Chapter 15

NORTH SEA AND NORTHWEST APPROACHES

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The Carboniferous strata of the Central and Northern North Sea occupy a depositional basin that is laterally contiguous with, and located to the east of, the Midland Valley of Scotland (Chapter 14). The Carboniferous strata of the Southern North Sea occupy a depositional basin located between the Mid North Sea High to the north and the Wales-Brabant High to the south (Fig. 15.1). It is laterally contiguous with the Pennine Basin complex. An isolated area of Carboniferous strata has also been proved in the Clair Basin of the Northwest Approaches, west of the Shetland Isles.

The Tournaisian and oldest Visean strata have been proved beneath Permian and younger cover in the Central and Northern North Sea, within the Outer Moray Firth, Western Platform and Central Graben, eastwards from the coast of Southeast Scotland along the crest and southern flanks of the Mid North Sea High and in the Clair Basin, west of Shetland (Fig. 15.1). The strata are dominated by red, fluvial and playa-lake deposits (Upper Old Red Group). Younger Visean strata include the grey, fluvio-lacustrine deposits within the Forth Approaches Basin and Outer Moray Firth Basin of the Central and Northern North Sea (Firth Coal Formation). Visean to lower Namurian lacustrine, marine, fluvial and fluvio-deltaic sediments are proved in the Southern North Sea eastwards from the Northumberland coast along the western crest and southern flanks of the Mid North Sea High (Farne Group). The Zeeland Formation, an offshore equivalent of the platform carbonate rocks of the Peak Limestone Group, is known to be present along the northern flank of the Wales-Brabant High in the Southern North Sea and could also occur on isolated horst blocks within the main basinal area. A late Visean and Namurian succession of hemipelagic mudstone and fluvio-deltaic cycles (Whitehurst Group) is present across the Southern North Sea, and is overlain by Westphalian strata dominated by grey fluvio-lacustrine (Coal Measures facies) and red alluvial deposits (Conybeare Group).

The lithostratigraphical nomenclature is that of Cameron (1993a) for the Central and Northern North Sea. The nomenclature for the Southern North Sea proposed by Cameron (1993b), has been greatly modified by Morscariello (2003), Collinson (2005) and Besly (2005). Kombrink *et al*. (2010) provide a review of Carboniferous stratigraphy, palaeogeographical reconstructions and key well data for the UK Southern North Sea and adjacent sectors. The dominance of non-marine successions in the Central and Northern North Sea has resulted in miospore zonation being the main biostratigraphical correlation tool (McLean 2005), though problems of reworking and borehole caving can make interpretation difficult. However, it can be used in conjunction with an inferred marine band stratigraphy derived from geophysical wireline logs and geochemistry (Pearce *et al*. 2010). In the Southern North Sea there is significant number of cored marine bands allowing constraint of the palynological biostratigraphy of Chokierian to Bolsovian strata.

Tournaisian

The Upper Old Red Group of the Central and Northern North Sea is the offshore equivalent of the onshore Upper Old Red Sandstone Group and the overlying Inverclyde Group. Miospore recovery from the Upper Old Red Group is often very

poor, and strata have commonly been assigned a general late Devonian-Early Carboniferous age without any accurate identification of the horizon of the Devonian-Carboniferous boundary. Palynology indicates the Upper Old Red Group to range from Frasnian to Tournaisian (Marshall & Hewett 2003). Within the NE-SW Clair Basin (Fig. 15.2, Col. 1), there are in excess of 300 m of Devonian to Carboniferous floodplain deposits comprising interbedded red sandstone and mudstone with calcrete nodules, similar to the Kinnesswood Formation (Blackbourn 1987). These are overlain by up to 100 m of fluviodeltaic to lacustrine carbonaceous sandstone and organic-rich mudstone with late Tournaisian miospores [^1]. Alluvial and fluvial sandstones and shales, 996 m thick, were penetrated by well 206/8-4 on the Rona Ridge, Clair Basin. Miospore dating indicates the section to be Devonian – Carboniferous (Mudge & Rashid 1987).

In the Outer Moray Firth (Fig. 15.2, Col. 2) and Forth Approaches Basin (Col. 3) the Upper Old Red Group consists of the Buchan and Tayport formations. Marshall & Hewett (2003) considered that the two formations may be laterally equivalent. The Buchan Formation comprises a sandstone-dominated succession, which in the Buchan Field has a broad upward-fining trend, deposited predominantly within a fluvial environment. The formation is at least 600 m thick in the Buchan Field, but only the top 100 m is Carboniferous and only the uppermost 200-315 m include calcretes typical of the Kinnesswood Formation. Most of the Buchan Formation is Famennian (Marshall & Hewett 2005; Bruce & Stemmerick 2005) but, the uppermost part provides Tournaisian miospores [^1] and is equivalent of the onshore Kinnesswood Formation of the Inverclyde Group (Chapter 14). The Tayport Formation comprises more than 500 m of red, interbedded mudstone and fluvial sandstone (Cameron 1993a), especially present in the Outer Moray Firth, and probably deposited in fluvial and playa-lake environments within a low-lying alluvial floodplain, the sandstone representing major distributary channels or sheet floods (Cameron 1993b). The formation, which is similar to the onshore Clyde Sandstone Formation (Cameron 1993b), is also recognised on the Mid North Sea High (Fig. 15.2, Col. 5), but probably does not extend far southward into the Southern North Sea. The Tayport Formation ranges from Famennian to early Tournaisian in the Mid North Sea High, with younger Visean (Cameron 1993a) and early Namurian (Andrews *et al*. 1990) ages envisaged in the Outer Moray Firth.

