Lithostratigraphic nomenclature of the UK North Sea

Editors:

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5. CARBONIFEROUS AND DEVONIAN
OF THE SOUTHERN NORTH SEA

T.D.J.CAMERON

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FOREWORD

Since the publication of standard lithostratigraphic schemes for the UK Southern North Sea in 1974, and for the Central and Northern North Sea in 1977, continued exploration has resulted in the acquisition of an enormous amount of additional stratigraphic data. As a result, the earlier standard schemes have become increasingly outdated. This has become especially apparent in the exchange of well data between companies, which has revealed differing application of existing names. The efficient use of exchange data is thus hampered by the lack of a common lithostratigraphic terminology and usage.

In order to resolve these problems, the Member Companies of UKOOA agreed to provide funding for a revision of the existing UK nomenclature, to establish a new standard scheme. The intention was to produce a document that served not only as a stratigraphic lexicon, serving the scientific community as a whole, but one also acting as a reference book presenting the data in a form more easily assimilated in the context of operational requirements.

These results were to be presented in a series of five volumes, mostly relating to the Central and Northern North Sea, but including the Carboniferous of the Southern North Sea, which was not adequately covered in the 1974 scheme. However, the British Geological Survey decided on its own initiative to complete the UK North Sea nomenclature scheme by carrying out a revision of the post-Carboniferous of the Southern North Sea. This was welcomed by UKOOA, who agreed to its inclusion as the sixth volume in the series.

I should like to extend my sincere thanks to the Member Companies of UKOOA who have provided data, and who supported their staff in serving on the technical committees. In turn I express my gratitude to all those who served in this way on these committees and whose collective contributions were vital to the success of this very ambitious project. Last, but certainly not least, we express our gratitude to the British Geological Survey and its staff who undertook this detailed and demanding work.

DR H.W.D.HUGHES, O.B.E.
Director-General, UKOOA
November 1992

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The first comprehensive lithostratigraphic schemes for the North Sea Basin were established by Deegan & Scull (1977) for the UK and Norwegian Central and Northern North Sea, and by Rhys (1974) for the UK Southern North Sea. The subsequent acquisition of an increasing body of new stratigraphic data has led to piecemeal additions to these formal nomenclature schemes and also to a proliferation of informal names, some of which are now widely used by oil companies. This, together with increasing divergence in the application of existing formal names, has led to considerable uncertainty as to the meaning of many lithostratigraphic terms. This work aims to rationalize lithostratigraphic usage and to provide a nomenclature that will have the widest acceptance within the oil industry as a whole. It does not attempt to review the genesis or economic importance of the North Sea rock successions.

The original UKOOA plan was to publish the revision in five volumes, concentrating on prospective parts of the succession that were considered to be most in need of lithostratigraphic revision. However, coverage of the UK North Sea succession has been completed by the addition, by BGS, of a sixth volume on the post-Carboniferous of the UK Southern North Sea Basin. The review of each of the stratigraphic intervals was carried out with the assistance of a steering committee, drawn from UKOOA member companies. The primary role of these committees was to critically assess the proposals presented by BGS and to agree the final nomenclature schemes.

The area of study was defined at the outset by UKOOA as the UK sector of the North Sea. As a consequence, there has been no comprehensive comparison with lithostratigraphic schemes used in the adjacent sectors of, for example, Norway and the Netherlands. However, each volume includes a summary of schemes used in adjacent sectors. The primary source of data for the review has been the several hundred completion reports of wells released by the Department of Energy and, more recently, by the Department of Trade and Industry. These reports provide wellsite lithology logs (mud logs), wireline logs, and lithostratigraphic reports. Additional information has been obtained from published papers and unpublished sources, including BGS reports, consultants' reports, and unreleased post-completion reports made available by UKOOA member companies.

One of the primary objectives of the study has been to review the lithostratigraphic terms currently in use, whether formal or informal, and to establish a comprehensive nomenclature scheme for the entire UK North Sea area. This provides a lithostratigraphic framework that will facilitate stratigraphic communication and the assimilation of stratigraphic information obtained through the exchange of well data.

The format has been designed to develop a scheme that, while satisfying the requirements of lithostratigraphic procedure, is of practical value to the diverse group of professionals needing to use it (e.g., exploration/development geologists, geophysicists, mud loggers, petroleum engineers, and members of the academic community). To this end, the aim has been to ensure that all lithostratigraphic units included within the scheme will be readily identifiable with the minimum of information, i.e., through the routine study of cuttings and wireline logs.

The format of these volumes differs significantly from the customary style of presentation. The new format aims to satisfy two requirements: (i) for an updated stratigraphic lexicon, and (ii) for a practical manual that meets the needs of operational activities. Consequently, each lithostratigraphic unit is illustrated by at least two key well sections, showing the lithological succession and corresponding gamma-ray and sonic log signatures. Lateral variation within units is displayed in a series of correlation panels at the end of the volume.

The lithostratigraphic procedures adopted in this revision follow the recommendations of the North American Commission on Stratigraphic Nomenclature (1983) and the Geological Society's recent guide to stratigraphical procedure (Whittaker et al. 1991). The underlying principle followed is that the fundamental lithostratigraphic unit is the formation. A formation must be mappable and must possess lithological characteristics that distinguish it from adjacent formations. Since this study is concerned exclusively with the subsurface, the definition of lithostratigraphic units depends on well data, primarily cuttings, but also side-wall cores and, to a lesser extent, continuous cores. Together, these provide the only direct information on the lithological succession. Wireline logs provide further essential control in characterizing more precisely the lithological succession, especially where they have been calibrated with lithological samples. The continuous nature of information from wireline logs ensures that they play a vital role in providing a consistent definition of lithological boundaries in the subsurface. As a consequence, wireline-log signatures constitute a significant element in the description, definition, and correlation of lithostratigraphic units. Furthermore, wireline-log signatures often provide lithological information of a more subtle nature than can be obtained from cuttings alone, for example, grain-size trends and variations in bed thickness. Such information plays an important role in the differentiation of lithostratigraphic units.

While the primary aim of the study has been to establish a formal lithostratigraphic nomenclature, informal lithostratigraphic units have been used for units that are of practical value but that do not justify formal status. This category includes, for example, reservoir rock units that are restricted to individual fields and rock units that cannot be identified with certainty without the acquisition of biostratigraphic data. The principal consideration has therefore been to limit the use of formal names to units of significant geographic extent that can be routinely defined on lithological and wireline-log character alone, and to apply informal names where these criteria cannot be met, but where a clear practical purpose is served by doing so.

The authors are aware of many lithostratigraphic schemes that have been devised by oil companies for their own internal use. These are often extremely detailed, having evolved as a result of exploration success and consequent appraisal and development activities. These are generally of limited value outside the specific areas for which they were intended, in which case they have not been included within the mainstream formal nomenclature. Other schemes have been devised by consultancy groups. Some of the lithostratigraphic terms proposed in these schemes have wide usage, but because their documentation is restricted to exclusive reports, their incorporation into the current scheme has been possible in only a limited number of cases.

Biostratigraphic data should not constitute an essential element in the definition of a lithostratigraphic unit. Rock units whose identification depends wholly on biostratigraphic data do not warrant formal status. However, it is a common practice for biostratigraphic data to be used as an aid to the identification and correlation of lithostratigraphic units. For this reason, a review of the various biostratigraphic schemes in common use has been included in this study and a selection of the most widely recognized biostratigraphic markers presented in an appendix to each part. These biostratigraphic markers are restricted to first downhole occurrences and first downhole acme occurrences, since these alone are identifiable in routine cuttings analysis.

It should be stressed that the biostratigraphic markers identified in this review are already in regular use, many of them in published form. They are not discussed in detail, although their selection has involved analysis of a large amount of data. The sole purpose of the review of the biostratigraphic markers has been to provide a basic biostratigraphic framework for each of the lithostratigraphic schemes and to provide a common link between the several published and unpublished schemes that will continue to be used within the oil industry.

The relationship of lithostratigraphy to seismic stratigraphy and sequence stratigraphy has been briefly discussed by Whittaker et al. (1991), and it is beyond the scope of this study to include any in-depth discussion of either discipline. It should be stressed, however, that sequence stratigraphy and lithostratigraphy are two quite separate methods which, to some extent, are complementary. Lithostratigraphy is essentially objective. It provides a means of describing the spatial relationships of rock units and thus acts as the 'lingua franca' for stratigraphic analysis, whether by sequence stratigraphy or by other methods. Although sequence stratigraphy has introduced a fresh approach to basin studies, therefore, lithostratigraphy remains an essential and continuing element in any stratigraphic analysis.

Structural elements referred to in the following text are shown on the accompanying map. This is based on the map entitled 'Structural framework of the North Sea area', issued by the Petroleum Exploration Society of Great Britain (revised edition, March 1992), but includes the additional terms 'Outer Moray Firth', 'UK Central North Sea' and 'UK Northern North Sea'. As used here, the UK Central North Sea encompasses the Central Graben, Outer Moray Firth and Inner Moray Firth basins, together with adjacent parts of the Western Shelf and the East Shetland Platform. The UK Northern North Sea encompasses the Viking Graben, Beryl Embayment and East Shetland Basin, together with adjacent parts of the East Shetland Platform.

References


KEY TO GRAPHICS

KEY WELLS
These illustrate the principal variations in lithology and wireline log signature. All depths are quoted below KB.

DISTRIBUTION MAPS
These are based primarily on well data. However, some up–dip limits are based on shallow seismic data. Colour boundaries without lines indicate minimum extent, corresponding to the limit of well data.

STRATIGRAPHIC SYNOPSIS
These summarize the lithostratigraphic relationships within each group.

STRUCTURAL NOMENCLATURE
Structural terms in this study are shown on the accompanying map. The southern limit of the Mid North High is taken from the map ‘Structural framework of the North Sea area’, issued by the Petroleum Exploration Society of Great Britain (revised edition, March 1992). The northern limit of the London–Brabant Massif is here defined by the southern limit of Carboniferous strata.
CARBONIFEROUS AND DEVONIAN STEERING COMMITTEE
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Rhys (1974) excluded the Carboniferous and Devonian from his formal lithostratigraphic scheme for the Southern North Sea, because only a few widely scattered wells had drilled a significant thickness of pre-Permian strata during the early years of North Sea exploration. He did, however, summarize the principal Carboniferous lithologies encountered (Rhys 1974, table 1). The base of the Permian was considered to be economic basement during early exploration (Rhys 1974). However, the discovery of gas reserves in Carboniferous sandstones of the Silver Pit area during the 1980s provided the impetus to drill beneath the Permian in many areas of the Southern North Sea. To date, approximately 160 wells have penetrated more than 100m of pre-Permian section, with the maximum penetration being 1600m. This has provided much new information on the offshore Carboniferous succession, and has confirmed early impressions of its similarity to successions in central and northern England.

