work of this type done here. Some specimens have been figured in the monographs by Kidston (1923–25) and Crookall (1955–76), and some distributional data provided Walton *et al.* (1938). However, there has been little documentation of the distribution of Upper Carboniferous plant fossils in Scotland, similar to that done in South Wales (see Chapter 4).

Plant microfossils were first studied here by Knox (1942, 1946), and more detailed distributional data for the Coal Measures are provided by Smith and Butterworth (1967). A major study on the palynological biostratigraphy of the Passage Group is given by Neves *et al.* (1965).

As pointed out by Read (1988), the thick Quaternary cover limits surface exposures and thus hinders detailed sedimentological analysis. The most significant advances have been made on the Passage Group, particularly by Read (1969, 1981, 1988) and Read and Dean (1982) using considerable additional data from boreholes. The only notable study on Coal Measures sedimentology in the Midland Valley of Scotland is by Kirk (1983).

Lithostratigraphy

The broad lithostratigraphical pattern of the Scottish Upper Carboniferous can be compared with that in England, especially Northern England. The Arnsbergian to the Langsettian, referred to in Scotland as the Passage Group, is in a predominantly arenaceous facies. This is overlain by more argillaceous beds of the Coal Measures Group. It is well known that the junction between these two groups is at a higher level in Scotland than the equivalent lithostratigraphical boundary in England, and this has caused some problems as to stratigraphical nomenclature (Macgregor, 1960; Lumsden and Wilson, 1979). As shown by Monro (1985), however, if the units are treated in a purely lithostratigraphical sense, the perceived difficulties mostly disappear.

Unfortunately, a full set of formations have yet to be proposed for the Passage Group. The following will only refer to those units relevant to the rest of this chapter:

Ayrshire Bauxitic Clay Formation
- Stratotype: High Smithstone Quarry
- Base defined: lowest occurrence of the bauxitic clay facies.
- Characteristic facies: alumina-rich clays with subsidiary coals and seat earths.
- Chronostratigraphical range: Namurian (exact range uncertain).

Roslin Sandstone Formation
- Stratotype: Joppa Shore
- Base defined: base of the lowest thick sandstone above the Castlecary Limestone and its lateral equivalents.
- Characteristic facies: thick, cross-bedded sandstones with subsidiary shales.
- Chronostratigraphical range: upper Arnsbergian to Yeadonian or possibly Langsettian.

Productive Coal Formation (as defined in South Wales, *q.v.*).

Barren Red Formation
- Stratotype: East Wemyss to Buckhaven Coast
- Base: so far, undefined.
- Characteristic facies: red sandstones, mudstones and seat earths.
- Chronostratigraphical range: (?)Bolsovian to Westphalian D.

Geological setting

The Upper Carboniferous Scottish Basin lies between the Southern Uplands Massif and the Caledonian Highlands, the latter having provided the bulk of the sediment (Figure 12.2). The basin was bounded both to the north and the south by faults, although they were not always active during the Late Carboniferous, and sometimes sedimentation spread over them (e.g. the Sanquhar Coalfield). The basin itself was divided into numerous local fault-bounded blocks and grabens. The faults show widespread evidence of strike-slip movement. Read (1988) uses this to interpret the basin having resulted from thermal subsidence combined with lateral strike-slip, although he recognizes that most of the evidence could also fit with Leeder's (1982) extensional tectonics model (see also Leeder and McMahon, 1988).

A distinctive feature of the Upper Carboniferous of the Scottish Basin is the presence of contemporary volcanicity, particularly in the Ayrshire and Fife coalfields (Francis, 1978, 1983). The resulting lavas are of the alkaline basalt type, and thought to be the result of partial melting associated with 'within-plate' rifting. The lava-piles had a strong influence on basin morphology, affecting both sediment

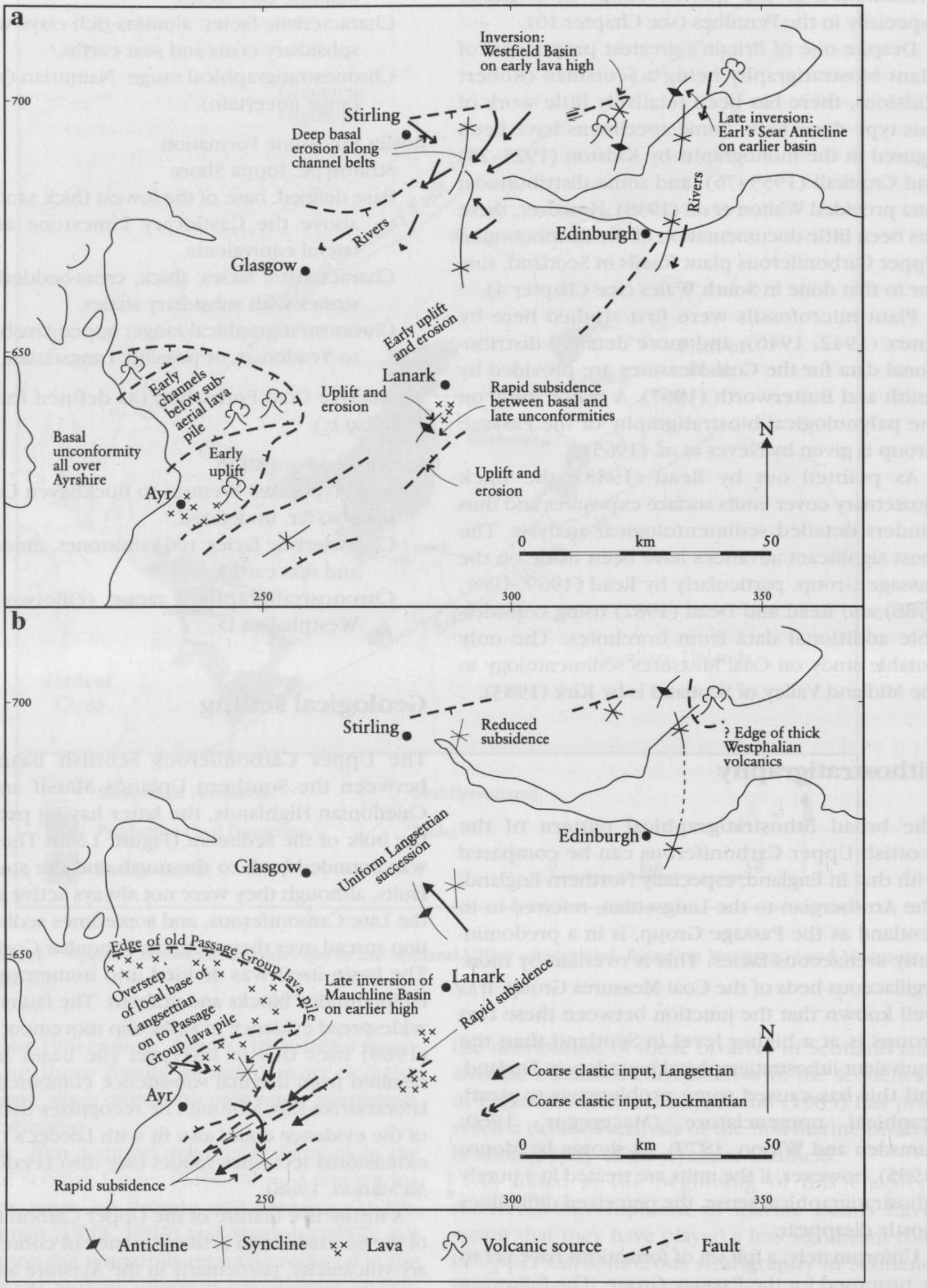

Figure 12.2 Main controls on sedimentation in the Scottish Basin in the Late Carboniferous. (a) Namurian; (b) lower Westphalian. Based on Read (1988, figs 16.12 and 16.14).

thickness and facies. Also, weathering of the lavas produced the bauxitic clays, which form such a characteristic feature of the Ayrshire Passage Group.

The base of the Passage Group in the Arnsbergian marked a major change in sedimentation pattern, with the progradation of major deltas over the area from the Caledonian Highlands. This is thought to be the result of tectonic activity, which caused uplift and erosion of the hinterland to the north, as well as causing uplift of local structural highs within the basin (Read, 1981, 1988; Read and Dean, 1982). Other than some localized deltaic deposits (e.g. Pendle Grit of the Craven Basin), this pre-dates the appearance of large-scale deltaic deposits in the Central Province of Northern England in the Kinderscoutian. Whether this reflects the more proximal position of the Scottish deposits remains to be seen.

Until the Kinderscoutian, marine incursions could still transgress over the delta. After this, however, marine conditions were kept at bay, and even the widely distributed Subcrenatum Marine Band has not been recognized.

During the early Westphalian, a major change in sedimentary regime occurred. Deltaic sand desposition declined, and delta-top flood-plain deposits become more important, resulting in the formation of the Coal Measures. Also, the effects of the basement fault-blocks reduced and volcanicity became restricted to present-day Fife. Finally, the Southern Uplands Massif became for the first time a significant source of sediment.

In the late Westphalian, yet another change occurred, resulting in the disappearance of Coal Measure deposition, and its replacement by deposits of the Barren Red Formation. These are more characteristically fluvial sediments, exhibiting calcretes, desiccation cracks and angular mud-flake breccias (Mykura, 1967), suggesting an increasingly arid climate. However, it has been widely argued that the reddening of these strata occurred during the Permian (e.g. Mykura, 1960), but penecontemporaneous coloration similar to that found in the Etruria Formation of the English Midlands (see Chapter 7) is considered more likely.

GCR site coverage

The selected sites are intended to demonstrate the main features of the Upper Carboniferous of the Scottish Basin.

1. Ayrshire Bauxitic Clay Formation–
   (a) *High Smithstone Quarry*
2. Roslin Sandstone Formation–
   (a) *Joppa Shore*
3. Productive Coal Formation–
   (a) *Dunaskin Glen (Langsettian)*
   (b) *Polhote and Polneul Burns (Langsettian-lower Duckmantian)*
   (c) *Lagrae Burn (upper Duckmantian-middle Bolsovian)*
   (d) *Corrie Foreshore (marginal deposits)*
4. Barren Red Formation–
   (a) *East Wemyss to Buckhaven Coast*

In addition, Inninmore Bay is selected for the enigmatic Coal Measures deposits north of the Highland Boundary Fault.