Tournaisian strata are not penetrated by any wells in the UK part of the southern North Sea Basin. In the Dutch Sector, carbonates of the Beveland Member of the Zeeland Formation are dated as Tournaisian.

Visean

On the Rona Ridge of the Clair Basin (Fig. 15.2, Col. 1), well 206/8-2 penetrated Visean marine, grey, argillaceous siltstone interbedded with subordinate, ripple cross-laminated, fine-grained, carbonaceous sandstone has been proved (Meadows *et al.* 1987).

In the Inner Moray Firth Basin (well 12/23-1) a 58 m-thick succession of olivine basalt and tuff beds have been interpreted as of early Visean age based on ^{40}Ar-^{39}Ar age determinations of 340 Ma (Mitchell in Andrews *et al*. 1990), but a Devonian age has since been assigned (see Bruce & Stemmerik 2003).

In the Central and Northern North Sea, the Visean part of the Tayport Formation is overlain by the Firth Coal Formation. The latter is most similar to the onshore Limestone Coal Formation (Chapter 14), although the Firth Coal Formation is more wide-ranging in age. The formation comprises coal-bearing, cyclic interbedded sandstone, carbonaceous siltstone and shale. The strata were deposited in a non-marine, fluviodeltaic environment, with sands deposited as lenticular delta lobes or fluvial channels, interbedded with overbank and prodelta muds. Microfloral assemblages in the Outer Moray Firth (Fig. 15.2, Col. 2) in the majority of wells indicate TC – NM Biozones of Asbian age [^2], although a Vm Subzone early Pendleian age has been determined in well UK 21/11-1 (Bruce & Stemmerik 2003). A range of Arundian or Holkerian ages (Leeder *et al*. 1990a) to Pendleian or Arnsbergian (Andrews *et al*. 1990), are also published. In the Forth Approaches Basin (Fig. 15.2, Col. 3), in well UK 26/7-1 the formation is shown to include miospores from TC Biozone (mid Holkerian) up to NM Biozone (late Asbian age) [^1] (Bruce & Stemmerik 2003).

The term "Farne Group" was introduced for the Tournaisian to early Namurian lacustrine, fluvial and fluvio-deltaic sediments, including Yoredale facies and Coal Measures facies of the Southern North Sea (Cameron 1993b). The deposits extend eastwards from the Northumberland coast along the western crest and southern flanks of the Mid North Sea High. Elsewhere in the Southern North Sea the group has not been penetrated.

The Cementstone Formation, equivalent of the onshore Ballagan Formation (Chapter 13) and of Tournaisian to Chadian age, comprises interbedded sandstone, mudstone and micritic dolostone, proved in wireline logs for wells (41/10-1, 42/10-2, 43/2-1 and 43/5-1) (Collinson 2005; Kombrink *et al*. 2010). The Fell Sandstone Formation, of Chadian (Pu Biozone) to Holkerian (TS Biozone), is equivalent to its onshore namesake. In wells 42/10-2 and 43/2-1 it is characterised by fine- to coarse-grained sandstone with subordinate beds of grey mudstone, becoming more heterogeneous towards the east (well 43/5-1), with thin siltstone and possible limestone beds in the lower part (Collinson 2005). Vertical stacking of fluvial-channel sandbodies occurs across the northern parts of Quadrants 42-43, across the Mid-North Sea High, with to the west, higher proportions of finer-grained strata suggesting overbank or shallow coastal plains, e.g. well 41/10-1 (Collinson 2005). The base of the Fell Sandstone Formation is markedly diachronous, appearing earlier in the east, and as a consequence, the Lyne Formation of the central and western parts of the onshore Northumberland Trough (Chapter 13) is not developed in the North Sea. The Scremerston Formation is equivalent of the onshore Scremerston Coal Member of the Tyne Limestone Formation. It comprises interbeds of sandstone, siltstone, mudstone and coal with a few beds of dolostone and limestone of late Holkerian to late Asbian age (Turner & Riley *in* Maynard & Dunay 1995; Collinson 2005). Channel sandbodies are variably developed. The succession represents a low-relief coastal plain traversed by river channels (Collinson 2005). The Yoredale Formation of Cameron (1993b), of late Asbian to early Namurian age, is characterised by thin marine limestone beds occurring in cycles between 30 and 130 m thick, dominated by upward-coarsening deltaic deposits. The environments of deposition of these formations are the same as for their onshore equivalents (Chapters 12 and 13). Contrasting with the nomenclature used on Fig. 15.2, the upper Asbian to lower Brigantian succession of "Yoredale facies" has been subdivided by Collinson (2005) as follows. An Asbian to Brigantian Lower Limestone Formation is broadly equivalent to the onshore Tyne Limestone Formation (Chapter