**Scope of study**

Assessment of lithostratigraphic nomenclature has been based on an analysis of pre-Permian sections from all Southern North Sea wells completed in the UK sector prior to 1988. Lower Paleozoic sediments have been encountered in only two wells, both on the northern flank of the London-Brabant Massif. Consequently, pre-Devonian strata have not been assigned a formal stratigraphic nomenclature. The regional relationships of the Lower Paleozoic and other deeply buried basement rocks have been summarized by Cameron et al. (1992). The stratigraphic nomenclature of the adjacent Dutch sector is also under revision (van Adrichem Boogaert & Kouwe, in prep.). Although there have been no formal attempts to devise a basinwide nomenclature for the UK and Dutch sectors, the respective schemes have some elements in common, mainly for the Dinantian and Devonian strata. At the time of writing, the nomenclature of the Dutch Namurian and Westphalian had not been finalized.

**Proposed scheme**

The proposed nomenclature for the Devonian and Carboniferous strata of the Southern North Sea is illustrated in Figure 3. A full definition, discussion, and illustration of each lithostratigraphic unit is given on subsequent pages. The proposed scheme is further illustrated in a regional well-correlation diagram (Fig.1) and in nine correlation panels. It should be noted that intraformational correlation lines (e.g. between marine bands) have been omitted from these panels, as regional correlations of this type cannot yet be regarded as firmly established offshore.

The term *Conybeare Group* is introduced for Westphalian coal measures and primary red beds. The group is divided into four formations, each of which represents a distinctive lithofacies. Lower boundaries of three of the formations are diachronous facies transitions, and the base of the fourth is probably an intra-Westphalian unconformity. This approach differs from that used for the Westphalian onshore in England and Wales, where subdivisions are based on regional marine bands (see Stubblefield & Trotter 1957). Specific marine bands are rarely identifiable in offshore sections. The term *Whitehurst Group* is introduced for strata that are approximately equivalent to the Millstone Grit and Bowland Shale groups onshore.

The term *Farne Group* is introduced for strata, mainly Dinantian in age, that are equivalent to the Cementstone, Fell Sandstone and Scremerston Coal groups of northeast England and southeast Scotland, together with an overlying succession characterized by development of Yoredale cycles. Group

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### Introduction

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status is considered inappropriate for the units offshore, as they cannot be divided into constituent formations. The units are therefore given formation status offshore. The term Zeeland Formation will be formally proposed by van Adrichem Boogaert & Kouwe (in preparation) for Dinantian platform carbonates in the southern Dutch sector; it is informally adopted here for equivalent strata in the UK sector.

The terms Upper Old Red Group and Kyle Group were introduced by Cameron (1993) for Late Devonian to Early Carboniferous terrestrial strata and mid-Devonian marine sediments, respectively, of the Central and Northern North Sea. These groups and their component divisions are adopted here for equivalent strata encountered in the area of the Mid North Sea High.

References


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Figure 1. Regional correlation of Carboniferous formations in the UK Southern North Sea
Figure 2. Pre–Permian subcrop map of the UK Southern North Sea
Figure 3. Lithostratigraphic nomenclature for the Carboniferous and Devonian of the Southern North Sea
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CONYBEARE GROUP
CONYBEARE GROUP
(new)

The term Conybeare Group is introduced here for Westphalian coal measures and primary red beds of the Southern North Sea. These strata were gently folded, faulted, and variably eroded prior to deposition of overlying Lower Permian desert sediments (Rotliegend Group). Consequently, the top of the Conybeare Group is a regionally angular unconformity. More than 1500m of coal measures and red beds are preserved below this unconformity in parts of the Silver Pit area, whereas Westphalian strata are now thin or absent in the north and north-west of the offshore area and over the crests of major NW-W-SE trending Variscan antilines farther south. The Conybeare Group generally rests on 'Millstone Grit' facies of the Whitehurst Group, but oversteps the latter to onlap Dinantian carbonates and Lower Paleozoic basement along the northern flank of the London-Brabant Massif.

Stubbefield & Trotter (1957) formally divided the Westphalian strata of England and Wales into the Lower, Middle, and Upper Coal Measures, and many offshore operators have adopted their scheme up to now. Hence the terms Lower and Middle Coal Measures have been applied to strata of Westphalian A and Westphalian B to early Westphalian C age respectively. Offshore equivalents of the upper Middle and Upper Coal Measures are generally lacking in coal seams. They comprise primary red bed sequences, variously termed Barren Red Beds, Barren Measures, Barren Red Measures, or Barren Red Group in published reports and on completion logs.

For Stubbefield & Trotter's scheme to be applied consistently offshore, there must be unequivocal recognition of the thin, but regionally widespread Gastrioceras subcrenatum, Anthracoceras vanderbeckei, and Anthracoceras cambriense marine bands that define the bases of the Lower, Middle, and Upper Coal Measures respectively. However, specific Westphalian marine bands cannot be consistently recognized on wireline logs, and have only rarely been identified in core. An alternative scheme is therefore proposed here (Fig.3), in which the Conybeare Group is divided into four formations, each representing a regionally widespread and distinctive lithofacies. Boundaries between these formations are diachronous, and in some cases strongly so. The base of the Conybeare Group is defined by the lowest Westphalian coal seam, which occurs up to 100m above the Namurian/Westphalian boundary in those few wells with good biostratigraphic control.

The term Caister Coal Formation is introduced for sandy Westphalian A to early Westphalian B coal measures; these are limited to the north of the UK Southern North Sea. They are overlain by, and pass southwards by lateral transition into, argillaceous coal measures, here termed the Westoe Coal Formation. Deposition of sandy coal measures resumed in the Silver Pit area late in Westphalian B or early in Westphalian C times. The term Schooner Formation is introduced for a composite unit that incorporates these sandy coal measures together with overlying primary red mudstones and sandstones of Westphalian C age. The term Ketch Member is introduced for the primary red beds, and its base is more easily resolved from cuttings than from its wireline log response.

Farther south, primary red beds are also preserved in Variscan synclines along the flank of the London-Brabant Massif, but are largely Westphalian D in age there (Besly et al. 1993). They are underlain by a thin, condensed unit of late Westphalian C or Westphalian D coal measures which is believed to be separated from the underlying Westoe Coal Formation by an intra-Westphalian unconformity (see Tubb et al. 1986). The term Brig Formation is introduced for the composite unit incorporating the coal measures and red beds above this unconformity. No comparable unconformity is represented in the Silver Pit area (Besly et al. 1993). The strata eroded from the flank of the London-Brabant Massif may be represented by much of the Schooner Formation farther north.

References


Name, (pronounced 'Connibare'). After W.D. Conybeare, co-author of the formal term Coal Measures (Conybeare & Phillips 1822).

Constituent formations
BRIG FORMATION p.9
CAISTER-COAL FORMATION p.13
SCHOONER FORMATION p.17
WESTOE COAL FORMATION p.25

Age
Westphalian.
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The term Brig Formation is introduced for a unit, preserved in Variscan synclines along the northern flank of the London-Brabant Massif, that includes sandy late Westphalian primary red beds and an underlying condensed sequence of late Westphalian C or Westphalian D coal measures. These strata subcrop Lower Permian desert sediments, and they rest on argillaceous Westphalian A to Westphalian B or early Westphalian C coal measures of the Westoe Coal Formation. The lower boundary of the Brig Formation is thus believed to be an unconformity, and equivalent to the intra-Westphalian unconformity interpreted by Tubb et al. (1986) in Quadrant 53.

Informal terms previously used for the primary red beds include the 'Barren Red Beds' (Rhys 1974), Barren Measures (Tubb et al. 1986) and Barren Red Group (Besly 1990). All of these terms have been applied to the primary red beds on completion logs. However, in a few wells, such terms have been applied erroneously to relatively argillaceous sections, up to 30m thick, of secondarily reddened early Westphalian coal measures where these subcrop the regional base-Permian unconformity. These sections were initially grey and carbonaceous, but have been reddened by the penetrative oxidation of early diagenetic siderite (Besly et al. 1993). Comparable weathering is well known from the coalfields of England (Trotter 1953) and Scotland (Mykura 1960). As in Scotland, the reddened Southern North Sea sections locally contain beds of carbonate that formed by in situ replacement of thin coal seams. Secondary red beds should not be assigned formal stratigraphic nomenclature.

References


Name. From the two-masted, square-rigged sailing vessel (also called a brigantine).

Type section
53/12-2: 1491.5-1628m (4893-5342ft) below KB.

Reference sections
52/5-1X: 1683-1758.5m (5522-5770ft)
53/12-3: 1265.5-1423m (4152-4668ft)
53/19a-1: 1457.5-1753.5m (4782-5753ft)
Lithology
The Brig Formation is largely composed of primary red beds, but also contains a thin basal unit of coal measures in many sections (e.g. 53/12-3). The red-bed unit consists of alternating grey, reddish-brown, or white sandstones and reddish brown, purple, or occasionally waxy, greenish grey mudstones and silty mudstones. Well 53/19a-1 also encountered minor partings of shelly, argillaceous limestone and pale grey, microcrystalline dolomite. The sandstone beds constitute between 15 and 50 per cent of the formation (Tubb et al. 1986), and are up to 35m thick. Most sandstones are argillaceous and are associated with a blocky log response; some of the thicker beds are composite and include mudstone partings. Grain size of the sandstones is mainly very fine or fine, but coarser beds have also been encountered in Block 53/12.

The coal-measures unit is largely composed of grey, purple and reddish brown mudstones and siltstones, but commonly includes two or three thin coal seams, and locally also includes thin, very fine grained sandstone beds. Sonic-log response for this unit is characteristically spiky, suggesting rapid alternation of these lithologies.

Upper boundary
The Brig Formation is unconformably overlain by Lower Permian aeolian and fluvial desert sandstones (Leman Sandstone Formation) in all sections, and the boundary is marked by a sharp downhole increase in gamma-ray response.

Lower boundary
The base of the Brig Formation is an intra-Westphalian unconformity, generally with late Westphalian C or Westphalian D coal measures resting on Westphalian B coal measures (Westoke Coal Formation), but early Westphalian C Coal Measures are also preserved beneath the unconformity locally. The unconformity in this case is marked by a downward change from rapidly alternating mudstones, siltstones and thin coal seams, associated with a spiky sonic-log response, to a relatively uniform succession of argillaceous coal measures. On wireline logs, this boundary is marked by a sharp downhole increase in velocity (e.g. 53/12-2), and sometimes also by a downhole decrease in gamma-ray response of the mudstones (e.g. 53/19a-l). In a few areas the late Westphalian coal measures are absent and the unconformity separates primary red beds from early Westphalian coal measures (e.g. 53/10-1, Panel 8). In such areas the boundary is marked by the lowest downhole occurrence of primary red beds.

Lithostratigraphic subdivision
On the basis of the lithological sequence described above, the Brig Formation may be informally divided into an Upper Brig unit, corresponding to the primary red beds, and a Lower Brig unit, comprising the underlying, condensed sequence of late Westphalian coal measures.