HIGH SMITHSTONE QUARRY

Highlights

High Smithstone Quarry (Figure 12.3) is the type locality for the Ayrshire Bauxitic Clay Formation, and includes several coals, suggesting that the clays are transported weathering-products of basaltic lavas.

Introduction

This quarry (NS 279455) 1 km NNE of Stevenston Loch, about mid-way between Dalry and Stevenston, Strathclyde, Scotland, shows an unusual deposit known as the Ayrshire Bauxitic Clay Formation, which has been used as a source of alum and of specialist refractory clays. The site is mentioned by Monro *et al.* (1983) and Monro (1985).

Description

The exposed sequence here is about 45 m thick (Figure 12.4). The lowest beds seen consist of about 1.5 m of dark, marine mudstone, immediately overlying basaltic lavas. Monro (1985) refers to the latter as the Passage Group Volcanic Formation, which has also been identified further west in Machrihanish (Kintyre) and Ulster. In Ayrshire, this basaltic lava-pile is thought to have

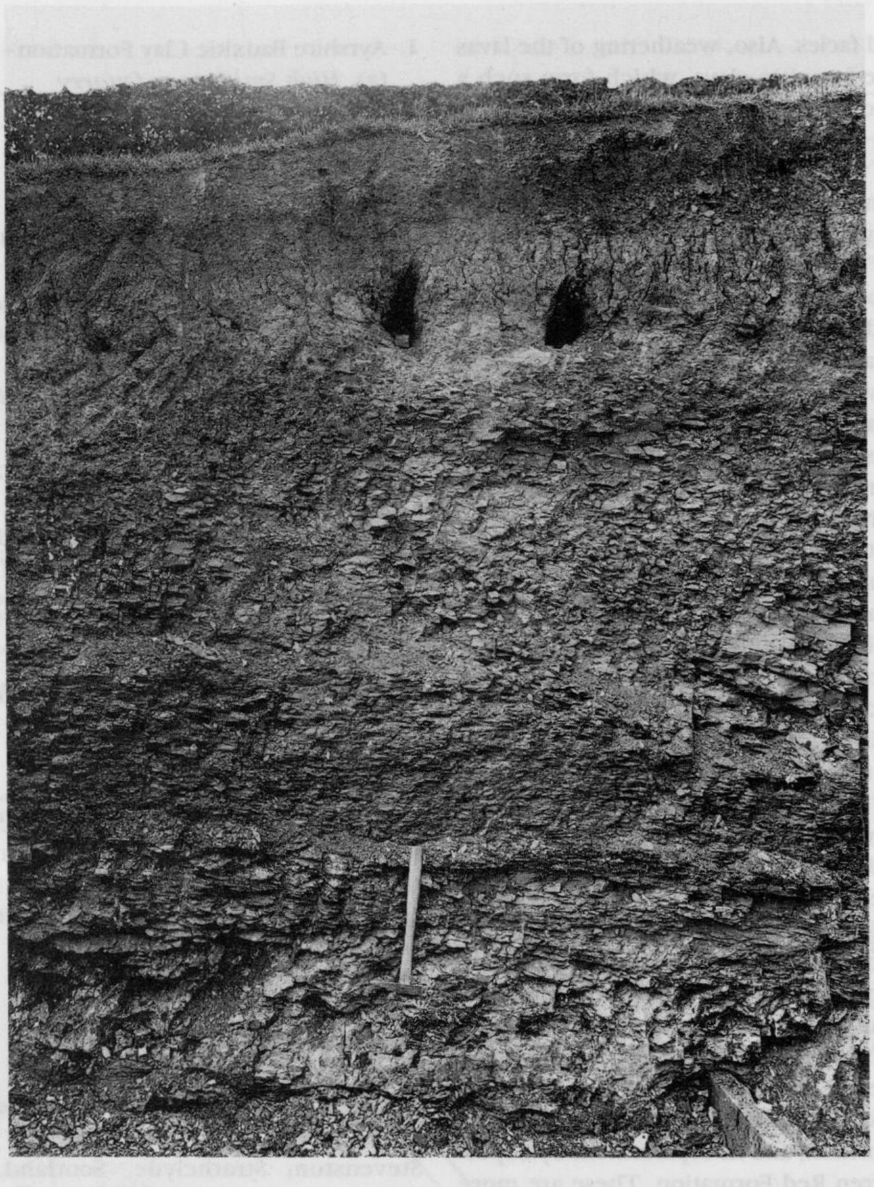

Figure 12.3 Opencast in bauxitic clay at High Smithstone. Reproduced by permission of the Director, British Geological Survey: NERC copyright reserved (C2427).

been associated with movement along the Inchgotrick Fault, and represents the last major volcanic episode in this part of the Scottish Basin.

The marine mudstone is overlain by a succession of mainly alumina-rich argillaceous deposits, known as bauxitic clays. It is now generally accepted that they were derived from the underlying basaltic lavas, representing transported lateritic weathering-products (Monro *et al.*, 1983; Monro, 1985). Associated with these clays are a number of coals and seat earths, showing no evidence of baking.

Although a marine mudstone has been reported from the lower part of the succession here, no details of its fauna have been given.

Interpretation

This is the best available exposure of the Bauxitic Clay Formation in the Namurian of the Scottish Basin, and may be taken as its type locality. It is the thickest development of the formation that can be seen at surface outcrop. Also, and more significantly, it shows well developed coals and seat earths, together with a marine mudstone immediately overlying the basalts, with no evidence of high temperature alteration. This was one of the key factors that caused Monro *et al.* (1983) to conclude that, at least at Smithstone, the clays were mainly transported weathering-products. Further

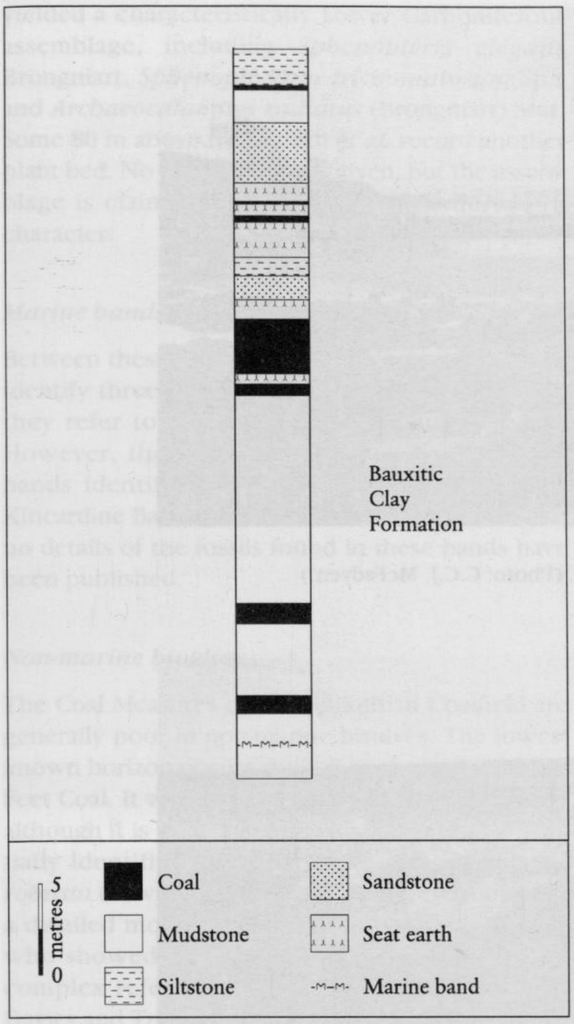

Figure 12.4 Bauxitic Clay Formation present at High Smithstone Quarry. Based on Monro (1985, fig. 7).

south, (south of the Dusk Water Fault), the formation is much thinner and may partly include some *in situ* weathering-products, that formed a crust on the lava-pile. This probably reflects the closer proximity of these more southerly exposures to the volcanic centre.

Conclusions

High Smithstone Quarry is the best locality for a distinctive suite of rocks of Namurian age (probably just over 315 million years old), and known as the Ayrshire Bauxitic Clay Formation. They are thought to be the transported weathering-products of basaltic lavas.

JOPPA SHORE

Highlights

Joppa Shore (Figure 12.5) is the type and best available exposure of the Roslin Sandstone Formation, the most important sandstone unit in the Namurian of Scotland. It also has the best exposed sequence through the lower Productive Coal Formation of the East Fife–Midlothian Trough.

Introduction

Foreshore exposures at Joppa (NT 321734), on the east side of Edinburgh, Scotland, show the Roslin Sandstone Formation and the lower part of the Productive Coal Formation of the Midland Valley of Scotland (Figure 12.6). The best account of the field geology is provided by Peach *et al.* (1910).

Description

Lithostratigraphy

Exposed here are 225 m of the Roslin Sandstone Formation, overlain by 120 m of Productive Coal Formation (Figure 12.7). The base of the Roslin Sandstone Formation is placed at the top of a calcareous band known as the Castlecary Limestone, and which is upper Arnsbergian. The exact level of the junction between the Lower and Upper Carboniferous is difficult to ascertain, but is probably about 90 m above the Castlecary Limestone (evidence discussed in the next section).

The lower part of the Upper Carboniferous segment of the Roslin Sandstone Formation consists mainly of mudstones and sandy shales, with only thin sandstone bands. The mudstones include some bands of nodular ironstone, representing brackish marine conditions. At higher levels, sandstone bands become increasingly important, and the top 31 m consists of an interval of cross-bedded sandstones. The entire sequence appears to be the result of the progressive infill of a shallow basin by a prograding delta complex.