13). This succession shows incised palaeovalleys, filled by thick multi-storey channel sandstones. The main part of the Brigantian succession is referred to as the Middle Limestone Formation and is broadly equivalent to the onshore Alston Formation (Chapters 12 and 13) and is characterised by thin limestones, thick upwards-coarsening cyclothems, lower proportions of sandstone and a lower incidence of channels. This is overlain by the early Pendleian-Arnsbergian Upper Limestone Formation (see below). To the south of the Yoredale facies deposits, a succession of hemipelagic mudstone of the Bowland Shale Formation dominates.

Miospore ranges from late Tournaisian to Brigantian are present in Quadrants 43 & 44 (Fig. 15.2, Col. 5 $^{\wedge 1}$), Tournaisian to Brigantian in Quadrant 38, Holkerian to Pendleian in Quadrant 39 and Brigantian to Pendleian in Quadrant 36 (Fig. 15.2, Col. 4 $^{\wedge 1}$) and Asbian to Brigantian foraminifers in Quadrant 38 ^{O2}. In the Southern North Sea Arundian to Arnsbergian miospores are present in Quadrant 41 (Fig. 15.2, Col. 6 $^{\wedge 1}$).

Visean shallow marine platform carbonates are developed along the margin of the Wales-Brabant Massif on the Hewett Shelf and Winterton High. The stratigraphy of these carbonates is poorly constrained due to a shortage of deep well penetrations. Cameron (1993b) referred to the platform carbonate rocks as the Zeeland Formation, based upon correlations with the Dutch sector. 450m of Visean shelf carbonates are proved in well 53/12-2 but the base of the carbonates have not been proved in the offshore UK sector. Seismic surveys suggest a total thickness locally in excess of 1000 m. The succession, proved in well 53/12-2, comprises a lower dark brown or dark grey finely crystalline dolostone 150 m thick, overlain by 300 m of pale brown to dark brown microcrystalline or very finely crystalline dolomitic limestone with some ooidal limestone beds. The northeastern limit of the carbonate platform has been proposed by Cameron (1993b) to occur along the NW-SE trending Dowsing Fault Zone. An equivalent succession is seen onshore in East Anglia in the Somerton No. 1 well, close to the southeastern margin of the Hewett Shelf, in which the platform carbonates rest upon early Holkerian sandstones and mudstones. More typically onshore within the area of the Wales-Brabant High the carbonates rest unconformably upon Lower Palaeozoic strata (Strank 1987). Short penetrations of carbonates are also known from the Saltfleetby Field on the coast of Linclonshire (Hodge, 2003).

The Zeeland Formation is better understood along strike in the offshore Dutch sector where it is penetrated by several deep wells (q.v. van Adrichem Boogaert & Kouwe 1993; Geluk *et al*. 2007). A succession of restricted marine dolostone/dolomitic limestone (Tournaisian Beveland Member) and overlying open-marine shelf carbonates (Visean Schouwen and Goeree members) are proved in wells S02-02 and S05-01. Well O18-01 penetrated the Zeeland Formation in slope and basinal carbonate facies. In each case the Zeeland Formation rests upon Devonian mudstones.

Further north into the southern North Sea basin, the carbonates increase in thicknesses northwestwards towards the UK sector, with a maximum of 1300 m (Kombrink *et al*. 2010). Seismic data indicate that platform carbonates occupy isolated basinal highs such as the Swarte Bank Hinge (Kombrink 2008), but these are not proved by any well penetrations.

Namurian

Along the Mid-North Sea High, the Pendleian to Arnsbergian Yoredale Formation (Upper Limestone Formation of Collinson 2005), is equivalent to the lower part of the onshore Stainmore Formation of Chapters 12 and 13, and comprises a sandstone-rich succession with limestones at the bases of Yoredale cycles.

The broadly Namurian succession of the Whitehurst Group is recognised offshore as comprising a lower Bowland Shale Formation with an overlying and in part laterally equivalent Millstone Grit Formation. This group equates with part of the onshore Craven Group and the entire Millstone Grit Group and was deposited in comparable environments. The Whitehurst Group is absent over the crest and southern flanks of the Mid North Sea High (Fig. 15.2, Col. 5), largely due to Variscan uplift and erosion. The Whitehurst Group onlaps onto, and is absent over, the crest of the Wales-Brabant High to the south. The group is also absent to the west where, offshore of Lincolnshire, Langsettian strata lie directly upon Brigantian platform carbonates of the Zeeland Formation. The group displays a broad depocentre located to the east of the East Midlands/Amethyst High (Quadrant 42/43), with in excess of 1200 m thickness of strata (Leeder & Hardman 1990).