Distribution and thickness
The Brig Formation occurs along the northern flank of the London-Brabant Massif, where it is restricted to the axial regions of NW-SE trending Variscan synclines. The Upper Brig unit has a maximum drilled thickness of 277m in well 53/19a-l, but is generally less than 100m thick. The Lower Brig unit is up to 30m thick, but may be absent in some wells (e.g. 53/10-1, Panel 8).

Regional correlation
The basal coal measures of the Brig Formation are approximately age-equivalent to the Upper Ketch unit of the Silver Pit area. The overlying primary red beds have a similar log character and age to the Keele Formation of central England (Besly et al. 1993).

Genetic interpretation
The basal unconformity of the Brig Formation developed in response to early Westphalian C uplift and partial erosion of coal measures along the margin of the London-Brabant Massif (Tubb et al. 1986). Resumption of sedimentation initially led to development of a paralic delta plain, but this was quickly superseded by more widespread development of an alluvial floodplain. Sandstones of the Brig Formation were mainly deposited in incised fluvial channels, with only limited development of overbank sheet deposits (see Besly et al. 1993). Most of the sandstone units are interpreted as single channel fills, but thicker units with mudstone partings are believed to represent stacked channel-fill units. Fine-grained sediments accumulated as soils and in poorly drained marshes and lakes during intermittent periods when the alluvial floodplain was waterlogged (Besly 1990).

Age
Palynomorph assemblages from the Lower Brig unit are of Westphalian D affinity in well 52/5-1IX (Ramsbottom et al. 1978), but are of late Westphalian C age in Quadrant 53 (Tubb et al. 1986). The Upper Brig unit lacks palynomorphs, but is considered unlikely to range above Westphalian D in age.

References
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CAISTER COAL FORMATION
(new)

The term Caister Coal Formation is introduced here for a basal division of Westphalian coal measures in the Southern North Sea that contains a significant component of sandstone beds. The formation is largely of Westphalian A (Langsettian) in age, but ranges into the early Westphalian B (early Duckmantian) in the north, where it includes the reservoir sandstones of the Caister and Murdoch Fields.

Up to now, many operators have applied the term Lower Coal Measures to the Westphalian A, and Middle Coal Measures to the Westphalian B to early Westphalian C strata of the Southern North Sea. These are the terms that were formally introduced by Stubblefield & Trotter (1957) for the equivalent coal measures of England and Wales. The regionally widespread Gastrioceras subcrenatum marine band defines the base of the Lower Coal Measures, and the internationally recognized Namurian/Westphalian A boundary. Similarly, the Anthracoceras vanderbeckei marine band defines the Lower to Middle Coal Measures transition and the Westphalian A/Westphalian B boundary.

Neither marine band can be located with certainty in uncored offshore wells. For this reason, the base of the Caister Coal Formation is defined instead with reference to the basal cluster of coal seams within the Carboniferous succession. Commonly where there is good biostratigraphic control, the transition from the underlying Millstone Grit Formation occurs between 50-100m above the Namurian/Westphalian boundary, but it can occur higher than this, and locally may even occur below the base of the Westphalian.

Except where overlain by Permian strata, the top of the Caister Coal Formation is defined with reference to a lithofacies transition to argillaceous coal measures (Westoe Coal Formation). In the north, this transition commonly occurs up to 100m above the A. vanderbeckei marine band. South of 54°N, however, the Caister Coal Formation passes progressively southwards into argillaceous coal measures and is generally absent south of 53°30’N. All the Westphalian A to early Westphalian C coal measures are referred to the Westoe Coal Formation in this southern area (see Fig.3).

Reference


Name. From the Caister Field in UK Block 43/23.

Type section

44/23-4: 3637-4138.5m (11932-13578ft) below KB.

Reference sections

41/20-1: 2190.5-2520.5m (7187-8270ft)
44/29-1A: 3793-4307m (12443-14131ft)
49/4-1: 3347.5-4087.5m (10982-13410ft)
Lithology

The Caister Coal Formation is composed of grey mudstones and silty mudstones, with varying proportions of sea earths, coal seams, and sandstone beds. One or more marine bands of dark grey or black shale may also be present towards the base of the formation, as such are present in onshore Westphalian A sections (see Ramsbottom et al. 1978). The A. vanderbeekii marine band has been identified near the top of the formation in cored sections from southern Quadrant 44. However, none of the marine bands forms a distinctive marker on the wireline logs.

Coal seams up to 3 m thick constitute up to 5 per cent of the formation, and some may be very widespread. White and grey sandstone beds constitute between 15 and 45 per cent of the formation, and display a range of upward-fining, upward-coarsening, blocky, and ratty wireline-log responses. Bed thickness generally ranges between 1 and 25 m, but the reservoir sandstones of the Murdoch and Caister fields are up to 50 m thick. The thickest sandstones have sharp bases and mainly gradational tops, and are composite, stacked channel units, containing intervals of argillaceous and carbonaceous detritus that accumulated during periods of channel abandonment. Grain size of the sandstones is mainly very fine, fine, or occasionally medium, but some of the composite beds contain coarser pebbly horizons. Most of the sandstones are argillaceous, but the pebbly reservoir sandstones of the Caister and Murdoch fields are clean.

Wireline log data enable cyclic sedimentation to be resolved on a variety of scales in most sections. Small-scale upward-coarsening cycles capped by a siltsand or sandstone bed, often overlain by a sea earth and coal seam, are commonly between 10 and 30 m, but are occasionally up to 50 m thick. Larger-scale cycles, defined by an upward increase in the proportion and thickness of sandstone beds, are exceptionally up to 300 m thick. In some of these cycles, the gross upward-coarsening trend is matched by a decrease in average gamma-ray and resistivity values of successive sandstone beds (e.g. in the section between 3740 and 3822 m in well 44/23-4). Some of the large-scale cycles may correlate between nearby wells, but their regional significance is unclear.

Upper boundary

In large areas of the Southern North Sea the Caister Coal Formation is unconformably overlain by Lower Permian red and grey desert sandstones (Leman Sandstone Formation) or, mainly to the north of 54°N, by reddish-brown sabkha and lacustrine mudstones and evaporites (Silverpit Formation). The uppermost coal measures are locally secondarily reddened in these areas, commonly for as much as 30 m beneath the basal Permian strata. The top of the Caister Coal Formation is a generally sharp facies transition from uniform Permian sandstones or mudstones above the unconformity, to interbedded sandstones and mudstones below. In sections where the facies transition is not clear from wireline logs, it may be located by a downward change from the brighter hues of the Permian red sediments to the duller hues of the secondarily reddened coal measures.

The Caister Coal Formation is overlain by the Westoe Coal Formation in remaining areas of the Southern North Sea, the boundary being defined by the upward lithofacies transition from sandy to argillaceous coal measures. This transition is typically sharp (e.g. 44/23-3; 44/27-1 p.27), occurring at the top of a large-scale upward-coarsening cycle. Overlying coal measures contain a significantly lower component of sandstone beds. The formational boundary is defined by the top of the highest sandstone bed of the sandy coal measures. This boundary is regionally diachronous.

Lower boundary

The Caister Coal Formation rests on the Millstone Grit Formation in all wells, and the boundary is defined with reference to the basal cluster of coal seams in the Upper Carboniferous succession. Specifically, the base of the Caister Coal Formation is defined along the base of the lowest coal seam of the coal measures, marked by the basal low-velocity spike on sonic logs. As so defined, the formational boundary is easily identified in most long sections (see Panels 3, 4, 6), but is occasionally less clear where the Westphalian A sequence contains relatively few coal seams (e.g. 48/3-3, p.37).

Lithostratigraphic subdivision

Ritchie & Pratsides (1993) introduced the informal terms 'Caister Sand' and 'Supra-Caister Sand' for the basal Westphalian B reservoir sandstones of the Caister Field. The Caister Sand is divisible into two units and is separated from the Supra-Caister Sand by a thin mudstone unit.

No formal divisions of the Caister Coal Formation are proposed here. The interval containing the Caister Sand and Supra-Caister Sand and minor interbedded mudstones is up to 92 m thick in the Caister and Murdoch fields (see Panel 4), and may be informally termed the Caister Sandstone unit.

Large-scale, upward-coarsening cycles in the Caister Coal Formation probably record regional changes in sedimentary environment. Small-scale cyclic patterns of sedimentation probably developed in response to migration of sedimentary regimes within the delta plain. Such migration may have been influenced by the following: delta geometry, local and regional subsidence patterns, fluctuation in sediment supply (perhaps related to climatic change or tectonic regime in the sediment source areas), changes in base level of the delta (some of which may have been caused by eustatic changes in relative sea level), or more likely, by a combination of all of these factors (Guion & Fielding 1988).

Age

Westphalian A, ranging up to early Westphalian B in the north.

References


LITHOLOGY

- Mudstone, interbedded with siltstone and sandstone
- Sandstone
- Dolomite
- Limestone

DISTRIBUTION MAP

- CAISTER COAL FORMATION
- WESTOE COAL FORMATION
- MILLSTONE GRIT FORMATION
- SILVERPIT FORMATION
- LEMAN SANDSTONE FORMATION

CAISTER COAL FORMATION

- Ketch Member
- Schooner Fm.
- Brig Fm.
- Westoe Coal Fm.
- Millstone Grit Fm.

CONYBEARE GROUP

- Permian
- Westphalian A

WHITE-HURST GROUP
The term Schooner Formation is introduced here for a composite unit, largely Westphalian C in age, that is sandwiched between argillaceous coal measures (Westoe Coal Formation) and Lower Permian desert sediments in the Silver Pit area. Outcrops of the formation also occur in axial regions of the deepest Variscan synclines of the northern offshore area. The formation was formerly more widespread, but Westphalian C strata were eroded from large areas of the Southern North Sea during uplift and folding associated with the Variscan Orogeny.

The Schooner Formation is characterized by alternating mudstones and channel-fill sandstones, and consists of grey, sandy coal measures overlain by primary red beds. The formal term Ketch Member is introduced for the primary red beds because these include hydrocarbon reservoirs, whereas the underlying coal measures are provisionally termed the Lower Schooner unit.

Up to now, most operators have applied elements of the onshore Westphalian lithostratigraphic scheme of Stubblefield & Trotter (1957) to the offshore area. Hence the Lower Schooner unit has been previously incorporated within the ‘Middle Coal Measures’, which range between basal Westphalian B and mid-Westphalian C in age. Informal terms previously applied to the deposits of the Ketch Member include the ‘Barren Red Beds’ (Rhys 1974), Barren Red Measures (Leeder & Hardman 1990), and Barren Red Group (Besly 1990).

References


Name. After the Schooner gas discovery in UK block 44/26.

Type section

44/27-1: 4038.5-4438 m (13250-14561 ft) below KB.