The base of the Productive Coal Formation is taken at the Seven Foot Coal, which lies just above the thick, cross-bedded sandstone mentioned in the previous paragraph. It is difficult to see this seam at Joppa Shore, although Peach *et al.* (1910) claimed to have been able to identify its position by comparing the exposed sequence with nearby undergound successions. Using similar evidence,

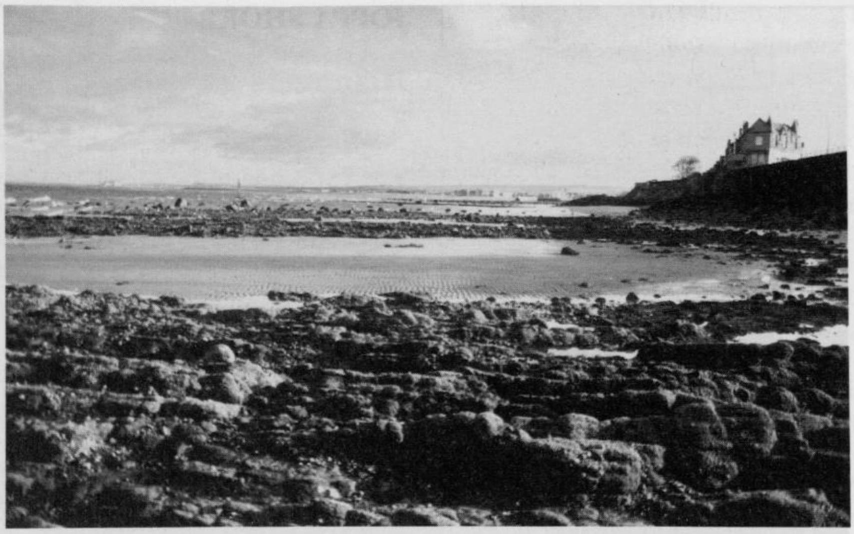

Figure 12.5 Joppa Shore GCR site, foreshore exposures. (Photo: C.C.J. McFadyen.)

Figure 12.6 Upper Carboniferous sequence exposed at Joppa Shore. (Photo: C.C.J. McFadyen.)

they were also able to place the levels of the Four Feet, Fifteen Feet and Nine Feet coals here. The position of the Fifteen Feet Coal in particular they were able to identify by the presence of an ironstone band containing non-marine bivalves which they regarded as characteristic of this stratigraphical level.

The lower 58 m of the Productive Coal Formation here consists predominantly of shales with only thin sandstones. In the upper part of the mainly argillaceous unit, two 60 cm thick coals separated by 1.2 m of seat earth can be seen (in contrast to the lower seams mentioned in the previous paragraph). This seam complex is known locally as the Salters Coal.

The Salters Coal is overlain by 64 m of cross-bedded, fluvial sandstone, with a distinctive brown to purple colour, and marks the highest beds visible here. Towards the top of this sandstone is a 4 m shale band, thought to mark the level of the Greymechan Coal, that has been commercially worked in the vicinity.

Biostratigraphy

Plant macrofossils

Peach *et al.* (1910) mention two plant horizons in the lower Roslin Sandstone. The lower one, lying about 60 m above the Castlecary Limestone, yielded a characteristically Lower Carboniferous assemblage, including *Sphenopteris elegans* Brongniart, *Sphenophyllum trichomatosum* Stur and *Archaeocalamites radiatus* (Brongniart) Stur. Some 80 m above this, Peach *et al.* record another plant bed. No species list was given, but the assemblage is claimed to be Upper Carboniferous in character.

Marine bands

Between these two plant beds, Peach *et al.* (1910) identify three bands of nodular ironstone, which they refer to as Nos 2, 3 and 4 marine bands. However, they are not the same as the marine bands identified using the same names in the Kincardine Basin (Ramsbottom *et al.*, 1978). So far, no details of the fossils found in these bands have been published.

Non-marine bivalves

The Coal Measures of the Midlothian Coalfield are generally poor in non-marine bivalves. The lowest known horizon occurs about 9 m above the Fifteen Feet Coal. It was formerly exposed at Joppa Shore, although it is no longer visible. The shells were initially identified by Peach *et al.* as *Carbonicola robusta* (Sowerby). However, they were subject to a detailed morphometric study by Leitch (1936), who showed that they belonged to the general complex referred to as *Carbonicola communis* Davies and Trueman *sensu lato*. They thus indicate a position in the middle Langsettian.

Interpretation

This is the type and best exposure of the Roslin Sandstone Formation. It clearly shows the characteristic facies of the formation, including both the basinal argillaceous deposits and the fluvial sandstones. There is also potential here for establishing details of the biostratigraphy, although it is in much need of revision.

The Roslin Sandstone Formation is the dominant unit of the Passage Group of Scotland. It is thought to reflect increased erosion of the Caledonian Highlands to the north, due to uplift following the collision of the Massif Central micro-plate with the main Laurasia Plate (Dewey, 1982). It would seem to coincide approximately with the flood of deltaic sandstones into the basins of the Central Province in Northern England, such as the Kinderscout Delta

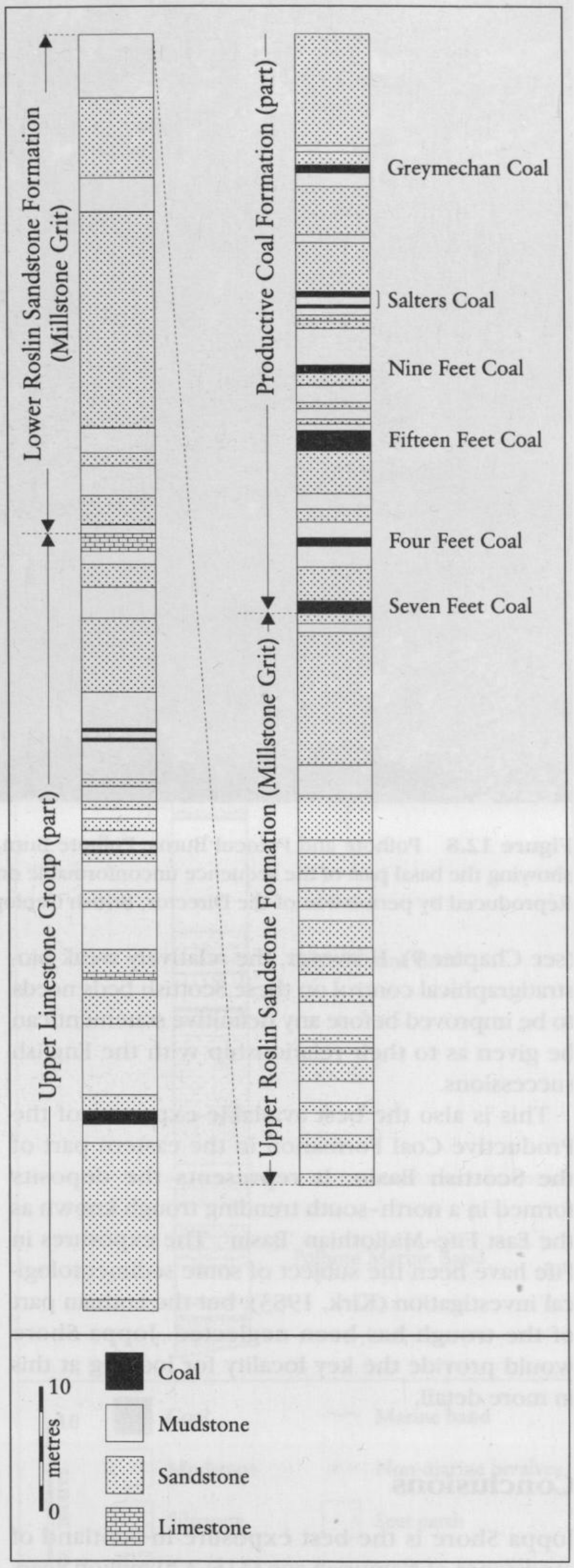

Figure 12.7 Exposed Upper Carboniferous beds at Joppa Shore. Based on Peach *et al.* (1910).

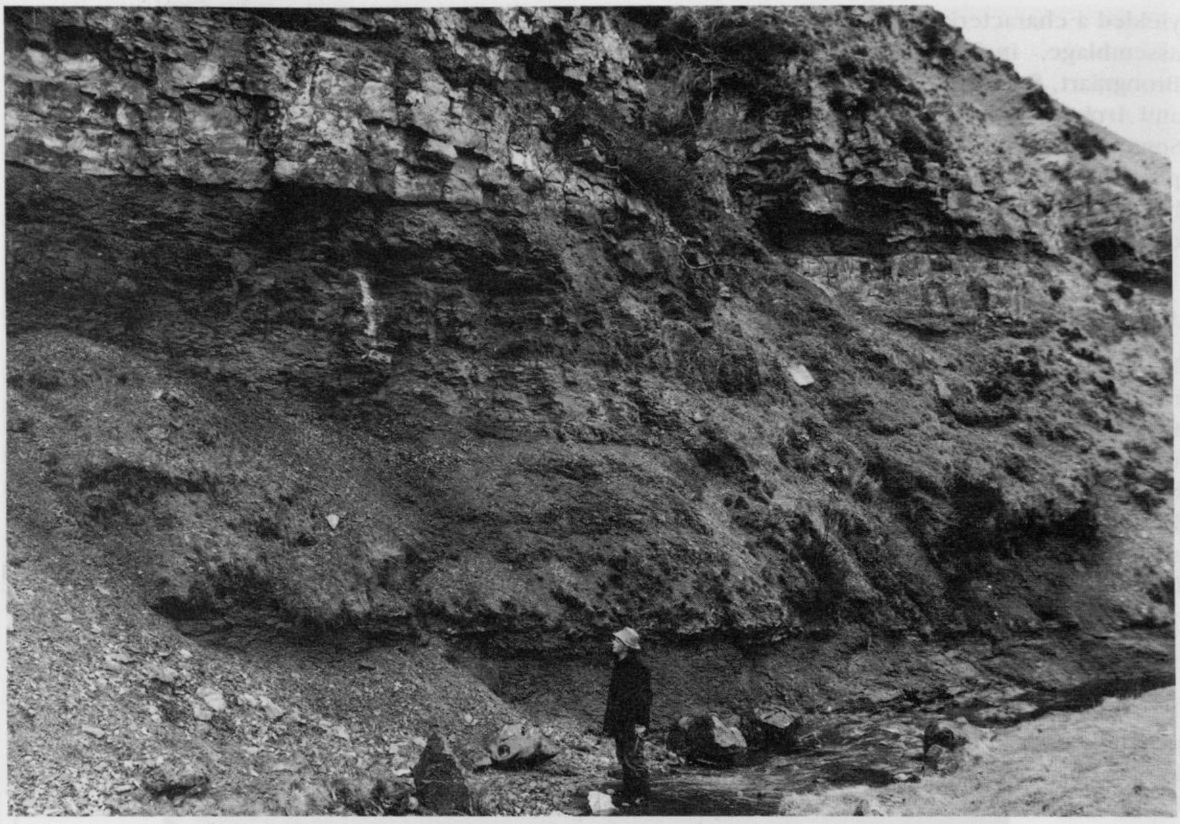

Figure 12.8 Polhote and Polneul Burns. Polhote Burn, 1.3 km upstream from the junction with the River Nith, showing the basal part of the sequence unconformable on Ordovician strata, and including the Polhote Marine Band. Reproduced by permission of the Director, British Geological Survey: NERC copyright reserved (D1159).