The Bowland Shale Formation of Cameron (1993b) consists of dark grey hemipelagic mudstone, equivalent to the onshore Bowland Shale Formation. The formation is of late Visean to early Namurian age. The formation present off the East Yorkshire coast is only 47 m thick (well 41/24a-2) , but is known to have a maximum thickness in the Southern North Sea in excess of 725 m (well 43/17b-2). In Quadrant 43 (Fig. 15.2, Col. 7 $^{+1}$) ammonoids indicative of the *Isohomoceras subglobosum* (H_{1a}), *Homoceras beyrichianum* ($H_{1b}1$) and *Hudsonoceras proteum* ($H_{2a}1$) marine bands are found. Pendleian miospores, foraminifers, bivalves and brachiopods are found in Quadrant 41 (Fig. 15.2, Col. 6 $^{\wedge O\sim *2}$). A Marsdenian age for deep basinal mudrocks recorded in the lowermost part of Well 48/3-3 has been proposed from miospores (Fig. 15.2, Col. 8 $^{\wedge 1}$; Leeder *et al*. 1990b), but may be older.

The Millstone Grit Formation of the Southern North Sea comprises grey, white and brown, locally conglomeratic, typically fine- to medium-grained, sandstone and interbedded grey or dark grey, partly carbonaceous mudstone and siltstone (Cameron 1993b). Thin coal seams and seatearths are relatively rare. Lithological cycles are typically about 50 m thick, but with a wide range, and generally show upward-coarsening trends. Marine band constraints within the formation present in the Trent Field (Fig. 15.2, Col. 7 $^{+*2\ \&\ +3}$) were described by O'Mara *et al*. (1999). The base of the Millstone Grit Formation rests conformably upon the Bowland Shale Formation over most of the region, the base taken at the base of the lowermost thick sandstone. The base is regionally diachronous, being Arnsbergian in the west and lying upon the early Pendleian Yoredale Formation in the northeast. Miospores provide the main biostratigraphical constraints for the Marsdenian to Asturian succession in Quadrant 49 (Fig. 15.2, Col. 8 $^{\wedge 1}$) and Kinderscoutian to Langsettian succession in Quadrant 54 (Fig. 15.2, Col. 10 $^{\wedge 1}$). On the southern flanks of the Mid North Sea High (well 41/24a-2), the formation rests conformably upon the Yoredale Formation, the base taken at the top of the highest marine limestone (Cameron 1993b). Along the northern flanks of the Wales-Brabant High the formation laps on to the platform margin deposits of the Zeeland Formation (Fig. 15.2, Col. 10) and overlies folded Lower Palaeozoic strata on the block. Offshore, the top of the formation is taken at the base of the lowermost thick Westphalian coal seam, and hence the formation ranges up into early Langsettian. The

maximum thickness for the Millstone Grit Formation is 1308 m (well 43/25-1; Cameron 1993), with a marked thinning towards the south and is only about 180 m thick in well 48/23-3 and is absent in the adjacent Dutch sector (Kombrink *et al*. 2010).

Westphalian to Stephanian

In the Southern North Sea the Conybeare Group, is equivalent of the onshore Pennine Coal Measures and Warwickshire groups. The Conybeare Group is thin or absent over the crest and southern flanks of the Mid North Sea High (Fig. 15.2, Col. 5), and over crests of WNW-trending Variscan anticlines in the south (Leeder & Hardman 1990). The base of the group is taken at the base of the lowest Westphalian coal seam. On the northern flank of the Wales-Brabant High, the Conybeare Group oversteps the Millstone Grit Formation, Zeeland Formation and to rest on Lower Palaeozoic strata. The group, described in detail by Cole *et al*. (2005), shows an overall southward decrease in the abundance of sandstone.

The fluvio-lacustrine facies component of the Conybeare Group comprises the Caister, Westoe and Cleaver formations. The Coal Measures facies succession is most extensively preserved beneath the base-Permian angular unconformity in the Silver Pit Basin (Fig. 15.2, Col. 7 & 8), where it is more than 1150 m thick (Cameron 1993b; Leeder & Hardman 1990). The Caister Formation comprises a coal measures succession with a significant component of sandstone, with major channel sandbodies locally up to 50 m thick, and coal seams up to 3 m thick (Cowan 1989). The Subcrenatum Marine Band is recognised by the presence of diagnostic ammonoids in Quadrant 43 (Fig. 15.2, Col. 7 $^{+3}$), where it occurs at the base of the formation, though elsewhere the age of the base is poorly constrained and probably of later Langsettian age. Also in Quadrant 43 the Listeri Marine Band is recognised by the presence of foraminifers (Fig. 15.2, Col. 7 ^{O4}). Late Langsettian palynomorphs of RA Biozone are recorded in Well 48/3-3 (Fig. 15.2, Col. 8 $^{\wedge 2}$; Leeder *et al*. 1990b). There is an upward and southward facies transition into argillaceous strata of the Westoe Formation, a dominantly argillaceous coal measures succession of grey and silty mudstone. Cycles are generally thin, less than 20 m, and coarsen upward. Coal seams are up to 5 m thick and are relatively widespread. Diachroneity of facies can be identified by reference to the position of significant marine flooding horizons such as the Vanderbeckei Marine Band (McLean *et al*. 2004). The Vanderbeckei, Maltby and Aegiranum marine bands are constrained by the presence of brachiopods in Quadrant 44 (Fig. 15.2, Col. 7 ^{*5}). Langsettian and Duckmantian miospores are also recorded in Quadrant 41 (Fig. 15.2, Col. 6 $^{\wedge 3}$) and Langsettian miospores in Quadrant 52 (Fig. 15.2, Col. 9 $^{\wedge 1}$) within these formations. The Cleaver Formation and the overlying Ketch and Boulton formations (Morscariello 2003; Besly 2005) are present in the Silver Pit Basin and in Variscan synclinal axes in the northern part of the Southern North Sea. The formations were more extensive prior to Variscan deformation and erosion. The late Duckmantian to middle Bolsovian Cleaver Formation, formerly the lower part of the Schooner Formation of Cameron (1993b), comprises grey sandstone-dominated coal measures with interbedded mudstone and coal seams typically less than 2 m thick.