Reference sections

44/21-2: 3868-4203 m (12690-13789 ft)
44/28-2: 3675-4060 m (12057-13329 ft)
49/1-3: 3927-4541 m (12883-14899 ft)

Formal subdivision

Ketch Member p21
Lithology

The Schooner Formation consists of sandy coal measures overlain by primary red beds.

The coal measures are composed of mudstones and silty mudstones, with beds of grey, pale brown or white sandstone and occasional sea urchins and coal seams. The mudstones are mainly grey, but reddish brown and purple beds also occur locally near the top of the unit. Sporadic beds of highly radioactive, possibly sapropelic, mudstone have been encountered in some wells (e.g. 49/1-3). Coal seams are mostly less than 2m thick and constitute between 1 and 5 per cent of the coal measures. Cyclicity of facies is generally less clearly developed in the Schooner Formation than in the underlying Westphalian formations.

Both the basal coal-measures unit and the overlying red beds contain between 10 and 40 per cent of sandstone, occurring as single and stacked channel-fill units mostly less than 10m, but exceptionally up to 20m thick. Such sandstones are associated with blocky and complex gamma-log profiles. Grain size of the sandstones is mainly very fine or fine, but the primary red beds also contain coarser, sometimes pebbly, poorly sorted beds. The sandstones are notably clean or only slightly argillaceous. The principal clast types in the pebbly sandstones are red mudstone and well rounded quartzite; the latter were presumably derived from Caledonian massif sources.

It is possible to recognize a lower red bed unit, in which the sandstones are interbedded with reddish brown or purple mudstones and siltstones. Cored sections reveal the presence of mature palaeosols, each comprising a grey, leached upper zone overlying red and grey, vertically veined and mottled beds. Units of interlaminated fine grained sandstone and mudstone also occur and are associated with ratty gamma-log profiles. The mudstones contain root systems, oxidised remains of plant fragments, and hematite concretions that replaced early diagenetic siderite (Besly et al. 1993). Desiccation cracks occur towards the top of the red-bed section in well 44/28-1.

An upper red-bed unit can be recognised by the additional presence of grey, coal-bearing intercalations and prominent caliche horizons (Besly et al. 1993). The height of the Drift bed unit varies between 40-300m. The Ketch Member has a maximum thickness of 357m in well 44/21-3, though seismic interpretation suggests that primary red beds may be up to 550m thick in parts of the Silver Pit area (Cameron et al. 1992).

Upper boundary

The Schooner Formation is unconformably overlain by Lower Permian desert sediments in all sections. In the north of the Silver Pit area, the overlying sediments are mainly reddish brown, anhydritic lacustrine mudstones and evaporites (Silverpit Formation). These have a brighter hue in cuttings than red mudstones of the Schooner Formation, and the boundary is commonly marked by a sharp downhole increase in gamma-ray response (e.g. 44/28-2). Farther south, thin sandstones also occur at the base of the Permian, but the boundary is generally marked by a downhole decrease in velocity (e.g. 49/1-3).

Lower boundary

The Schooner Formation rests, apparently conformably, on argillaceous coal measures of the Westoe Coal Formation. The boundary is marked by a sharp downward decrease in abundance and bed thickness of sandstones (see Panel 5), and is hence defined along the base of the lowest clean sandstone unit of the Schooner Formation. This boundary is likely to be regionally diachronous.

Lithostratigraphic subdivision

The formal term Ketch Member (see p.21) is introduced here for the upper part of the formation, which is dominated by primary red beds. The Ketch Member is informally divided into the Lower Ketch unit and the Upper Ketch unit. The Lower Ketch unit is characterized by the additional presence of grey mudstone and caliche horizons. It has been encountered in only one UK well, 44/21-3. The Lower part of the formation, consisting of grey sandy coal measures, is not formally named, but is provisionally termed the Lower Schooner unit.

Distribution and thickness

Preservation of the Schooner Formation from pre-Permian erosion has been limited to the Silver Pit area and to the axial regions of other deep, mainly NW-SE trending Variscan synclines in the northern offshore area. Thickness of the Lower Schooner unit varies between 40-300m. The Ketch Member has a maximum thickness of 357m in well 44/21-3, though seismic interpretation suggests that primary red beds may be up to 550m thick in parts of the Silver Pit area (Cameron et al. 1992).

Regional correlation

Based on their lithology and log character, the lower and upper primary red-bed units of the Ketch Member correlate with the Etruria and Keele formations of central England, respectively (Besly et al. 1993). Comparable strata occur in the E and K quadrants of the Dutch sector. Lateral equivalents of the Lower Schooner unit occur within the Middle Coal Measures of England.

Genetic interpretation

Deposition of the Schooner Formation spanned the mid-Westphalian period of regional transition from a waterlogged delta-plan environment to a better drained alluvial plain. This process occurred in response to tectonic uplift of the coal-measures basin (Besly et al. 1993). Rejuvenation of the sediment source areas probably caused the influx of sandy sediment that distinguishes the Lower Schooner unit from the underlying Westoe Coal Formation.

At first the Silver Pit area was permanently occupied by swamps and brackish to freshwater lagoons in which muds, silts, and layers of plant debris accumulated. Such conditions became intermittent during deposition of the Ketch Member, enabling soils to form during periods of emergence above the local water table (Besly 1990). Besly et al. (1993) speculated that sandstones of the Ketch Member were mainly deposited in incised fluvial channels, with only limited development of overbank sheet deposits. Their deduction that individual sandstone bodies have a mainly shoestring, with poor lateral continuity normal to palaeoflow, may also apply to sandstone bodies in the Lower Schooner unit.

Primary red beds of the Silver Pit area acquired their pigmentation by syn-deposition oxidation of alluvial overbank deposits in relatively well drained soils profiles, and by penetrative oxidation of initially grey, siderite-bearing coal-measure facies (Besly et al. 1993). The latter process occurred shortly after deposition, during periods when the local water table was lowered (Besly & Turner 1983).

Age

Mainly Westphalian C; the Lower Schooner unit may be partly late Westphalian B in age.

References


LITHOLOGY
- Mudstone
- Interbedded mudstone, siltstone and sandstone
- Siltstone
- Sandstone
- Coal
- Halite

DISTRIBUTION MAP

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The term Ketch Member is introduced here for the late Westphalian primary red beds that form an upper division of the Schoone Formation in the UK sector. These red beds have been preserved from pre-Permian erosion in the Silver Pit area and locally along the axes of other Variscan synclines in the northern offshore area. Informal terms used previously for the member include the ‘Barren Red Beds’ (Rhys 1974), Barren Red Measures (Leeder & Hardman 1990), and Barren Red Group (Besly 1990). NAM & RGD (1980) formally introduced the term Barren Measures for equivalent sediments in the Dutch sector.

In the Silver Pit area, deposition of primary red beds superseded coal-measures sedimentation early in Westphalian C times (Cameron et al. 1992; Besly et al. 1993). The latter authors reported late Westphalian C palynomorphs from uppermost red beds at 44/21-3, and deduced that only Westphalian C red beds are preserved in the Silver Pit area. In adjacent parts of the Dutch sector Westphalian D red beds are also preserved beneath Permian strata (Besly et al. 1993).

Some operators have also applied the terms ‘Barren Red Beds’, Barren Measures, or Barren Red Measures to sections of secondarily reddened early Westphalian coal measures subcropping the regional base-Permian unconformity. Such sections are generally argillaceous and up to 30m thick. They were initially grey and carbonaceous, but were reddened by the penetrative oxidation of early diagenetic siderite (Besly et al. 1993). Comparable weathering is well known from the coalfields of England (Trotter 1953) and Scotland (Mykura 1960). As in Scotland, the reddened Southern North Sea sections locally contain beds of carbonate that developed by in situ replacement of thin coal seams. Secondary red beds should not be assigned formal stratigraphic nomenclature.

References


Name. From the Ketch gas discovery in UK block 44/28.

Type section

44/28-1: 3786.5-4008m (12423-13150ft) below KB.

UK reference sections

44/21-3: 3828-4185m (12558-13730ft)
49/1-3: 3927-4262m (12883-13983ft)
Lithology

The Ketch Member is composed of reddish brown to purple mudstones and silty mudstones, and grey, reddish-brown, or occasionally white, fine to coarse grained, sometimes pebbly sandstones. The sandstone beds occur as single and stacked channel-fill units that are mostly less than 10m, but are exceptionally up to 20m thick. Such sandstones are respectively associated with blocky and complex gamma-log profiles, and they constitute up to 40 per cent of the member. They are moderately or poorly sorted, and variably micaceous. Where the sandstones are pebbly, intraformational clasts of red mudstone are common, but the predominant clast type comprises well rounded quartzite, presumably derived from Caledonian masif sources. The sandstones are cemented mainly by silica and hematite, but halite and anhydrite cements have been reported locally near the top of the member.

Red mudstones and siltstones occur in units that are mostly less than 40m thick. In cores, such units are seen to include mature palaeosols, each comprising a grey, leached upper zone overlying red and grey, vertically veined and mottled beds (S.J. Stoker, written comm. 1988). Units of interlaminated fine-grained sandstone and mudstone also occur and are associated with ratty gamma-log profiles. The mudstones contain root systems, oxidized remains of plant fragments, and hematite concretions that replaced early diagenetic siderite (Besly et al. 1993). Desiccation cracks occur towards the top of the red-bed section in well 44/28-1.

Besly et al. (1993) reported grey, coal-beam intercalations and prominent caliche horizons near the top of the primary red beds in well 44/21-3. Sandstone bed thickness is significantly reduced in the coal-beam section, and gamma-ray response of the mudstones is higher than in the underlying red beds. This lithofacies is absent from other wells in the Silver Pit area, presumably due to pre-Permian erosion.

Upper boundary

The Ketch Member is unconformably overlain by Lower Permian desert sediments in all sections. In the north of the Silver Pit area, the overlying sediments are mainly reddish brown, anhydride lacustrine mudstones and evaporites (Silverpit Formation). These have a brighter hue in cuttings than the red mudstones of the Ketch Member and the boundary is commonly marked by a sharp downhole increase in gamma-ray response (e.g. 44/27-1, p.19). Farther south, thin sandstones also occur at the base of the Permian, but the boundary is generally marked by a sharp downhole decrease in velocity (e.g. 49/1-3).

Lower boundary

Westphalian red beds display complex, laterally diachronous and locally unconformable relationships with underlying coal measures in central England (Besly & Turner 1983). According to Besly et al. (1993), the base of primary red beds in the Silver Pit area and in adjacent parts of the Dutch sector seems to occur at an approximately constant height above a regionally persistent, near-top Westphalian B wireline log marker, implying a conformable facies transition. Secondly reddened horizons occur in underlying coal-measure facies locally (e.g. in 44/28-2) but, unlike in the Ketch Member, the red pigmentation is concentrated around the sandstone beds.