(see Chapter 9). However, the relatively weak biostratigraphical control on these Scottish beds needs to be improved before any definitive statement can be given as to their relationship with the English successions.

This is also the best available exposure of the Productive Coal Formation in the eastern part of the Scottish Basin. It represents the deposits formed in a north–south trending trough known as the East Fife–Midlothian 'Basin'. The exposures in Fife have been the subject of some sedimentological investigation (Kirk, 1983), but the Lothian part of the trough has been neglected. Joppa Shore would provide the key locality for looking at this in more detail.

Conclusions

Joppa Shore is the best exposure in Scotland of sandstones of Namurian age (315–320 million years old), known as the Roslin Sandstone. It is also the best site for seeing the lower part of the Productive Coal Formation of the East Fife-Midlothian Trough.

POLHOTE AND POLNEUL BURNS

Highlights

Polhote and Polneul Burns (Figure 12.8) provide the best exposed sequences through the lower part of the Sanquhar Coalfield, including outcrops of Tait's Marine Band, the Fauldhead Mussel Band and the Kirkconnel Splint Coal.

Introduction

These stream sections (NS 688123–NS 691117, NS 697123–NS 695101) extend south from McCrierick's Cairn and Nether Cairn, 4 km west of Kirkconnel, Dumfries and Galloway, Scotland. They expose the Passage Group and the Langsettian and lower Duckmantian parts of the Productive Coal Formation in the Sanquhar Coalfield. A general description of the geology of this area is provided by Simpson and Richey (1936), and details of the field geology of the site can be found in Davies (1970).

Description

Lithostratigraphy

The exposed sequence here is about 60 m thick, of which 46 m is Upper Carboniferous (Figure 12.9). The lowest unequivocally Upper Carboniferous stratum is a 2 m thick marine mudstone, known locally as Tait's Marine Band. It overlies a sequence of non-marine mudstones and kaolinitic sandstones of the Passage Group. There is no clear evidence as to the age of these lower beds, but they themselves overlie the Polhote Marine Band which is thought to be Pendleian. It is likely therefore that there is a major non-sequence between the Polhote and Tait's bands, and Davies (1970) implies that it is immediately below the Tait's band.

Above the Tait's Marine Band are about 18 m of mainly mudstones, including two unnamed *Lingula* bands, both of which are underlain by thin coals. At the top of this unit the beds become more sandy.

There follows a non-sequence, and then a 5 m thick sandstone. This sandstone has been identified throughout the coalfield, and on the eastern margins of the coalfield it onlaps directly onto Ordovician strata. The top of the sandstone is marked by a seat earth and thin coal, which is overlain by a lacustrine mudstone, known as the Fauldhead Mussel Band. This mudstone is a laterally persistent stratum throughout the coalfield, and acts as a valuable marker band.

Exposure of the beds above the Fauldhead Mussel Band is poor and discontinuous, but there are probably about 12 m of mainly sandy beds present. There then follows about 12 m of repeated thin coals and seat earths known as the Swallowcraig Coals. These are the stratigraphically lowest coals of any significance in the coalfield. According to Davies (1970), one of the Swallowcraig seams (he does not say which) was worked commercially at Gateside Colliery in the northern part of the coalfield, but that this was discontinued.

Above the Swallowcraig Coals are about 4 m of sandstone, overlain by about 2 m of lacustrine mudstones, and then a 1 m thick coal known as the Kirkconnel Splint Coal. This was the most widely worked seam in the coalfield since, although it is nowhere particularly thick (a maximum of 1.6 m was present at Fauldhead Colliery), it is a good quality, bright coal. Polneul Burn provides the best natural exposure of the seam, where the bands of dull, splinty coal characterizing the upper part of the seam, can be clearly seen.

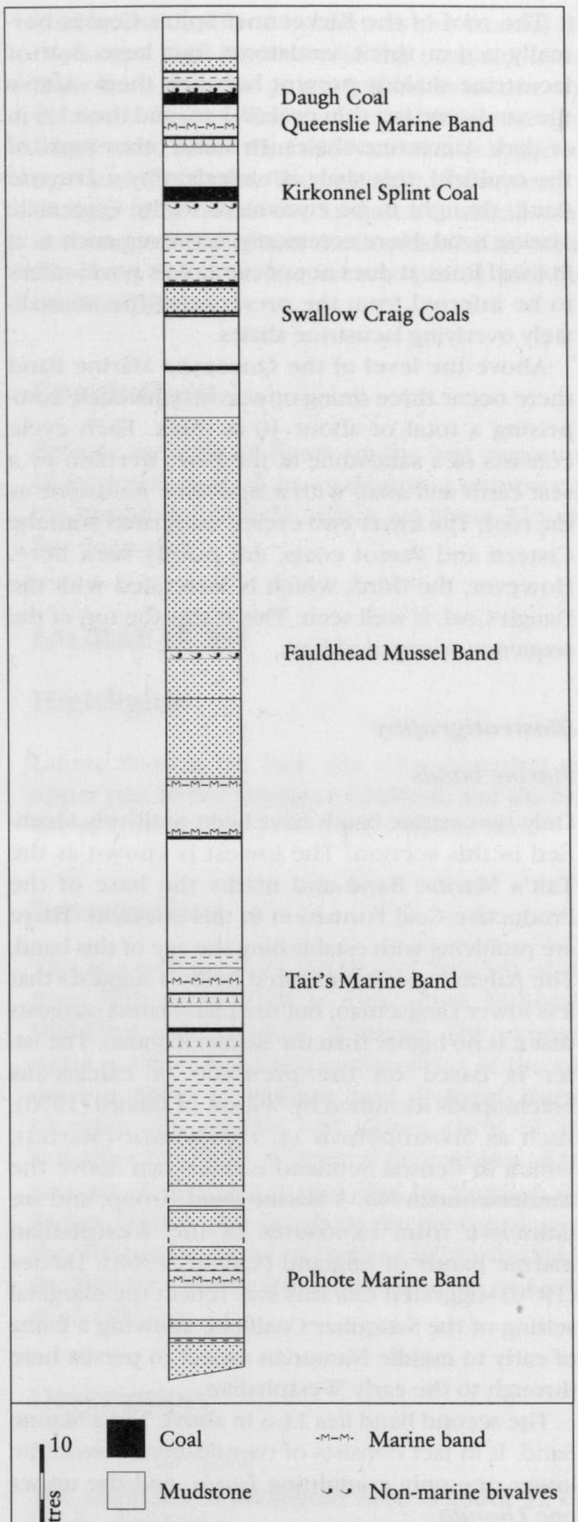

Figure 12.9 Upper Carboniferous exposed along the Polhote and Polneul Burns. Based on data given in Davies (1970).

The roof of the Kirkconnel Splint Coal is normally a 4 m thick sandstone, but here 2 m of lacustrine shale is present between them. Above the sandstone is a thin coal (0.1 m) and then 1.5 m of dark, lacustrine shales. In some other parts of the coalfield, this shale is underlain by a *Lingula* Band, thought to be equivalent to the Queenslie Marine Band. More commonly, however, such as at Polneul Burn, it does not occur and its position has to be inferred from the presence of the immediately overlying lacustrine shales.

Above the level of the Queenslie Marine Band there occur three fining-upwards sequences, comprising a total of about 40 m thick. Each cycle consists of a sandstone at the base, overlain by a seat earth and coal, with a lacustrine mudstone as the roof. The lower two cycles, associated with the Cistern and Parrot coals, are poorly seen here. However, the third, which is associated with the Daugh Coal, is well seen. This marks the top of the sequence as exposed here.

Biostratigraphy

Marine bands

Only two marine bands have been positively identified in this section. The lowest is known as the Tait's Marine Band and marks the base of the Productive Coal Formation in this coalfield. There are problems with establishing the age of this band. The palynology (summarized below) suggests that it is lower Langsettian, but the macrofauna suggests that it is no higher than the Kinderscoutian. The latter is based on the presence of calcareous brachiopods identified by Wilson *in* Davies (1970), such as *Schizophoria* cf. *resupinata* (Martin), which in Central Scotland is unknown above the Kinderscoutian No. 3 Marine Band Group, and are unknown from exposures of the Westphalian marine bands of England (Calver, 1968). Davies (1970) suggested that this may reflect the marginal setting of the Sanquhar Coalfield, allowing a fauna of early to middle Namurian aspect to persist here through to the early Westphalian.

The second band lies 11.6 m above Tait's Marine Band. It in fact consists of two discrete leaves, the lower one only containing *Leaia*, and the upper one *Lingula*.

In other nearby sections in the Sanquhar Coalfield, a third marine band has been identified. It does not contain much more than inarticulate brachiopods, but it is generally taken to be a lateral equivalent of the Queenslie Marine Band of the Central Scottish Coalfield (Brand, 1977). Since this in turn is taken to be equivalent to the Vanderbeckei Marine Band in England, it marks the boundary between the Langsettian and Duckmantian stages. In Polneul Burn, not even the *Lingula* band has been identified, although its position has been inferred from the occurrence of a characteristic non-marine bivalve assemblage in shales overlying the Kirkconnel Splint Coal.