The Ketch and Boulton formations of the Silver Pit Basin (Morscariello 2003) and the Brig Formation which is confined to the Wales-Brabant High (Cameron 1993b) equate to the onshore Warwickshire Group (Chapter 9). The bases of both the Ketch and the Brig formations are marked by an intra-Westphalian unconformity. In the case of the middle to upper Bolsovian Ketch Formation, the extent of the unconformity increases

from south to north. The Ketch redbeds overlie the earliest Duckmantian Westoe Formation in the area of the Tyne field, whereas in the Schooner area, further south, the unconformity is minimal or absent. The Ketch Formation commonly has coarser, pebbly sandstone compared with the underlying Coal Measures facies. Reddish brown and purple mudstone with mature palaeosols is present throughout the Ketch Formation, whereas grey, coal-bearing intercalations and caliche horizons are common in the overlying unit (Besly *et al*. 1993), the locally preserved Boulton Formation. Late Bolsovian palynomorphs of the later part of the SL Biozone have been found in the Ketch Formation in Well 44/21-3 (Fig. 15.2, Col. 7 ^6) (Besly *et al*. 1993; Pearce *et al*. 2005). The red sediments of the Ketch Formation are the age equivalents of the Etruria Formation of the onshore Warwickshire Group (Besly *et al*. 1993). These formations share some sedimentological features, but the Ketch Formation has a much higher sandstone content, reflecting a different provenance. The presence in this formation of palaeocurrents towards the south-west in the Schooner field and heavy mineral assemblages indicate a source from the Rinkøbing-Fyn High to the north (Morton *et al*. 2001, 2005). The overlying Boulton Formation (Fig. 15.2, Col. 7 ^7), with Asturian miospores in Quadrants 43/44, shows a heavy mineral assemblage indicative of transport from the south and equates with the onshore Halesowen Formation. On the southern side of the basin, the Brig Formation commonly comprises a thin basal Coal Measures component of grey, purple and reddish brown mudstone and siltstone with thin coal seams and thin, very fine-grained sandstone beds with palynomorph assemblages indicative of an Asturian age (Fig. 15.2, Col. 9 ^2) in well 52/5-11X (B. Owens in Ramsbottom *et al*. 1978) or late Bolsovian age (Col. 10 ^2) in Quadrant 53 (Tubb *et al*. 1986). These rest unconformably upon strata of early Bolsovian to late Langsettian age. The overlying red beds are characterised by alternating grey, reddish brown or white, very fine- or fine-grained sandstone and reddish brown, purple or greenish grey mudstone and lack diagnostic palynomorphs. The formation therefore equates most closely with the Boulton Formation further north and has the same southerly provenance.