The base of the Ketch Member is therefore defined by the lowest horizon of primary red clays. As this boundary is generally not marked by a distinctive wireline log break, it must be distinguished by careful analysis of cuttings, or of core where available. The boundary is commonly close above the highest coal seam of the Schooner Formation.

Lithostratigraphic subdivision

In well 44/21-3, the Ketch Member may be divided into a Lower Ketch unit, consisting of a relatively sandy, 272m-thick red-bed succession lacking caliche, overlain by an Upper Ketch unit, consisting of a 78m-thick succession containing caliche horizons, grey mudstones and minor coal seams (see Besly et al. 1993). The upper unit is associated with a relatively high gamma-ray response. These divisions are here formally termed the Lower and Upper Ketch units; the latter unit has a very limited distribution in the Silver Pit area.

Distribution and thickness

Preservation of the Ketch Member from pre-Permian erosion has been limited to axial regions of deep, mainly NW-SE trending Variscan synclines. The most significant areas of preservation are in southeastern Quadrant 42 and in southern Quadrant 44/ southern Quadrant 49 (the Silver Pit area). Up to 357m of primary red beds have been drilled in the latter area, though seismic interpretation suggests that they may be locally up to 550m thick (Cameron et al. 1992). Late Westphalian red beds are up to 1400m thick in parts of central England (Besly & Turner 1983).

Regional correlation

On the basis of lithofacies and log character, Besly et al. (1993) correlated the lower primary red-bed unit of the Silver Pit area (the Lower Ketch unit with the Eturia Formation (Westphalian B-C) of central England. The Eturia Formation also lacks caliche, being characterized by hydromorphic and ferruginous palaeosols, and its clays are mainly composed of disordered kaolinite. The Upper Ketch unit in well 44/21-3 compares more closely with the Keele Formation (Westphalian D) of central England. The Keele Formation contains caliche, and its clays are dominated by illite and minor chlorite (Besly et al. 1993).

Genetic interpretation

Deposition of primary red beds in the Southern North Sea commenced during a regional late Carboniferous improvement in drainage conditions, enabling an alluvial plain to become established across the former waterlogged delta plain of the coal measures (Besly 1990). This process had begun during Westphalian B times in parts of central England (Besly & Turner 1983) but was delayed until early Westphalian C times in the Silver Pit area (Besly et al. 1993).

Sandstones of the Ketch Member were mainly deposited in incised fluvial channels, with only limited development of overbank sheet deposits (Besly et al. 1993). These authors speculated that individual sandstone bodies have a mainly shoestring form, with poor lateral continuity normal to palaeoflow. Fine-grained sediments accumulated as soils, and in poorly drained marshes and lakes during intermittent periods when the alluvial floodplain was waterlogged (Besly 1990). The primary red beds acquired their pigmentation by syn-depositional oxidation of the alluvial overbank deposits in relatively well drained soil profiles, and by penetrative oxidation of initially grey, siderite-bearing coal-measure facies (Besly et al. 1993). The latter process occurred shortly after deposition, during periods when the local water table was lowered (Besly & Turner 1983). Besly et al. (1993) have invoked intermittent fluvial incision caused by tectonic uplift as the most likely mechanism for improved regional drainage and for local fluctuation in the water table.

Age

Westphalian C (Bolsovian) in the UK sector. Laterally equivalent sediments in the Dutch sector range up to Westphalian D in age (Besly et al. 1993).

References


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WESTOE COAL FORMATION
(new)

The term Westoe Coal Formation is introduced here for an argillaceous unit of Westphalian coal measures in the Southern North Sea. In the north, the formation lies above coal measures of the Caister Coal Formation and below sandy coal measures and primary red beds of the Schooner Formation or, in areas of deeper sub-Permian erosion, below Permian desert sediments. In the south, the formation extends beyond the Caister Coal Formation to overstep Dinantian strata on to Lower Paleozoic basement.

In the Silver Pit area, the boundary between the Caister Coal and Westoe Coal formations commonly occurs between 50 and 100m above the Anthracoceras vanderbekei marine band, which defines the internationally recognized boundary between the Westphalian A (Langsettian) and Westphalian B (Duckmantian) stages.

The proportion of sandstone beds in the Westphalian A coal measures decreases southwards across Quadrants 47, 48 and 49. As a result, the boundary between the Caister Coal and Westoe Coal formations is transitional and regionally diachronous, becoming progressively older to the south. The sandy coal measures of the Caister Coal Formation are absent south of approximately 53°30'N in the UK sector. Consequently, the Westoe Coal Formation incorporates all of the Westphalian A to early Westphalian C coal measures farther south, where its base is marked by the basal Westphalian coal seam.

Name. From the Westoe Colliery in northeast England, from where subsea workings have extracted coal for up to 11km from the North Sea coast.

Type section
44/27-1: 4438-4891m (14561-16047ft) below KB.

Reference sections
41/20-1: 2050.5-2190.5m (6727-7187ft)
44/21-2: 4203-4411.5m (13789-14473ft)
52/5-11X: 1758.5-2215m (5770-7266ft)
Lithology
The Westoe Coal Formation is dominated by grey mudstones and silty mudstones, but contains varying proportions of sand grains, coal seams, and sandstone beds. Beds of dark grey or black marine mudstone form a minor component of most sections, but form marker horizons on spectral gamma-ray logs. White and grey, fine to very fine grained sandstone beds occur but constitute less than 10 per cent of the formation and are mostly less than 10m thick. Coal seams up to 5m thick are conspicuous in all sections, and constitute up to 5 per cent of the formation. Some of these may be very widespread.

All sections show wireline-log responses indicative of small-scale, upward-coarsening sedimentary cycles, i.e. a gradual upward increase in velocity and resistivity, followed by a distinct trough. They characteristically display an upward gradation from mudstone to siltstone, with or without a sandstone bed, and are capped by a coal seam or carbonaceous mudstone. The cycles are mostly less than 20m thick, but are exceptionally up to 50m thick.

Upper boundary
Over large areas the Westoe Coal Formation is unconformably overlain by Lower Permian desert sediments, with secondary reddening of the uppermost coal measures penetrating up to 30m below the unconformity in some sections. In such areas south of 54°N, the formation is normally overlain by the mainly uniform, red or grey sandstones of the Leman Sandstone Formation, whereas to the north the overlying Lower Permian is largely composed of lacustrine mudstones and evaporites. The downward facies transition to coal measures is generally sharp (see Panel 4). Even where this transition is not clear from wireline logs, the boundary may be recognized by a downward change from the brighter hues of the Permian red-beds to the duller hues of the secondarily reddened sediments of the Westoe Coal Formation.

Along the northern flank of the London-Brabant Massif, younger Westphalian C-D coal measures and primary red beds (Brig Formation) are preserved above the Westoe Coal Formation in the axes of Variscan synclines. The boundary was interpreted by Tubb et al. (1986) to be an intra-Westphalian unconformity. It is commonly defined by a downward change from thinly bedded mudstones, siltstones and coal seams (Lower Brig unit), associated with a spiky sonic-log response, to a cyclic coal-measures facies. On wireline logs, the boundary is marked by a sharp downhole increase in velocity (e.g. 53/12-2, p.11), that is sometimes accompanied by a downdip decrease in gamma-ray response of the mudstones (e.g. 53/12-3, 53/19a-1, p.11). Primary red beds (Upper Brig unit) rest unconformably on the Westoe Coal Formation locally (e.g. 53/10-1: panel 8), the boundary being marked by the lowest occurrence of red mudstones.

Farther north, in the Silver Pit area and in the axes of other deep Variscan synclines, the basal sandy coal-measures unit of the Schooner Formation rests conformably on the Westoe Coal Formation. The downward transition to argillaceous coal measures is marked by a sharp decrease in abundance and bed thickness of the sandstones (see Panel 5). The formational boundary is defined along the base of the lowest clean sandstone unit of the Schooner Formation, and is likely to be diachronous.

Lower boundary
The Westoe Coal Formation generally rests on sandy coal measures (Caister Coal Formation) north of 53°30’N. The lithofacies transition is typically sharp (e.g. 44/27-1, 44/23-4, p.15), with bed thickness and abundance of the sandstones significantly reduced above the boundary. The top of the highest sandstone bed of the sandy coal measures defines the formational boundary.

Because sandy coal measures are largely absent south of 53°30’N, the Westoe Coal Formation has a wider stratigraphic range and commonly rests on the Millstone Grit Formation. The lithofacies transition is marked by a downward change from coal-bearing to coal-free strata. The formation boundary is defined by the base of the lowest coal seam; it is easily identified in most long sections (e.g. 52/5-1IX), but is less clear in sections where the Westphalian A strata include relatively few coal seams.

Along the northern flank of the London-Brabant Massif, the Westoe Coal Formation oversteps the Millstone Grit Formation onto Dinantian platform carbonates or Lower Palaeozoic basement.

Distribution and thickness
In the north, the Westoe Coal Formation is largely confined to the axes of regional Variscan synclines, and ranges up to 450m in thickness. The formation is more widespread south of 53°30’N, and is commonly thicker, reflecting its wider stratigraphic range in this area. The southern limit of the formation is determined by pinch out between base-Silesian and base-Permian unconformities.

Regional correlation
The Westoe Coal Formation in and to the west of the Silver Pit area is partly equivalent to the Middle Coal Measures of England and Wales; farther south it is largely equivalent to the combined Lower and Middle Coal Measures. These relationships are summarized in the table on p. 1.

The most prominent coal seam in many southern Quadrant 44 wells is between 90-150m above the Westphalian A/B boundary (e.g. at 3584-3587m in 44/23-4). This seam has been informally termed the ‘B Coal’ in the Caister Field (Ritchie & Pratsides 1993) and may correlate with the Low Main Coal of the Durham Coalfield. Using this as a reference, other named seams of the Durham Coalfield may be tentatively identified in the Quadrant 44 wells. As in England, however, detailed correlation is hampered by the likelihood of seam splitting and local erosion of the coals by channel sandstone ‘wash-outs’.

Sandstone units between 1900-1939m and 1981-2037m in well 41/20-1 may be respectively equivalent to the Oaks Rock and Woolley Edge Rock in the nearby Yorkshire Coalfield.

Genetic interpretation
The coal measures of England were deposited on a low-lying, paralic delta plain, occupied by swamps and brackish to freshwater lagoons in which muds, silts, and layers of plant debris accumulated. Argillaceous coal measures, such as characterize the Westoe Coal Formation, were deposited during periods when there were relatively few major river distributaries bringing channel sands on to the plain.

Small-scale cyclic facies patterns in the Westoe Coal Formation probably represent changes in local and regional subsidence patterns, fluctuation in sediment supply, changes in base level, or, more likely, a combination of all these factors (Guion & Fielding 1988).

Age
Mainly Westphalian B in the north, but spanning the range early Westphalian A to Westphalian B or early Westphalian C in the south.