Non-marine bivalves

This site has proved particularly rich in non-marine bivalves. The lowest assemblage is from the Fauldhead Mussel Band, between Tait's Marine Band and the Swallowcraig Coals. It has yielded *Carbonicola communis* Davies and Trueman, *C. polmontensis?* (Brown), *C.* cf. *robusta* (Sowerby), *C.* cf. *pseudorobusta* Trueman and *?Anthracosphaerium dawsoni* (Brown). Such an assemblage belongs to the *C. pseudorobusta* Subzone in the upper part of the *C. communis* Zone, thus indicating upper Langsettian.

The next highest assemblage is from mudstones between the Swallowcraig and Kirkconnel Splint coals. This mussel band has been identified over much of the coalfield, but Polneul Burn is reputed by Davies (1970) to be the best exposure. From here have been reported *Anthracosia regularis* (Trueman) and *Carbonicola oslancis* Wright, which would seem to belong to the *A. regularis* Subzone. This indicates the upper Langsettian.

A second *A. regularis* Subzone assemblage has been found from between the Kirkconnel Splint Coal and the level of the Queenslie Marine Band. It includes *A. regularis*, but this time in association with *Anthracosphaerium cycloquadratum* (Wright) and *Anthracosia* aff. *modiolaris* (Sowerby).

In other parts of the coalfield, a mussel band occurs immediately above the Queenslie Marine Band. In Polneul Burn, the marine band has not been found, but the mussel band is well exposed and yields *A. modiolaris?*, *Anthracosia* aff. *aquilina* (Sowerby), *A.* cf. *ovum?* Trueman and Weir and *Anthracosphaerium turgidum* (Brown). This evidently belongs to the *A. ovum* Subzone, and is typical of the bivalves found immediately overlying the Vanderbeckei Marine Band (cf. Cwm Gwrelych-Nant Llyn Fach in South Wales - see Chapter 4).

The highest assemblage is found in mudstones overlying the Daugh Coal. Davies' (1970) list from here includes *Anthraconaia robertsoni* (Brown), *Anthracosia ovum*, *A.* cf. *phrygiana* (Wright), *Anthracosphaerium affine* (Davies and Trueman), *A. exiguum* (Davies and Trueman) and *Naiadites quadratus* (Sowerby). This is very similar in composition to the assemblage from immediately overlying the Queenslie Marine Band, and also belongs to the *A. ovum* Subzone.

Plant macrofossils

The only plant macrofossils reported from here are from immediately below Tait's Marine Band. Chaloner *in* Davies (1970) lists from here *Karinopteris acuta* (Brongniart) Boersma, *Sphenophyllum cuneifolium* (Sternberg) Zeiller and *Alethopteris lonchitica* Sternberg. Such an assemblage is not particularly diagnostic, and could be found anywhere between the *Lyginopteris larischii* and *L. hoeninghausii* zones (Arnsbergian to Langsettian).

Palynology

Neves *in* Davies (1970) investigated the pollen and spores from coals a short distance above and below the Tait's Marine Band at Polneul Burn. He found a very similar assemblage in both seams. Biostratigraphically significant species include *Apiculatisporites variocorneus* Sullivan, *Raistrickia fulva* Artuz, *Densosporites marginatus* Artuz, *D. belliatus* Artuz, *Triquitrites variabilis* Sabry and Neves, *Cristatisporites connexus* Potonié and Kremp and *Florinites mediapudens* (Loose) Potonié and Kremp. A similar assemblage was reported by Neves *et al.* (1965) from near the upper Langsettian Bowhouse Bog Coal near Stirling. Neves *in* Davies (1970) also reported a similar assemblage from above the lower Langsettian Listeri Marine Band in Yorkshire. It is thus strong evidence that Tait's Marine Band is Langsettian.

Interpretation

These are the best sections through the lower Westphalian part of the Sanquhar Coalfield, combining generally good exposure and close biostratigraphical control, particularly with the non-marine bivalves. They show most of the key stratigraphical levels within the lower part of the Sanquhar Coalfield succession, including Tait's Marine Band, the Fauldhead Mussel Band and the Kirkconnel Splint Coal.

The site has been particularly important in helping understand the stratigraphical position of Tait's Marine Band, which is taken as the base of the Productive Coal Formation in this coalfield. It was from here that the palynological evidence was obtained, showing that the band is almost certainly Langsettian, rather than mid-Namurian as suggested by the shelly fauna. The apparent discrepancy is thought to be due to the Sanquhar Coalfield being in a marginal position in the Scottish Basin, which allowed a Namurian-like fauna to persist here into the Westphalian.

Conclusions

Polhote and Polneul Burns are the best exposures of the lower part of the coal-bearing sequence in the Sanquhar Coalfield, which are about 313 million years old.

LAGRAE BURN

Highlights

Lagrae Burn is the best site demonstrating the upper part of the Sanquhar Coalfield, and the best site in Scotland for the Skipsey's Marine Band.

Introduction

This is a tributary (NS 705153-NS 706135) of the River Nith, 3 km WNW of Kirkconnel, Nithsdale, Dumfries and Galloway, Scotland. The exposed strata in effect provide a continuation of the succession seen at Polhote and Polneul Burns, showing the middle and upper parts of the Sanquhar Coalfield. A general description of the geology of this area is provided by Simpson and Richey (1936), and details of the field geology of the site can be found in Davies (1970). Details of the Skipsey's Marine Band here are given by Currie *et al.* (1937).

Description

Lithostratigraphy

The sequence represented here is about 125 m thick, although it is not continuously exposed. However, the isolated outcrops can been interpreted in the context of a number of boreholes drilled in the immediate vicinity and described by Davies (1970). The lowest strata represented here are the Calmstone and Creepie coals, neither of which are now exposed but their positions can be identified by old surface workings. The stratigraphically lowest beds to actually outcrop are a lacustrine mudstone, overlain by a siltstone and seat earth. The latter underlies a coal known as the Target Seam, although it cannot be seen here.

The next highest exposed strata are about 6 m of fine sandstone separating two beds of marine mudstones. The latter are known locally, in ascending order, as the Bankhead and Eastside marine bands. In the nearby Sanquhar No. 243 Borehole, the Bankhead Marine Band is about 10 m above the Target Seam.

There then follows about 15 m of poorly exposed, mainly arenaceous deposits, overlain by a thin coal (0.2 m thick) and a marine carbonaceous siltstone – the Skipsey's Marine Band. This band is well known throughout the coalfield, and in fact in most of the coalfields of the rest of the Scottish Basin (Currie *et al.*, 1937), but Lagrae Burn provides one of the best and most fossiliferous exposures.

Above the Skipsey's Marine Band are 13 m of mainly mudstones with thin beds of sandstone. About 1.5 m above the Skipsey's band, the mudstones represent brackish conditions, but the rest appear to be non-marine, probably inter-distributary bay deposits. This part of the succession is eventually capped by a 1 m thick seat earth and then a thin lacustrine mudstone.

The rest of the sequence is poorly exposed, although certain features can be seen. About 39 m above the Skipsey's Marine Band are 2.7 m of mudstones and thin coals. Of greater interest is a 1 m thick coal overlain by dark grey, marine mudstones. This is the Lagrae Marine Band, which has only been identified at this locality. Some distance above this marine band then comes poorly exposed, red mudstones of the Barren Red Formation, which are the highest strata exposed here.

Biostratigraphy

Marine bands

Both the Bankhead and Eastside marine bands only yield inarticulate brachiopods and 'non-marine' bivalves *Anthracosia* and *Naiadites*. They thus represent brackish rather than fully marine conditions. According to Davies (1970), these probably represent what have become known as the Clowne and Haughton marine bands in the standard classification of Ramsbottom *et al.* (1978).

The fauna of the Skipsey's Marine Band here is described in detail by Currie *et al.* (1937). They identify the following species: brachiopods – *Lingula pringlei* Currie; bivalves – *Posidonia sulcata* (Hind) and *Dubarella macgregori* (Currie); cephalopods – *Orthoceras* cf. *asciculare* (Brown) and *Homoceratoides jacksoni* Bisat. In addition, Davies (1970) lists from here *Coleolus?* sp., *Aviculopecten delepinei* Demanet, *Limatulina* cf. *alternans* (McCoy), *Donetzoceras aegiranum* (N. J. Riley, pers. comm.), *Metacoceras costatum* (Hind), *Cypridina*, *Hindeodella* sp. and *Lonchodina* sp. Currie *et al.* (1937) argued that such an assemblage is diagnostic of what is now referred to as the Aegiranum Marine Band, and this view is still generally accepted (e.g. Ramsbottom *et al.*, 1978). It thus marks the junction between the Duckmantian and Bolsovian stages in this sequence.

A mudstone 1.5 m above the Skipsey's band has yielded *Planolites*. According to Calver *in* Davies (1970), this marks 'the final retreat stage of the incursion' (i.e. the Aegiranum transgression) rather than a separate marine band in its own right.

The Lagrae Marine Band has only yielded a restricted assemblage of *Lingula*, *Curvirimula*, *Planolites*, *Glomospira* and fish remains. Such an assemblage is not diagnostic of any of the marine bands in the standard set outlined by Ramsbottom *et al.* (1978), but Calver *in* Davies (1970) argued that its position relative to the Skipsey's Marine Band and the inferred position of the Top Marine Band suggested that it may be equivalent to the Edmondia Marine Band.

Non-marine band

Non-marine bivalve assemblages are known from just three horizons in this section. The lowest comes from a mudstone between the Creepie and Target coals. Davies (1970) does not list what occurs here, beyond '*Estheria*' sp. and mussels. Elsewhere in the coalfield, however, this band has yielded an assemblage of the *Anthracosia atra* Subzone, indicating the upper Duckmantian. *A. atra* (Trueman) was also found in the Bankhead Marine Band.