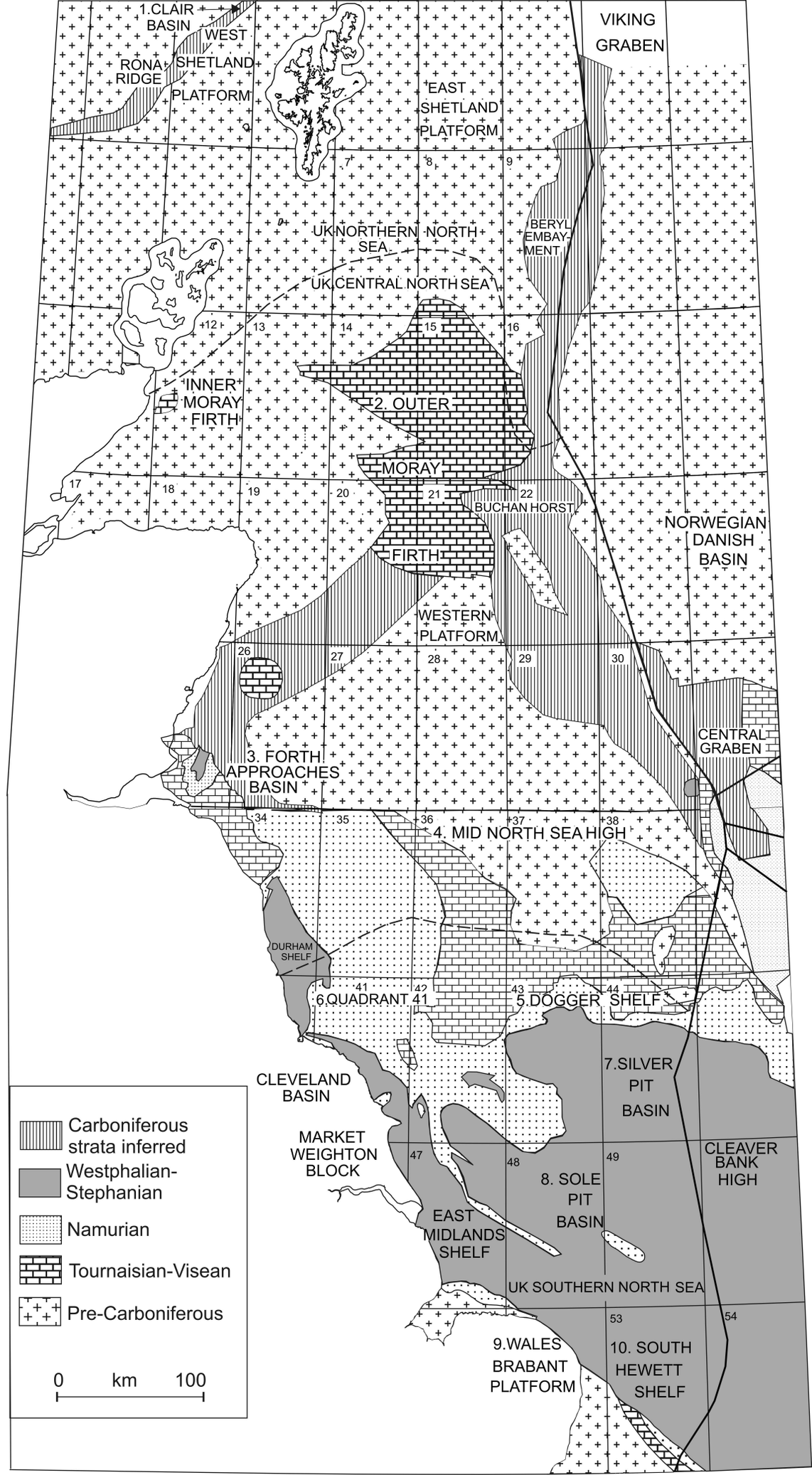
Similar Westphalian facies distributions are recognisable along strike in the Dutch Sector of the southern North Sea. Although criteria defining lithostratigraphic units may vary slightly between areas, the general correlation is as follows. The Caister and Westoe Formations equate to the Klaverbank Formation and in part to the lower part of the Maurits Formation (as defined by van Adrichem Boogaert & Kouwe (1993) the base of the Maurits Formation is strongly diachronous). The Cleaver Formation correlates with the Maurits Formation, or just the upper part of the Maurits Formation. The Ketch Formation correlates with the Hospital Ground Formation and the Boulton Fomration is equivalent to the lower part of the Step Graben Formation.