References
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WHITEHURST GROUP
KYLE GROUP
BUCHAN FORMATION
CEMENTSTONE FORMATION
TAYPORT FORMATION
YOREDALE FORMATION

WESTOE COAL FORMATION
CAISTER COAL FORMATION

WESTPHALIAN D
WESTPHALIAN C (BOLSOVIAN)
WESTPHALIAN B (DUCKMANTIAN)
WESTPHALIAN A (LANGSETTIAN)

YEADOMIAN
MARSDENIAN
KINDERSCOUTIAN
ALPORTIAN
CHOKERIAN

ARNSBERGIAN
PENDLEIAN
BRIGANTIAN
ASHIAN
HOLKERIAN
ARLUNDIAN
CHADIAN
COURCEYAN

ALPORTIAN
YEADOMIAN
MARSDENIAN
KINDERSCOUTIAN

ALPORTIAN
YEADOMIAN
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YOREDALE FORMATION

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The term Whitehurst Group is introduced for strata, mostly Namurian in age, that are broadly equivalent to the Bowland Shale and Millstone Grit groups as defined formally for onshore England (e.g. Aitkenhead et al. 1992). The terms Bowland Shale Formation and Millstone Grit Formation are formally defined here as the offshore lithofacies equivalents of these groups. The Bowland Shale Formation is composed of basal mudstones, whereas the Millstone Grit Formation encompasses a range of turbidite, delta-slope, deltaic, and fluvial braided facies.

The Whitehurst Group is widespread in the central part of the UK Southern North Sea. Its maximum proven thickness exceeds 1600m, although it may be appreciably thicker than this locally as few wells have penetrated its base. The southern limit of the group is defined by onlap against the London-Brabant Massif. It is absent over the crest and southern flank of the Mid North Sea High, largely due to erosion following Variscan uplift.

The base of the Whitehurst Group is regionally diachronous, ranging between late Asbian (Late Dinantian) and mid-Namurian in age. Underlying strata, where penetrated, are mainly Dinantian to early Namurian fluviodeltaic and minor marine sediments (Fame Group) or Dinantian platform carbonates (Zeeland Formation). Locally in the south, the Whitehurst Group rests on Lower Paleozoic basinal marine sediments.

In the north of the area, and locally elsewhere, the Whitehurst Group is unconformably overlain by Permian desert sediments of the Rotliegend Group. In central and southern areas, the Whitehurst Group is generally overlain conformably by coal measures of the Conybear Group. Offshore, however, specific marine bands can be recognized only in cored sections, and the base of the group is therefore taken at the base of the lowermost coal seam, being up to 100m above the Namurian/Westphalian boundary in those wells with good biostratigraphic control. Hence the top of the Millstone Grit Formation of the Whitehurst Group is within Westphalian A strata, but is diachronous, reflecting local variation in timing of the transition to coal-measures lithofacies.

References

Name. After J. Whitehurst, who introduced the term Millstone Grit in 1778.

Constituent formations

BOWLAND SHALE FORMATION 31
MILLSTONE GRIT FORMATION 35

Age
Mainly Namurian, but ranging between late Dinantian or early Namurian to early Westphalian A (early Langsettian).
The term Bowland Shales was first used as a lithostratigraphic unit in Yorkshire by Phillips (1836). This informal term has become synonymous in Yorkshire and Lancashire with a unit of late Dinantian (late Asbian/Brigantian) to early Namurian (Pendleian) mudstones, containing minor limestone and sandstone stringers, that is well developed south of the mid-Craven Fault. In recent British Geological Survey Memoirs (e.g. Aitkenhead et al. 1992), the formal term Bowland Shale Group has been applied to this unit, and the group is divided into Lower and Upper Bowland Shale formations, of late Dinantian and early Namurian age respectively. Laterally equivalent basinal mudstones of the East Midlands include the Widmerpool Shales (Dinantian) and Edale Shales (Namurian).

The term Bowland Shale Formation is adopted here for Southern North Sea sections, mainly early Namurian in age, that are dominated by dark grey and black basinal mudstones and silty mudstones. Their transition to overlying Millstone Grit facies (Millstone Grit Formation) is diachronous. In the Craven Basin of northern England, mudstone-dominated sections occur not only at the base of the Namurian, but recur locally at higher levels (Collinson 1988). Hence the Bowland Shale Formation may interdigitate with basal strata of the Millstone Grit Formation in some offshore sections.

**References**


**Name.** From the Forest of Bowland in Lancashire, northwest England (Phillips 1836).

**Offshore reference sections**

<table>
<thead>
<tr>
<th>Section</th>
<th>Depth Range</th>
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<tbody>
<tr>
<td>41/24a-2</td>
<td>2454-2501m</td>
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<td>48/3-3</td>
<td>4374-4591m TD</td>
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<td>48/23-3</td>
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</tbody>
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(8051-8205ft) below KB
(14351-15063ft TD)
(9206-10114ft TD)
Lithology
The Bowland Shale Formation is characterized by thick, often homogeneous sections of dark grey to black mudstone, with minor beds of dark grey siltstone, and rare partings of pale brown or light grey dolomitic limestone, of possible diagenetic origin. Some sections contain a few stringers of white or brownish grey sandstone. The mudstones are generally described as being firm to hard, and blocky to sub-fissile; they are commonly carbonaceous and occasionally pyritic.

At outcrop in northern England, equivalent mudstones and fine siltstones are mainly devoid of marine fossils, but include sporadic units of more fully marine aspect which are fossiliferous, finer grained and relatively carbonaceous (Collinson 1988). Similar facies associations are probably present offshore. The bulk of the formation displays uniformly high gamma-ray values, typically exceeding 100 API units. However, superimposed on this are sporadic intervals with very high gamma-ray values which, in well 48/3-3, were shown by Leeder et al. (1990) to represent uranium-rich marine bands. The formation displays occasional high-velocity spikes that may correspond to beds of siltstone or of highly calcareous mudstone.

Upper boundary
The top of the Bowland Shale Formation is defined as the base of the lowest significant sandstone bed of the Millstone Grit Formation. This boundary may be regionally diachronous, but it represents an upward transition from basinal mudstone to turbidite or delta-related lithofacies. The transition is abrupt in wells 48/3-3 and 48/23-3, although occasional sandstone stringers do occur below the boundary. In well 41/24a-2, the lithofacies transition is gradational, but the boundary is marked by a sharp downhole decrease in velocity.

Lower boundary
In well 41/24a-2, the base of the Bowland Shale Formation is marked by a sharp downhole increase in velocity and decrease in gamma-ray response, corresponding to the top of the highest limestone bed of the Yoredale Formation. The base of the formation has not been penetrated in other North Sea wells.

Equivalent basinal mudstones of northern England are sometimes banked against, and locally overlie, Dinantian platform carbonates, whereas units such as the Sabden Shales overlie sediments of deltaic facies (Collinson 1988). The Lower Bowland Shale rests on limestone turbidites and debris flows at Clitheroe (Leeder 1992), whereas mudstones equivalent to the Edale Shales rest on argillaceous, basinal Dinantian limestones in the Gainsborough Trough (Steele 1988). Hence offshore, the Bowland Shale Formation can be expected to overlie a wide variety of sedimentary facies.

Distribution and thickness
As few offshore wells have been drilled to sufficient depths to penetrate early Namurian sediments, the distribution of the Bowland Shale Formation is poorly constrained. Basinal mudstones are only 47m thick in well 41/24a-2. Wells 48/3-3 and 48/23-3 terminated after drilling 217m and 277m of basinal mudstones respectively, but the Bowland Shale Formation is likely to be appreciably thicker in areas adjacent to Dinantian growth faults.

Regional correlation
Equivalent mudstones of northern and central England include the Lower Bowland Shales and Widmerpool Shales (of late Asbian/Brigantian age), the Upper Bowland Shales and Pendle Shales (Pendleian), the Edale Shales (Pendleian to Alportian), and the Sabden Shales (Arnsbergian to Alportian). Many of these terms have been used informally by Southern North Sea operators up to now. In the Dutch sector, equivalent basinal mudstones will be included in the Epen-Baarlo Formation (see Introduction).

Genetic interpretation
The basinal Early Namurian mudstones of onshore England accumulated in quiet, relatively deep-water conditions (Collinson 1988). Most of the mudstones were deposited when basinal water, at least in the photic zone, was brackish or fresh (Collinson 1988). The fossiliferous units record periods of higher salinity resulting from freer connection with the contemporary ocean. In condensed basinal mudstone sections, these more fully marine units display small-scale faunal cyclicity that reflects increase and decrease of salinity (Holdsworth & Collinson 1988).

Age
Biostratigraphic data from the offshore wells are limited. By analogy with England, the formation may include components of Brigantian, Pendleian to Arnsbergian, and Chokierian/Alportian age.

References


BOWLAND SHALE FORMATION

41 / 24a-2

48 / 3-3

48 / 23-3

DISTRIBUTION MAP

100 km

BOWLAND SHALE FORMATION PROBABLY PRESENT AT DEPTH

LITHOLOGY

- Mudstone
- Siltstone
- Sandstone
- Coal
- Limestone

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MILLSTONE GRIT FORMATION

The term Millstone Grit was introduced by Whitehurst (1778) for massive Carboniferous sandstones and interbedded shales cropping out in the Chatsworth and Matlock areas of Derbyshire. Phillips (1836) proposed the formal term Millstone Grit Series for all strata overlying Holland (now Bowland) Shales, and overlain by Coal Measures; its type area is in Yorkshire. This term has been replaced by the Millstone Grit Group in recent BGS memoirs (e.g. Aitkenhead et al. 1992), and its base, defined by the influx of feldspathic sandstones, is diachronous.

The term Millstone Grit Formation is proposed here for the composite Southern North Sea unit, composed of turbidite, deltaic and sheet-like channel sandstones and interbedded mudstones and siltstones, that is broadly equivalent to the Millstone Grit Group of northern England. The boundary with underlying basinal mudstones, Yoredale facies, or Dinantian platform carbonates is regionally diachronous, though largely within the Namurian. Basal strata of the Millstone Grit Formation may interdigitate with thick sections of basinal mudstone (Bowland Shale Formation) in some areas. The formation is overlain conformably by coal measures, or, in areas of deep pre-Permian erosion, unconformably by Permian desert sediments. At the northeastern flank of the Mid North Sea High the Millstone Grit Formation is overlain by Cretaceous strata.

As defined by Stubblefield & Trotter (1957), the boundary between the Millstone Grit Series and the Lower Coal Measures of England is the base of the very widespread Gastrioceras subcrenatum marine band. This marine band, which coincides with the internationally accepted biostratigraphic boundary between the Namurian and Westphalian series, cannot be located precisely in the majority of offshore wells. In well 48/3-3 for instance, Leeder et al. (1990) concluded that the boundary could be placed either between 3920 and 3929m (12860 and 12890ft) or as high as 3797m (12458ft) depending on interpretation of the palynomorph assemblages. For this reason, the top of the Millstone Grit Formation is defined here with reference to the base of the ‘coal-measures’ lithofacies, identified within individual sections by the base of the first cluster of coal seams within the Upper Carboniferous succession.