The third horizon is a thin mudstone 14 m above the Skipsey's Marine Band, from where Davies (1970) mentions *Naiadites* cf. *daviesi* Dix and Trueman. According to Trueman and Weir (1955), this species ranges from the upper part of the 'Lower *similis-pulchra*' Zone to the basal *A. phillipsi* Zone.

Interpretation

This is the best exposed sequence through the upper part of the Sanquhar Coalfield, ranging from upper Duckmantian to probably middle Bolsovian (biostratigraphical control in the upper part of the sequence is poor). It represents a time of maximum basinal subsidence in this area, allowing the development of numerous coals and marine bands. It seems that this was caused by the effective absence of movement along the Southern Uplands Fault during the Westphalian, which allowed deltaic sedimentation to spread into this area from the Scottish Basin to the north. There was certainly some post-Carboniferous movement of the fault (Lumsden and Davies, 1965), and the absence of Permian strata in the area suggests that it may have been re-activated by end-Variscan tectonics.

The exposure of the upper part of the sequence is incomplete, although there is potential for excavation work, which may reveal the transition zone between the Productive Coal and Barren Red formations. Davies (1970) implied that the coloration is the result of staining from overlying Permian red beds. If, as suggested above, the Permian was never deposited here due to uplift along a rejuvenated Southern Uplands Fault, however, then the reddening of the Barren Red Formation may be primary or sub-primary, similar to that seen in the Etruria Formation of the English Midlands.

The site is also of considerable interest because of the exposure of the Skipsey's Marine Band, the presumed equivalent in the Scottish Basin of the Aegiranum Marine Band. Currie *et al.* (1937) provide a detailed palaeontological analysis of the most important outcrops of the band in the Scottish Basin, from which it becomes clear the Lagrae Burn contains one of the most diverse faunas. Furthermore, it is the only one of the sites with a diverse assemblage where the band can be seen in a reasonably continuous stratigraphical succession. Lagrae Burn is also the only known site for the Lagrae Marine Band, and the only place where the Bankhead and Eastside marine bands can be seen in the Sanquhar Coalfield in a continuous stratigraphical succession.

Conclusions

Lagrae Burn is the best exposure of the upper part of the coal-bearing sequence in the Sanquhar Coalfield, which is about 305 million years old.

CORRIE FORESHORE

Highlights

Corrie Foreshore provides the best exposure of Westphalian deposits on the western margins of the Scottish Basin.

Introduction

Foreshore exposures (NS 026432) by the post office at Corrie, on the east coast of the Isle of Arran, Cunninghame, Strathclyde, Scotland, show beds of the Productive Coal Formation, as developed on the western margins of the Scottish Basin. The site has been described by Gunn (1903), Gunn *in* Tyrrell (1928) and Leitch (1942).

Description

Lithostratigraphy

The exposed sequence here is 85 m thick, and lies unconformably on Lower Carboniferous limestones (Figure 12.10). The lower 53 m consists mainly of a sequence of alternating sandstones and seat earths. At least some of the sandstones are cross-bedded and have an erosive base. The lower sandstones are white, but those higher in this interval have picked up a secondary iron staining, probably from the overlying Permian red sandstones. Gunn (1903) and Gunn *in* Tyrrell (1928) suggested that they may belong to what is now referred to as the Passage Group, but Leitch (1942) and all subsequent authors have referred them to the Coal Measures.

Above the sandstone/seat earth interval are 28 m of more argillaceous strata. Although there is one seat earth in the lower part of this interval, most of it consists of lacustrine shales, with some thin sandstones probably representing crevasse-splay deposits. Particularly the shales have a secondary red coloration.

The top 4 m of the succession see a return to sandstone. They are strongly cross-bedded and and in places shows convoluted bedding. This was interpreted by Bailey (1926) as the result of synsedimentary slumping down a palaeoslope.

Biostratigraphy

Non-marine bivalves

These were found at three levels within the red shales in the upper part of the succession. All three

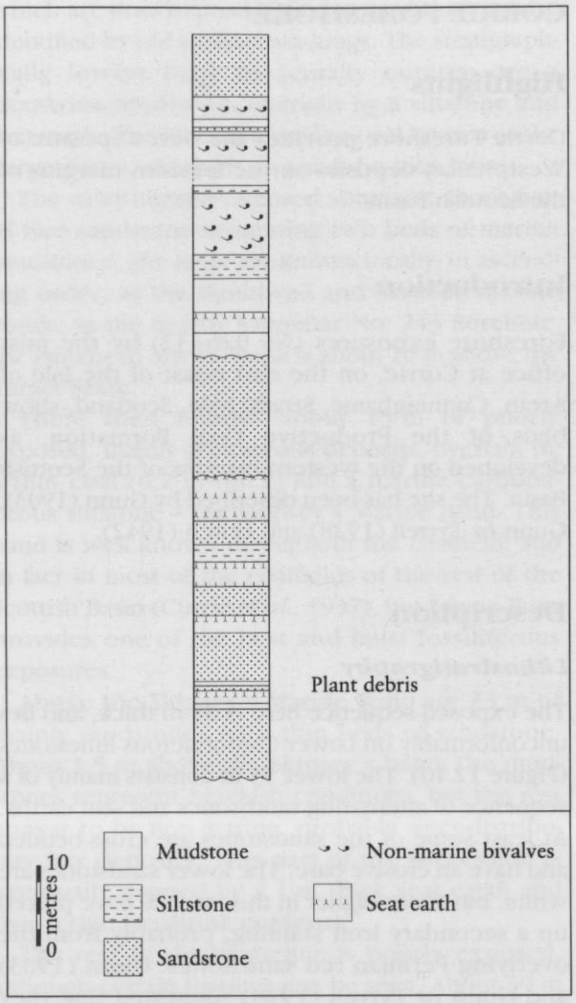

Figure 12.10 Upper Carboniferous succession exposed at Corrie Burn, Arran. Drawn from measurements given by Leitch (1942).

assemblages clearly belong to the *A. modiolaris* Zone. The lowest bed was reported by Leitch (1942) to yield *Carbonicola oslancis* Wright and *C.* cf. *rhomboidalis* Hind. He compared it with an assemblage reported from Kiltongue Mussel Bed of the Central Coalfield (Weir and Leitch, 1936), and would now be referrable to the *Carbonicola cristagalli* Subzone (upper Langsettian).

The upper two non-marine bivalve horizons contain shells of the *Anthracosia regularis* Subzone, indicating the upper Langsettian. In addition to the eponymous species, Leitch records '*Carbonicola elliptica*', which is now regarded as a synonym of *A. regularis* (Trueman) (see Trueman and Weir, 1952), as well as *Anthracosia aquilina* (Sowerby) and *Naiadites triangularis* (Sowerby). Leitch compared it with a similar assemblage associated with the upper Langsettian Blackband Coal of the Central Coalfield (Weir and Leitch, 1936).

Plant macrofossils

Plant fossils have been reported from a thin shale in the lower part of the succession. However, they have not been described in detail, or even a species list published. This is unfortunate, as they occur in that part of the succession for which there has been doubt as to whether it is Namurian or Westphalian, and for which the plant fossils might provide an answer.

Interpretation

This is the best exposure of Upper Carboniferous rocks on Arran, representing marginal deposits at the western end of the Scottish Basin. There are a number of other exposures of Upper Carboniferous rocks on Arran, including both coastal and inland stream sections (reviewed by Leitch, 1942). However, none of the stream sections offer the same opportunity to examine the sedimentology of these beds as can be done at Corrie. The coastal exposures near the Cock of Arran are comparable in extent, and in some features are better (e.g. the slumping of the upper sandstones), but there is not the same quality of biostratigraphical control as at Corrie.

The sequence here is far more condensed than comparable strata in the central part of the basin, at least if Leitch's (1942) correlation of the lower and middle mussel bands with the Kiltongue and Blackband mussel bands of the Central Coalfield is correct. The latter two bands in the Kincardine and east Fife areas are separated by some 60 m, whereas in Arran the two bands are separated by only about 1 m of sandy shales.

Leitch (1942) pointed out a number of other major differences between the Arran sequences and the more typical Productive Coal Formation of the Scottish Basin, such as the absence of coals, despite the occurrence of thick seat earths, and the presence of slump-structures in some of the sandstones. In addition, the sequence is considerably more arenaceous, especially in the lower part of the succession. The alternation of cross-bedded sandstones and seat earths in the lower part of the Corrie succession in fact finds its closest comparison with the Westphalian of the English Midlands, where the Pennines Basin laps up against the Wales-Brabant

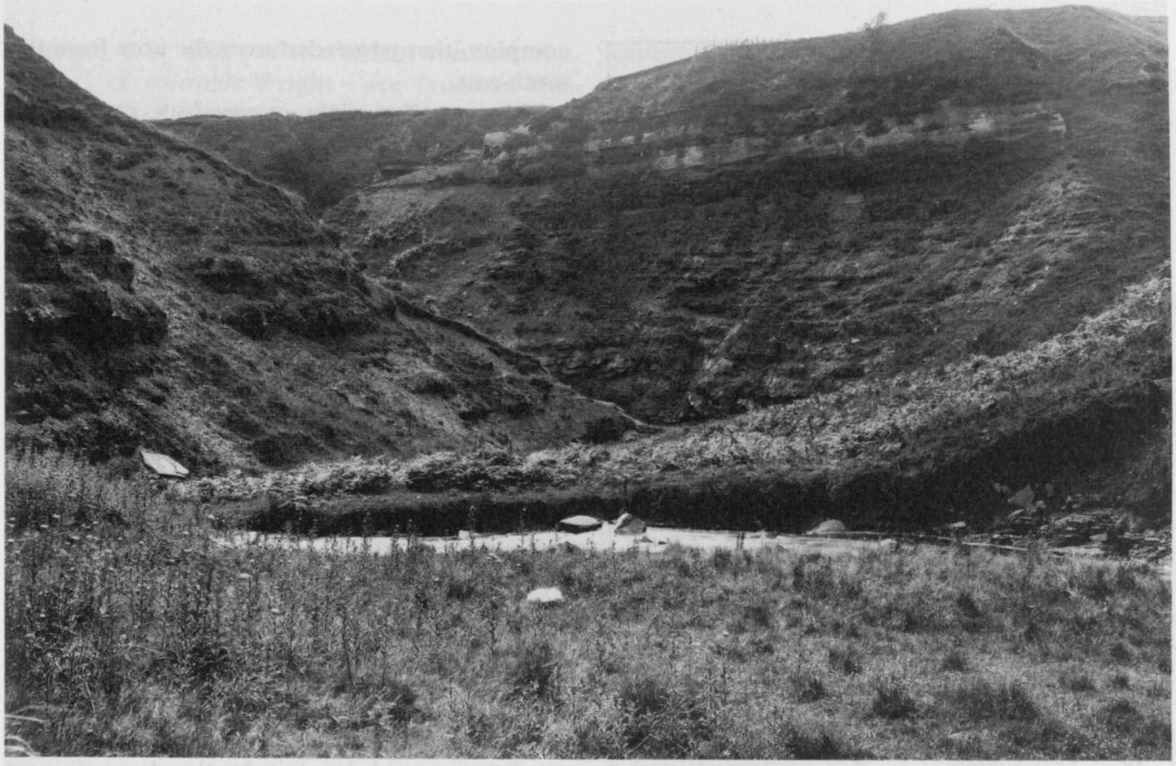

Figure 12.11 Dunaskin Glen. View of the lower part of the succession. Reproduced by permission of the Director, British Geological Survey: NERC copyright reserved (C3083).