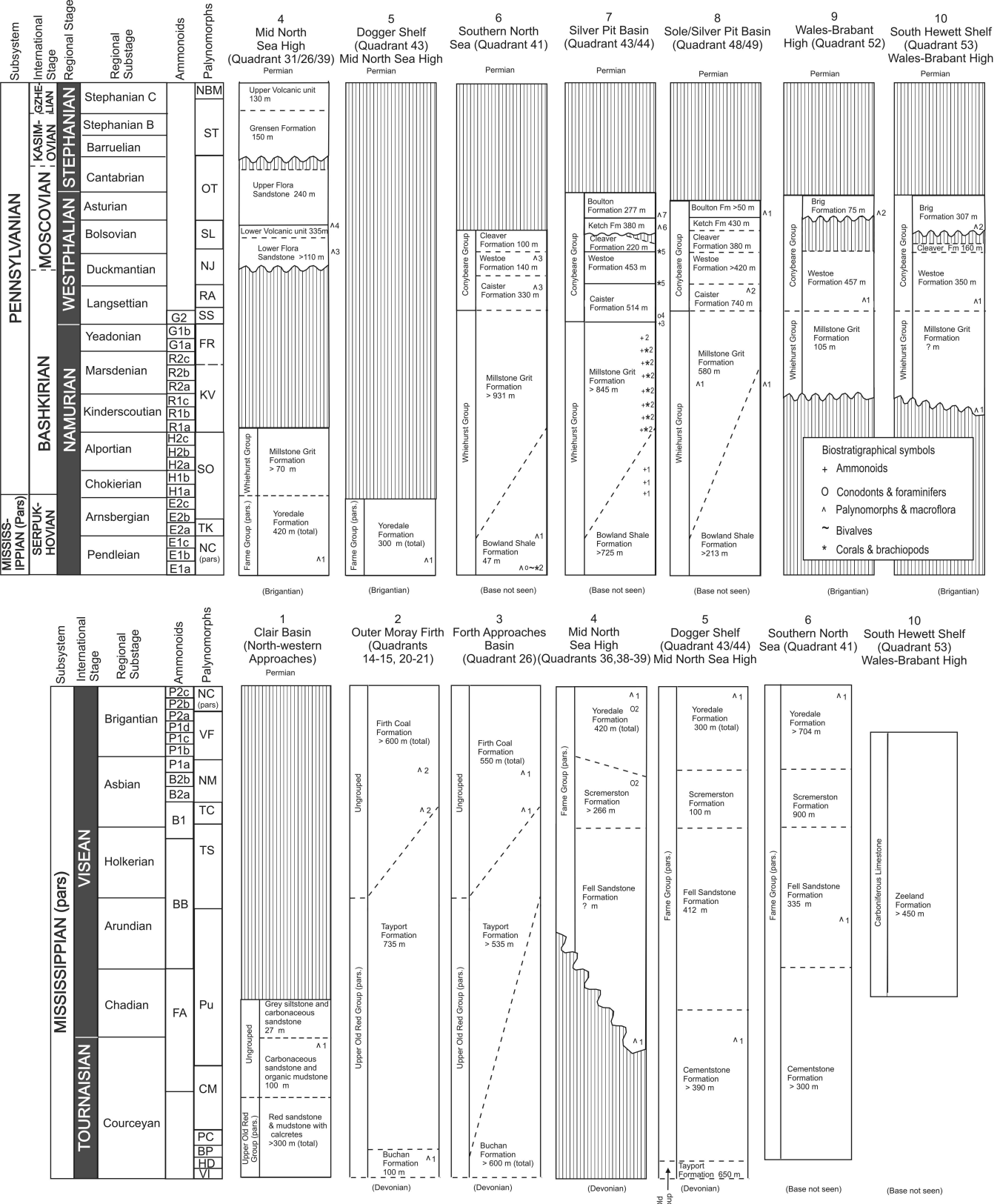
On the Mid North Sea High (Fig. 15.2, Col. 4; Quadrant 31/26) the Westphalian is represented by the Upper and Lower Flora Sandstones. Basaltic lavas, tuff and mudstone between the two sandstones have been dated using K-Ar at 299±9 Ma (Martin *et al*. 2002). The Lower Flora Sandstone floodplain deposits include palynomorphs indicative of a Duckmantian to Bolsovian age ^3 (D. McLean in Martin *et al*. 2002). The Upper Flora Sandstone comprises red fluvial conglomerate and sandstone of mid to late Bolsovian to Asturian, possibly Stephanian age ^4 (D. McLean in Martin *et al*. 2002). In wells 39/2-4 and 31/26d-15Z of the Grensen Nose, the Upper Flora Sandstone is overlain unconformably by reddened mudstone and interbedded siltstone, which are in turn overlain by a further volcanic unit dated using Ar-Ar at

299±1.6 Ma (M. J. Timmerman in Martin *et al*. 2002), approximating to the Carboniferous-Permian boundary. Both volcanic units are interpreted by Martin *et al*. (2002) as equivalents of the Inge Volcanic Formation (Rotliegend Group) of the Central North Sea (Cameron 1993a).

Fig. 15.1. Geological map showing the distribution of Carboniferous strata for the North Sea, modified from Bruce & Stemmerik (2003), (Kombrink *et al*. 2010) and Cameron (1993a & b).

Fig. 15.2. Correlation of Carboniferous successions in the. The nomenclature is that of Cameron (1993a & b), with details from the following publications: Col. 1 from Blackbourn (1987) and Meadows *et al*. (1987); Col. 2 from Cameron (1993a); Col. 3 from Cameron (1993a); Col. 4 from Cameron (1993b) and Martin *et al*. (2002); Col. 5 from Cameron (1993b) and Collinson (2005); Col. 6 from Cameron (1993b) and Collinson (2005); Col. 7 from Cameron (1993b), O'Mara *et al*. (1999), Morscariello (2003) and Besly (2005); Col. 8 from Cameron (1993b), Morscariello (2003) and Besly (2005); Col. 9 from Cameron (1993b); Col. 10 from Cameron (1993b).