Where good biostratigraphic data are available, the lithofacies transition commonly occurs between 50 and 100m above the Namurian/Westphalian boundary, but in some sections it occurs higher than this, whereas locally it may occur below the base of the Westphalian.

References


Name. From the colloquial term for Carboniferous sandstones of the southern Pennines (Whitehurst 1778).

Offshore reference sections

<table>
<thead>
<tr>
<th>Well</th>
<th>TD Depth</th>
<th>KB Depth</th>
</tr>
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<tbody>
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<td>44/12-1:</td>
<td>3785.5-4630m TD</td>
<td>(12420-15190ft TD)</td>
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<td>3932-4374m</td>
<td>(12900-14351ft)</td>
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<tr>
<td>48/12b-4:</td>
<td>2996.5-4017m TD</td>
<td>(9831-13179ft TD)</td>
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</table>
Lithology
The Millstone Grit Formation is composed of variable proportions of grey, white and brown sandstone, and grey or dark grey, partly carbonaceous mudstone and siltstone. Some sections additionally contain rare thin coal seams and seatears. The sandstones are commonly fine to medium grained, but locally, interbedded beds vary from very fine to coarse grained and very fine to coarse beds. Mudstone-dominated intervals, exceptionally up to 100m thick, occur in many sections, sometimes including thin beds of silstone and sandstone. 

Leeder et al. (1990) described the principal Namurian lithofacies and their wireline log characteristics in well 48/3-3. There, and across most of the southern North Sea, the Millstone Grit Formation contains many sharp-based sandstone units over 10m thick and exceptionally up to 80m thick; such sandstones either have sharp tops or grade upwards into mudstone. These sandstone intervals are stacked, with component sandstone beds sometimes separated by thin argillaceous intervals. Towards the base of the Millstone Grit Formation in well 48/3-3, argillaceous, poorly sorted sandstone beds with sharp tops occur, each of which grades downwards into mudstone (Leeder et al. 1990).

Wireline-log responses for the Millstone Grit Formation can be used to identify lithological cycles comparable in scale and style to those that characterize the Millstone Grit Group in northern England (see Collinson 1988). In the North Sea, such cycles are commonly about 50m thick, but their thickness ranges from less than 10m to hundreds of metres. Most cycles have mudstone intervals containing marine bands at their base. The marine bands are typically associated with high or very high gamma-ray response, and they occur generally within intervals of low sonic velocity. However, they are best identified using up-slope wireline logs as they are enriched in uranium. Most cycles then display a gross upward-coarsening trend. In some cycles this is achieved by an increase in abundance of thick, amalgamated sandstone beds at the expense of thinly interbedded sandstones and mudstones. In other cycles, the transition from argillaceous to sandstone-dominated sections is abrupt, and presumably corresponds to an erosion surface. Deposition of the highest sandstone in a cycle was followed by a rapid return to argillaceous sedimentation, marked by a sharp increase in gamma-ray values and a sharp decrease in velocity. Cycle boundaries can often be inferred in sections lacking significant sandstone development where there is a similarly sharp drop in velocity followed by a gradual return to normal shale velocity. 

Holdsworth & Collinson (1988) showed that there are both single and compound lithological cycles in the Millstone Grit of England. Single lithological cycles are confined to consecutive regional marine bands, whereas in compound cycles one or more of the marine bands is not developed locally. Both single and compound cycles are likely to be represented in all offshore sections. A well-developed marine band and cycle boundary in one well might be absent in an adjacent well due to non-deposition or erosion. Consequently, correlation of cycle boundaries between wells should be attempted only with extreme caution.

Upper boundary
In large parts of the northern offshore area, the Millstone Grit Formation subcrops Lower Permian lacustrine and sabkha facies (Silvertip Formation), the boundary being defined by an abrupt facies transition. Along the axes of Variscan anticlines farther south, the formation is locally overlain by Lower Permian desert sandstones (Leman Sandstone Formation). Where Westphalian strata are also preserved beneath the base-Pennian unconformity, the Millstone Grit Formation is overlain by coal measures (the sandier Caisteal Coal Formation or argillaceous Westoe Coal Formation). In such areas, the chronological boundary is defined with reference to the top of the most prominent cluster of coal seams in the Upper Carboniferous succession. Specifically, the base of the coal measures in an individual well is defined along the base of the lowest coal seam in the basal cluster of seams. As so defined, the top of the Millstone Grit Formation is easily identified in most long sections (e.g. 44/12-1, 48/12b-4), but is less clear where the Westphalian A strata contain relatively few coal seams (e.g. 48/3-3).

Lower boundary
The Millstone Grit Formation rests conformably on basal mudstones of the Bowland Shale Formation in wells 41/24a-2, 48/3-3 and 48/23-3 (see p.33), the boundary being defined by the base of the lowest significant sandstone bed. The wireline log characteristics in the Bulwell Shale Formation rest directly on Yoredale facies (Yoredale Formation) along the flanks of the Mid North Sea Sea. Here, the formational boundary is defined as the top of the highest marine limestone bed, and is generally more than 100m above the Dinantian/Namurian boundary. In well 39/7-1, the boundary occurs within a secondarily reddened section about 200m below the base-Pennian unconformity, and is placed at the uppermost blocky gamma-ray trough and corresponding sonic spike, interpreted to be a diagenetically altered limestone (see p.55). Strata above this horizon display the typical Millstone Grit cyclicity.

The Millstone Grit Formation also continues southwards beyond the Bowland Shale Formation to rest on Dinantian platform carbonates (Zeeland Formation) or on folded Lower Paleozoic basin-margin sequences (e.g. in well 47/29a-1, Panel 9) along the flank of the London-Brabant Massif. The Zeeland/Millstone Grit formalional boundary is a log lithofacies transition in well 52/5-1IX (See Panel 8).

Lithotratigraphic subdivision
Sandstone-dominated and argillaceous units in the Millstone Grit Group have been assigned an assortment of formal and informal lithotratigraphic terms (e.g. Rough Rock Group, Haslington Flags etc.), but only those of the Marsdenian and Yeadonian stages have a regional distribution. No comparable divisions of the offshore Millstone Grit Formation are proposed. However, it is likely that some of the offshore Namurian reservoir sandstones will acquire formal or informal names in due course.

Distribution and thickness
The Millstone Grit Formation is widespread between the London-Brabant Massif and the Mid North Sea High. An outlier of the formation is diachronous, as early as Pendleian or even Brigantian in the north, but Arnsbergian in well 48/3-3 (Collinson et al. 1993).

Age
Mainly Namurian, but often extending into the early Westphalian A. The base of the formation is diachronous as early as Pendleian or even Brigantian in the north, but Arnsbergian in well 48/3-3 (Collinson et al. 1993).

References


Turbidite-fronted delta sequences accumulated in basinal areas of northern England during the early to mid Namurian (Collinson 1988). In these sequences, interbedded mudstones and turbidite sandstones, with beds up to tens of metres thick, form a basal unit up to 300m thick that is overlain by up to 200m of slope deposits. Large bodies of sandstones coarsen upwards to include channel-filling sandstones up to 30m thick, and are often capped by a thick, stacked channel sequence, representing a major deltaic subdivision of the delta. The top of this body in well 48/3-3 may be representative of a turbidite-fronted delta sequence.

Shallow-water, sheet delta sequences were deposited by lobate deltas in much of northern England during the late Namurian (Collinson 1988). These sequences are often 30-50m thick; they commonly have a basal marine band, and coarsen upwards to include sheet-like sandstones that were deposited in mouth bars and distributary channels, interbedded with fine-grained intertidal sediments. Turbidite deposits occur as isolated bodies within the slope deposits and thin coals. In the North Sea, sheet delta sequences are widespread towards the top of the Millstone Grit Formation (e.g. between 3220 and 3652m in well 48/12b-4).

The Rough Rock of northern England is an example of a coarse, pebbly, sheet-like, stacked channel sandstone that was deposited in a fluvial braidplain (Collinson 1988). Unusually, the Rough Rock does not often form part of a upward-coarsening cycle, but rests erosively on delta-top sediments of the preceding cycle. Because of its very widespread distribution in England, an equivalent sheet sandstone may be represented near the top of the Millstone Grit Formation in many North Sea sections.
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FARNE GROUP

ZEELAND FORMATION
The term Fame Group is introduced here for the Dinantian to early Namurian succession, largely of lacustrine, fluvial, coal-measures, and 'Yoredale' facies, that extends offshore from the Northumberland coast over the western crestal area and the southern flank of the Mid North Sea High. The succession continues eastwards into the Dutch sector, where it will also be designated the Fame Group (van Adrichem Boogaert & Kouwe, in preparation). None of the UK wells has penetrated the complete Dinantian succession.

The Fame Group rests on Upper Devonian to early Courceyan terrestrial sediments (Upper Old Red Group), the boundary being defined by the widespread appearance of dolomitic micrite beds (cementstones). In most wells, the group subcreeps Upper Permian marine sediments and evaporites of the Zechstein Group. Where Namurian to early Westphalian basinal and deltaic deposits of the Whitehurst Group are also preserved beneath the base-Permian unconformity, the facies transition is diachronous. The group boundary is defined by the highest marine carbonate bed in the succession. The southern limit of the Fame Group is poorly constrained, as no wells have penetrated Dinantian strata in the central Southern North Sea area.

In the UK sector, the Fame Group is divided into four formations, three of which are named after their onshore equivalents, the Cementstone, Fell Sandstone, and Scremerston Coal groups of the Northumberland Trough (see George et al., 1976). The overlying Yoredale Formation is named after the Yoredale cycles which are its chief characteristic, and correlates with the Lower, Middle, and Upper Limestone groups of northeast England. Formational hierarchy has been adopted for the offshore units to conform with modern stratigraphical procedures (see Whittaker et al. 1991). With the exception of the Yoredale Formation, the Southern North Sea units are unlikely to be capable of subdivision.

Name. From the Fame Islands, off the Northumberland coast of northeast England.

Constituent formations

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Age

Early Courceyan to early Namurian.

References


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CEMENTSTONE FORMATION

The term Cementstone Group has been applied onshore since the 19th century to sequences comprising alternating sandstones, mudstones, and dolomitic micrites (cementstones), of Courceyan to early Chadian (early Dinantian) age, that extend from the Northumberland Trough into the Tweed Basin of southeast Scotland (George et al. 1976). Day (1970) redesignated these sediments part of the Lower Border Group in western parts of the Northumberland Trough. Leeder et al. (1989) extended the Lower Border Group to the Northumberland coast, whereas Francis (1991) and Leeder (1992) have continued to refer to the Cementstone Group in the eastern coastal areas.