Barrier. Another probable comparison is with the condensed succession at Machrihanish on Kintyre (Manson, 1957; Johnstone, 1966), although this has still to be described in detail.

Conclusions

Corrie Foreshore is the best place to examine the rocks of Westphalian age (about 313 million years old), as developed on the western margins of the Scottish Basin. The sequence here, which consists mainly of sandstones and seat earths, is much thinner than in the central part of the basin, such as near Edinburgh. It can be compared with similarly marginal deposits of the Pennines Basin, in the English Midlands (see Chapter 7).

DUNASKIN GLEN

Highlights

Dunaskin Glen (Figure 12.11) is the best exposure of the lower Productive Coal Formation in the Scottish Basin.

Introduction

This stream section (NS 454088) 3 km NW of Dalmellington, Cumnock and Doon Valley, Strathclyde, Scotland, shows the lower part of the Productive Coal Formation of the Ayr Coalfield. Details of the geology are provided by Simpson and Macgregor (1932) and Mykura (1967).

Description

Lithostratigraphy

The exposed sequence consists of 143 m of Productive Coal Formation, lying unconformably on deposits of the Upper Limestone Group (Figure 12.12). Elsewhere in the southern part of the Ayrshire Coalfield, the base of the formation is marked by a 30 m thick sandstone. Here, however, it is absent and the basal beds are mudstones, which form the start of a 41 m thick coarsening-upwards interval. The top of this unit is a 24 m thick sandstone, capped by a thick seat earth, known as the Dunaskin Fireclay, and which has been worked in the vicinity of Dunaskin Glen, for refractory bricks. The clay occurs over large areas of this southern

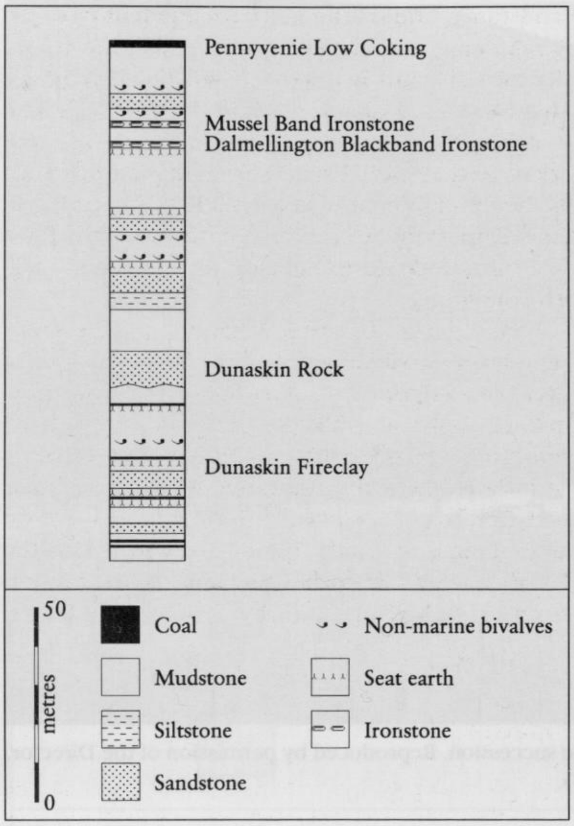

Figure 12.12 Coal Measures exposed at Dunaskin Glen. Based on Mykura (1967, pl. 1).

part of the Ayrshire Coalfield, but Dunaskin Glen is the only good exposure. The coarsening-upwards unit as a whole probably represents a deltaic infill of a shallow, inter-distributary bay.

The succeeding 17 m represent transgressive conditions. At the base is a thin *Lingula* band, overlain by a 0.4 m lacustrine deposit known as the Dunaskin Clayband Ironstone. These then pass up through inter-distributary bay mudstones into a seat earth and 0.3 m thick coal. This brief period of emergence is then terminated by a return to brackish conditions, resulting in the deposition of a second *Lingula* band.

There then follows a 10 m thick sandstone, known as the Dunaskin Rock (Simpson and Macgregor, 1932). It has been identified over a large part of the southern Ayrshire Coalfield, but Dunaskin Glen is the type and best exposure. Here, it is a buff, medium to coarse-grained quartzitic sandstone, with an erosive base and marked cross-bedding. It was probably formed in large, fluvial complex, that prograded over the area from the south-east.

The next 67 m of the exposed succession here can be interpreted in terms of three coarsening-upwards cycles. The lower part of each cycle consists of mudstones. At other localities, the mudstones of the lower cycle include a marine band, but here they appear to be relatively featureless, inter-distributary bay deposits. Those of the second cycle are lacustrine mudstones, with an abundant non-marine bivalve fauna (see below), and for which Dunaskin Glen is one of the best localities (Mykura, 1967). The lowest beds of the third cycle are also lacustrine, but this time include two clay-band ironstones, known as the Dalmellington Blackband and Mussel Band ironstones. The former is over half a metre thick here, and has been extensively worked in the area.

The lower two cycles have a sandstone in the upper part, capped by a seat earth. It seems reasonable to assume therefore that they are deltaic infills of a slowly subsiding basin. The third cycle seems to have been terminated before fully emergent conditions could develop, by the deposition of lacustrine deposits immediately over the sandstone. These 12 m of lacustrine mudstones form the top of the Dunaskin Glen sequence.

Biostratigraphy

The only stratigraphically useful fossils reported from here are non-marine bivalves. However, there are diverse assemblages of these fossils available, which provide a good biostratigraphical control.

The lowest assemblage is associated with the Dunaskin Clayband Ironstone. It is not discussed in detail by Brand (1983), although it is probably from about the same level as the 'Pathhead 4 ft 6 in' assemblage in his tabulated species lists. Calver *in* Mykura (1967) identified from here *Carbonicola proxima* Eagar and *C.* aff. *extenuata* Eagar. Macgregor and Pringle (1934) argued that the assemblage belonged to the *C. communis* Zone, but Weir and Leitch (1936) correctly pointed out that it must belong to the *C. lenisulcata* Zone. It almost certainly belongs to the *C. proxima* Subzone, in the uppermost part of the zone, and indicates the lower Langsettian.

The next highest assemblage is from the lacustrine mudstone about 30 m below the Dalmellington Blackband Ironstone. The species list from the Dunaskin Glen exposure of this band given by Mykura (1967) includes *Carbonicola communis* Davies and Trueman, *C. pseudorobusta*

Trueman, *C.* cf. *subconstricta* Wright *non* Sowerby (syn. *C.* cf. *oslancis* Wright - see Trueman and Weir, 1947), *Curvirimula subovata* (Dewar) (syn. *Curvirimula belgica* (Hind) - see Weir *in* Trueman and Weir, 1960) and *Naiadites flexuosus* Dix and Trueman. This clearly belongs to the *C. pseudorobusta* Subzone in the upper *C. communis* Zone, and indicates a level in the upper Langsettian.

The Mussel Band Ironstone yields an almost identical *C. pseudorobusta* Subzone assemblage. The Dalmellington Blackband Ironstone here only yielded a few species, such as *Curvirimula belgica* (Hind), which are not particularly diagnostic biostratigraphically. Elsewhere, however, this ironstone has yielded some of the classic assemblages of the *C. pseudorobusta* Subzone (Hind, 1894; Weir and Leitch, 1936; Trueman and Weir, 1947)

The stratigraphically highest fossils here occur in the topmost lacustrine mudstone exposed. The horizon is shown in the stratigraphical section by Mykura (1967), but no species list is provided.

There is little published palaeobotanical evidence from this coalfield, and nothing from this particular site. However, Absalom *in* Walton *et al.* (1938) claims that that the junction between Dix's floras C and D occurs at the Dalmellington Blackband Ironstone. This equates essentially with the junction between the *Neuralethopteris jongmansii* and *Laveineopteris loshii* subzones in the classification given in Cleal (1991).

Interpretation

This is the best exposure through part of the lower Productive Coal Formation in the Ayrshire Coalfield. The coalfield has one of the thickest developments of Coal Measures in the Scottish Basin. The only significant exception is the small Douglas Coalfield (Lumsden and Calver, 1958), but exposure here is much poorer. In contrast, the Ayrshire Coalfield, especially the southern part, provides some excellent natural exposures, of which Dunaskin Glen provides the longest and most complete succession. It thus plays an important role in understanding the Upper Carboniferous stratigraphy of the Scottish Basin.

The general sedimentology observable at Dunaskin Glen reflects a lower delta-plain setting, with small-scale deltas infilling a slowly subsiding basin. This can be seen in the predominance of brackish and marine deposits, alternating with sandstones, and the limited development of coals. A clear comparison can be drawn with the coeval deposits in South Wales (e.g. Cwm Gwrelych-Nant Llyn Fach - see Chapter 4) and the Pennines (e.g. Ravenhead Brickworks - see Chapter 10). There are nevertheless differences from these areas, such as the development of at least one thick seat earth (the Dunaskin Fireclay), and the fact that the 'marine' bands never develop further than brackish conditions.