1.CLAIR BASIN
WEST SHETLAND PLATFORM
RONA RIDGE
EAST SHETLAND PLATFORM
VIKING GRABEN
BERYL EMBAY-MENT
UK NORTHERN NORTH SEA
UK CENTRAL NORTH SEA
INNER MORAY FIRTH
2. OUTER MORAY FIRTH
BUCHAN HORST
NORWEGIAN DANISH BASIN
WESTERN PLATFORM
CENTRAL GRABEN
3. FORTH APPROACHES BASIN
4. MID NORTH SEA HIGH
DURHAM SHELF
6.QUADRANT 41
5.DOGGER SHELF
7.SILVER PIT BASIN
CLEVELAND BASIN
MARKET WEIGHTON BLOCK
8. SOLE PIT BASIN
CLEAVER BANK HIGH
EAST MIDLANDS SHELF
UK SOUTHERN NORTH SEA
9.WALES BRABANT PLATFORM
10. SOUTH HEWETT SHELF
Carboniferous strata inferred
Westphalian-Stephanian
Namurian
Tournaisian-Visean
Pre-Carboniferous
0 km 100


Subsystem
International Stage
Regional Stage
Regional Substage
Ammonoids
Palynomorphs
PENNSYLVANIAN
MISSISS-IPPIAN (Pars)
SERPUK-HOVIAN
BASHKIRIAN
MOSCOVIAN
KASIM-OVIAN
GZHE-LIAN
NAMURIAN
WESTPHALIAN
STEPHANIAN
Stephanian C
Stephanian B
Barruelian
Cantabrian
Asturian
Bolsovian
Duckmantian
Langsettian
Yeadonian
Marsdenian
Kinderscoutian
Alportian
Chokierian
Arnsbergian
Pendleian
G2
G1b
G1a
R2c
R2b
R2a
R1c
R1b
R1a
H2c
H2b
H2a
H1b
H1a
E2c
E2b
E2a
E1c
E1b
E1a
NBM
ST
OT
SL
NJ
RA
SS
FR
KV
SO
TK
NC (pars)
4 Mid North Sea High (Quadrant 31/26/39)
5 Dogger Shelf (Quadrant 43) Mid North Sea High
6 Southern North Sea (Quadrant 41)
7 Silver Pit Basin (Quadrant 43/44)
8 Sole/Silver Pit Basin (Quadrant 48/49)
9 Wales-Brabant High (Quadrant 52)
10 South Hewett Shelf (Quadrant 53) Wales-Brabant High
Permian
Upper Volcanic unit 130 m
Grensen Formation 150 m
Upper Flora Sandstone 240 m
Lower Volcanic unit 335m
Lower Flora Sandstone >110 m
Millstone Grit Formation > 70 m
Yoredale Formation 420 m (total)
Yoredale Formation 300 m (total)
Cleaver Formation 100 m
Westoe Formation 140 m
Caister Formation 330 m
Millstone Grit Formation > 931 m
Bowland Shale Formation 47 m
Boulton Formation 277 m
Ketch Fm 380 m
Cleaver Formation 220 m
Westoe Formation 453 m
Caister Formation 514 m
Millstone Grit Formation > 845 m
Bowland Shale Formation >725 m
Boulton Fm >50 m
Ketch Fm 430 m
Cleaver Formation 380 m
Westoe Formation >420 m
Caister Formation 740 m
Millstone Grit Formation 580 m
Bowland Shale Formation >213 m
Brig Formation 75 m
Westoe Formation 457 m
Millstone Grit Formation 105 m
Brig Formation 307 m
Cleaver Fm 160 m
Westoe Formation 350 m
Millstone Grit Formation ? m
Conybeare Group
Whitehurst Group
Farne Group (pars.)
(Brigantian)
(Base not seen)
Biostratigraphical symbols
+ Ammonoids
O Conodonts & foraminifers
^ Palynomorphs & macroflora
~ Bivalves
* Corals & brachiopods
MISSISSIPPIAN (pars)
TOURNAISIAN
VISEAN
Courceyan
Chadian
Arundian
Holkerian
Asbian
Brigantian
P2c
P2b
P2a
P1d
P1c
P1b
P1a
B2b
B2a
B1
BB
FA
NC (pars)
VF
NM
TC
TS
Pu
CM
PC
BP
HD
VI
1 Clair Basin (North-western Approaches)
2 Outer Moray Firth (Quadrants 14-15, 20-21)
3 Forth Approaches Basin (Quadrant 26)
4 Mid North Sea High (Quadrants 36,38-39)
5 Dogger Shelf (Quadrant 43/44) Mid North Sea High
6 Southern North Sea (Quadrant 41)
10 South Hewett Shelf (Quadrant 53) Wales-Brabant High
Ungrouped
Upper Old Red Group (pars.)
Grey siltstone and carbonaceous sandstone 27 m
Carbonaceous sandstone and organic mudstone 100 m
Red sandstone & mudstone with calcretes >300 m (total)
Firth Coal Formation > 600 m (total)
Tayport Formation 735 m
Buchan Formation 100 m
Firth Coal Formation 550 m (total)
Tayport Formation > 535 m
Buchan Formation > 600 m (total)
Yoredale Formation 420 m (total)
Scremerston Formation > 266 m
Fell Sandstone Formation ? m
Yoredale Formation 300 m (total)
Scremerston Formation 100 m
Fell Sandstone Formation 412 m
Cementstone Formation > 390 m
Tayport Formation 650 m
Yoredale Formation > 704 m
Scremerston Formation 900 m
Fell Sandstone Formation 335 m
Cementstone Formation > 300 m
Carboniferous Limestone
Zeeland Formation > 450 m
(Devonian)
(Base not seen)