From a biostratigraphical standpoint, the site is significant for yielding one of the best examples of the *Carbonicola pseudorobusta* Subzone non-marine bivalve assemblages, from the Mussel Band Ironstone. The three-dimensionally preserved shells from here allow the full range of morphological variation to be observed. It is an almost identical assemblage to that found elsewhere in the Dalmellington Blackband Ironstone, and which has been discussed in detail by Trueman and Weir (1947).

Conclusions

Dunaskin Glen is the best exposure of coal-bearing, early Westphalian rocks (about 313 million years old) in Scotland.

INNINMORE BAY

Highlights

Inninmore Bay is the northernmost exposure of coal-bearing Upper Carboniferous in Europe, probably representing either a tongue of sediment extending north from the Scottish Basin, or a discrete intra-montane basin.

Introduction

This site (NM 710423–NM 729421) refers to exposures along the shore and a short distance inland on the southern coast of Morvern, 5 km south-east of Lochaline, Lochaber, Highland Region, Scotland. They show a small patch of strata, less than one-third of a square kilometre in extent, which is the northernmost exposure of terrestrial Upper Carboniferous in Europe. It was first discovered by Judd (1874, 1878), and the most recent account of the geology is provided by Macgregor and Manson (1935).

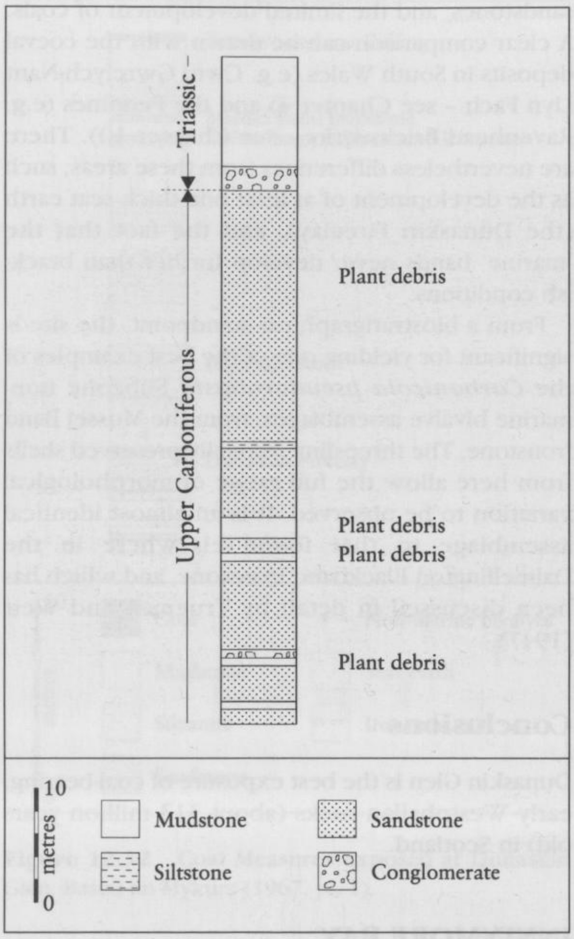

Figure 12.13 Coal Measures exposed along Quarry Burn, Inninmore Bay. Based on measurements given in Macgregor and Manson (1935).

Description

Lithostratigraphy

There are a number of discrete exposures of Upper Carboniferous strata here, which have yet to be correlated in detail. Macgregor and Manson (1935) estimate that there is a total thickness of at least 90 m, and may be more than 150 m. Of the available exposed sections, that near Quarry Burn is the most complete (Figure 12.13), where some 53 m of Upper Carboniferous can be seen. Their lower contact is not exposed, but they are overlain by Triassic red beds.

The succession is predominantly arenaceous, with white, coarse-grained quartzitic sandstones, and dark, micaceous sandstones. Three shales more than 1 m thick have been recorded, but mostly the argillaceous beds are inconspicuous, only a few centimetres thick. There is also at least one seat earth with lycophyte roots. Some 275 m NW of Inninmore Cottage, this is associated with a 10 cm thick bituminous coal, which in the past was worked in small-scale drifts.

Biostratigraphy

The only fossils reported from here so far are plant macrofossils. None have been described or illustrated, and our only knowledge of them are species lists reviewed by Macgregor and Manson (1935). The presence of form-genera such as *Calamites*, *Annularia*, *Asterophyllites* and *Cordaites* strongly suggests that the beds are Upper Carboniferous. There are also a number of pteridospermous frond fragments, which were identified as *Adiantites bondii* Kidston, *Mariopteris muricata?* (Brongniart) Zeiller, *Neuropteris heterophylla?* (Brongniart) Sternberg, *Paripteris gigantea* (Sternberg) Gothan and *Eusphenopteris striata* (Gothan) Novik. On the face of it, such an assemblage would belong to the *Lyginopteris hoeninghausii* Zone, indicating the Langsettian. However, nearly all of these species have been the subject of misidentification in the past, and the material will need to be re-assessed in the light of current taxonomy.

Interpretation

The main interest of this site lies in its isolated situation, compared with the rest of the Upper Carboniferous of Scotland. It lies 100 km distant from the nearest other exposure (the Cock of Arran – see Leitch, 1942). It is one of the few known exposures of such strata north of the Highland Boundary Fault (the only others being Cock of Arran and Machrihanish Bay on Kintyre), and the only one north of the Great Glen Fault. It thus lies outside of the area normally taken to delimit the Scottish Basin.

The relationship between the Inninmore deposits and the Scottish Basin is unclear. Such a predominantly arenaceous succession could be interpreted in terms of it being very marginal in the basin, similar to the marginal deposits of the Pennine Basin found in the English Midlands (see Chapter 7). However, it is too far from the rest of the basin's deposits for such a view to be accepted without question. One possible explanation is that the Inninmore deposits are the remains of a 'gulf' that extended the Upper Carboniferous in a narrow belt north of the main part of the basin. A similar

Figure 12.14 Barren Red Formation exposed near caves at Wemyss, East Wemyss to Buckhaven Coast GCR site. Reproduced by permission of the Director, British Geological Survey: NERC copyright reserved (B410).

situation, albeit on a smaller scale, can again be found along the southern margins of the Pennine Basin, in the English Midlands. Alternatively, it may represent marginal deposits of a small intra-montane basin, quite separate from the main Scottish Basin, and which would also be expected to be predominantly arenaceous (cf. Courel, 1988). There is clearly much potentially important work to be done on these Inninmore deposits, both on their sedimentology and establishing their exact chronostratigraphical position.

Conclusions

Inninmore Bay is the northernmost exposure of coal-bearing Upper Carboniferous rocks in Europe.

EAST WEMYSS TO BUCKHAVEN COAST

Highlights

East Wemyss to Buckhaven Coast provides the best exposure of Barren Red Formation in the Scottish Basin.

Introduction

Foreshore exposures (NT 339964-NT 363981) on the southern coast of Fife, Scotland, show Upper Carboniferous red beds, as developed in the north-eastern part of the Scottish Basin. The only published account is by Binney and Kirkby (1882).

Description

The original section described by Binney and Kirkby (1882), which was exposed between Leven and East Wemyss, was some 290 m thick. However, the section between Leven and Buckhaven is now obscured by the Methil Dockyard, and the remaining outcrop shows a succession only about 105 m thick. It nevertheless is an excellent example of the red beds known as the Barren Red Formation (Figure 12.14).

The base of the succession is reported to lie on grey shales of the Productive Coal Formation, although the contact is not well seen. The lowest well exposed beds comprise a prominent soft, red sandstone, 30 m thick. It displays well-developed cross-bedding and has numerous lenses and stringers of pebbles.

The sandstones are overlain by a 58 m unit dominated by seat earths of various shades of red, purple, yellow and white. Binney and Kirkby (1882) provide the following interesting footnote, 'After a gale, when these fireclays have been swept bare of sand, the colouring is something gorgeous.' Interbedded between the seat earths are irregular beds of red and yellow sandstone.

The top part of exposed succession is another soft, variegated sandstone, 9 m thick. It does not show the marked cross-bedding seen in the lower unit, but has more prominent pebbly bands, especially in the lower part of the unit.

None of the strata presently exposed along this stretch of coast have yielded fossils. However, the beds just to the east, which are now covered by Methil Dockyard, included several fossiliferous horizons. Binney and Kirkby (1882) provide species lists, which include numerous plants, limulids, estheriids and fish fragments. However, none are illustrated, other than some putative roots which are of no stratigraphical value. Furthermore, the species lists include a number of names which are almost certainly misidentifications (e.g. '*Neuropteris*' *auriculata* Brongniart, which is an upper Stephanian and Autunian species). Consequently, the lists are impossible to use as a basis for establishing the stratigraphical position of the beds.

Interpretation

This is the best exposure of the upper part of the Coal Measures of the Scottish Basin, and which are referred to as the Barren Red Formation. There has been no published sedimentological study on these beds in recent years. However, the occurrence together of seat earths (palaeosols), cross-bedded sandstones and conglomerates suggests some comparison with the alluvial fan facies association of the Etruria Formation in the English Midlands, as described by Besly (1988). According to Besly, this association typically occurs near the margins of fault-bounded basins. This site indeed lies near a major fault, the Ochil Fault a few kilometres to the north. However, the isopach map for the lower Westphalian given by Read (1988) suggests that this was not a basin margin. Alternatively, the facies association may be related to the contemporary volcanicity that developed in this part of the Scottish Basin (Francis and Ewing, 1961).

It is widely assumed that these beds were secondarily reddened during the Permian (e.g. Read, 1988). However, if the comparison with the Etruria Formation can be maintained, a pene-contemporaneous reddening of the beds becomes more plausible.

Conclusions

East Wemyss to Buckhaven Coast is the best place to see the upper part of the Coal Measures in Scotland. The succession, which is dominated by seat earths and red sandstones, belongs to the Barren Red Formation, and is probably about 310 million years old.