The term Cementstone Group was adopted by Cameron et al. (1992) for the unit of interbedded sandstones, shales and dolomites occurring above Upper Devonian to early Courceyan beds of Old Red Sandstone facies in well 44/2-1. However, no widely applicable subdivisions of this unit can be recognized in the offshore wells. The unit is therefore renamed the Cementstone Formation in North Sea sections to comply with recommended stratigraphic procedure (see Whittaker et al. 1991). This change in hierarchy is currently restricted to the offshore area.

The Cementstone Formation is overlain by coarse fluvial sediments (Fell Sandstone Formation) in the Southern North Sea. This facies transition is regionally diachronous, since it occurs within the Chadian on the Northumberland coast (George et al. 1976) and offshore, but is within the Arundian in the western Northumberland Trough (Leeder 1992).

References


Name. From the cementstone beds (dolomitic micrites) which are the unit's most distinctive lithological component.

UK offshore reference sections

43/2-1: 3465.5-3855m TD (11370-12647ft TD) below KB.
44/2-1: 3198-3381m (10493-11092ft)
Lithology
The Cementstone Formation consists of sandstones and shaly mudstones with thin beds of dolomite and dolomitic limestone. The sandstones are grey or white, and in well 44/2-1 are thinly bedded and mainly fine grained. However, they are very fine to medium, or occasionally coarse grained, and moderately or poorly sorted in well 43/2-1, where they form beds up to 25m thick that are commonly cemented by calcite. Most sandstone beds display blocky log motifs, but some form upward-fining units. The mudstones are silty, yellowish brown, reddish brown or grey, and non-calcareous. Dark grey, carbonaceous and pyritic mudstone beds have also been reported from well 43/2-1. The dolomites are microcrystalline or, locally, cryptocrystalline and are brown, brownish grey or grey, and commonly argillaceous. They are responsible for the spiky velocity log signature that characterizes the Cementstone Formation in well 44/2-1. In well 43/2-1, the spiky signature is muted because there are fewer dolomite beds.

Cyclicity of facies, which characterizes the Cementstone Group on the Berwickshire coast (Smith 1967), is also apparent in well 43/2-1.

Upper boundary
The top of the Cementstone Formation in well 43/2-1 is defined by a downward change from massive sandstones of the Fell Sandstone Formation to more thinly bedded sandstones, dolomites and mudstones. It is marked by a sharp downward increase in gamma-ray response. The facies change is more gradational in well 44/2-1, where the boundary is placed along the top of the uppermost cementstone bed and sonic-log spike. In onshore sections, the boundary with the Fell Sandstone is associated with a downward change from mica-free to micaceous sandstone (Smith 1967); this feature may help locate the Fell Sandstone / Cementstone formation boundary offshore in relatively sandy sections that lack significant cementstone development.

Lower boundary
Offshore, the base of the Cementstone Formation has been penetrated only in well 44/2-1, where it is defined by the velocity-log spike corresponding to the lowest cementstone bed. In north-east England, the base of the Cementstone Group occurs within a gradual transition from terrestrial red-bed facies to mixed lacustrine/quasi-marine and fluvial sediments (George et al. 1976).

Distribution and thickness
The Cementstone Formation may be continuous from the Northumberland coast across western crestal areas of the Mid North Sea High, and along its southeastern flank to the median line. The southern limit of the formation cannot be defined offshore because there are no well penetrations of Dinantian strata in the central Southern North Sea area. The formation is 183m thick in well 44/2-1, and at least 390m thick in well 43/2-1.

Regional correlation
Sediments of comparable age and facies to the Cementstone Formation extend into the Dutch Sector, where they will be assigned to the Cementstone Member of the Elleboog Formation. The section in Dutch well E2-1 is illustrated in Panel 1.

Genetic interpretation
Much of the Cementstone Group of northern England and the Scottish borders accumulated in desiccating, hypersaline lakes on an arid coastal plain (Leeder 1992), with quasi-marine faunas restricted to western parts of the Northumberland Trough. The offshore wells have confirmed that this coastal plain extended at least as far east as well E2-1 in the Dutch sector. The sandstone units represent single and stacked, multistorey fluvial channels, related to lobate deltas that advanced southwards along the axis of the Northumberland Trough (Leeder 1992), resulting in the periodic infilling of the hypersaline lakes.

Age
Dinantian, Courceyan to early Chadian.

References


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FELL SANDSTONE FORMATION

The term Fell Sandstone Group has been applied since the 19th century in Northumberland (northeast England) and Berwickshire (southeast Scotland) to a unit characterized by massive cross-stratified sandstones, and ranging in age from mid-Chadian to near the top of the Holkerian (George et al. 1976). Westwards from Northumberland, the sandstone unit includes increasingly thick intercalations of argillaceous and calcareous marine sediments (Hodgson 1978). The influx of sand was delayed until the Arundian in Cumbria (Leeder 1992), where the massive sandstones form part of the Middle Border Group (Day 1970).

The term Fell Sandstone Group was adopted by Cameron et al. (1992) for the unit of massive sandstones encountered in well 44/2-1 between thinly bedded Courceyan to early Chadian sandstones, mudstones and dolomitic micrites (cementstones) and overlying late Dinantian coal measures. However, no widely applicable subdivisions can be recognized within the unit offshore, and, following recommended stratigraphic procedure (see Whittaker et al. 1991), it is here renamed the Fell Sandstone Formation. This change in hierarchy is currently restricted to the offshore area.

References


Miller, H. 1887. The geology of the country around Otterburn and Elsdon. Geological Survey of the United Kingdom, Memoir.


Name. From Larriston Fell, the high ground in the Scottish Borders between the North Tyne and Liddesdale valleys (Miller 1887).

UK offshore reference sections

43/2-1: 3083.5-3465.5m (10116-11370ft) below KB.
44/2-1: 2862-3198m (9390-10493ft)
**Lithology**

The Fell Sandstone Formation is characterized by massive, pale grey and white, fine to medium or coarse grained, poorly sorted sandstones. However, it also contains sporadic beds of grey, blocky to subfissile, non-calcareous mudstone that are up to 10m thick, and occasional beds of dark grey, pyritic, carbonaceous mudstone. In well 43/2-1, the sandstones are partly cemented by silica.

In well 44/2-1, a basal 80m-thick sandstone unit includes partings of argillaceous dolomite, and is overlain by 12m of thinly bedded shales and dolomites. Middle and upper massive sandstone units, 106m and 98m thick respectively, are separated by a 40m-thick, relatively argillaceous interval that includes yellowish brown, reddish brown and grey mudstones.

**Upper boundary**

In the two offshore wells that have penetrated the Fell Sandstone / Scremerston formational boundary, it is defined by an abrupt facies transition from massive sandstones to argillaceous coal measures. This transition is marked by a sharp downhole decrease in gamma-ray response in well 43/2-1. A thin coal seam occurs close above the facies transition in well 44/2-1.

**Lower boundary**

An erosion surface separates the Fell Sandstone and Cementstone groups at the Berwickshire coast (Smith 1967). The base of the Fell Sandstone Formation in well 43/2-1 is defined by a downward change from massive sandstones to interbedded mudstones, sandstones and limestones. It is marked by a sharp downward increase in gamma values. In well 44/2-1, the Fell Sandstone rests on thinly interbedded cementstones and clastic sediments; the boundary is taken at the top of the highest cementstone bed, and is marked by a high-velocity spike. Smith’s observation (1967) that, uniquely within the lower Dinantian, the onshore Fell sandstones lack mica, argillaceous and carbonaceous detritus, may prove useful in locating the boundary in gradational offshore sections.

**Distribution and thickness**

The Fell Sandstone Formation may be continuous from the Northumberland coast across western crestal areas of the Mid North Sea High, and along its southeastern flank to the median line. The southern limit of the formation is not known, because of insufficient penetration of Dinantian strata in the central Southern North Sea area. The formation is 382m thick in well 43/2-1 and 338m thick in well 44/2-1. Equivalent strata are 230m thick on the Berwickshire coast (Smith 1967).

**Regional correlation**

Sediments of comparable age and facies extend into the Dutch sector, where they will be assigned to a division of the Middle Clastics Member of the Elleboog Formation.

**Genetic interpretation**

Hodgson (1978) deduced that the Fell Sandstone Group of Northumberland was deposited in an alluvial complex, partly in low-gradient meandering rivers, and partly in high-gradient, braided perennial rivers. Discharge of the rivers was variable, and they flowed through channel belts that were several kilometres wide. Measured palaeocurrent directions, lateral facies changes, and sandstone thickness trends indicate that the rivers formed a tectonically controlled axial system that drained southwards into contemporary deltas of the western Northumberland Trough (Leeder et al. 1989). The occurrence of occasional reddened horizons suggests that the regional climate was semi-arid, but less extreme than during the Courceyan (Hodgson 1978).

**Age**

Dinantian, Chadian to Holkerian or early Asbian.

**References**


FELL SANDSTONE FORMATION

LITHOLOGY
- Mudstone
- Interbedded mudstone and siltstone
- Siltstone
- Sandstone
- Coal
- Dolomite
- Interbedded dolomite and mudstone

FELL SANDSTONE FORMATION PROBABLY PRESENT AT DEPTH

DISTRIBUTION MAP

CEMENTSTONE FORMATION

SCREMERSTON FORMATION

FELL SANDSTONE FORMATION

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The term Scremerston Coal Group has been applied since the 19th century to early Asbian mudstone-dominated sections with numerous coal seams in Berwickshire (southeast Scotland) and Northumberland (northeast England) (George et al. 1976). Farther west in the Northumberland Trough, equivalent early Asbian sections are dominated by sandstones or by Yoredale facies and comprise the Upper Border Group (Day 1970). Leeder et al. (1989) extended the term Upper Border Group to the Northumberland coast, whereas Francis (1991) and Leeder (1992) have continued to refer to the Scremerston Coal Group in the eastern coastal areas.

The term Scremerston Coal Group was adopted for late Dinantian coal measures encountered in well 38/16-1 (Leeder & Hardman 1990) and in wells 44/2-1 and 44/7-1 (Cameron et al. 1992). However, no widely applicable subdivisions of this unit can be recognized in the offshore wells. The unit is therefore renamed the Scremerston Formation in North Sea sections to comply with recommended stratigraphic procedure (see Whittaker et al. 1991). A similar unit encountered c. 80 km east of well 44/2-1 in the Dutch sector will be assigned to the Middle Clastics Member of the Elleboog Formation.

In Northumberland, the Scremerston Coal Group occurs between massive, mid-Dinantian fluvial sandstones (Fell Sandstone Group) and late Asbian Yoredale facies of the Lower Limestone Group. Also resting on massive fluvial sandstones in the offshore wells, the Scremerston Formation is either overlain conformably by the Yoredale Formation or unconformably by Permian strata.

References


Name. Named by Tate (1867) after the village of Scremerston in northeast Northumberland.

UK offshore reference sections

<table>
<thead>
<tr>
<th>Well</th>
<th>TD</th>
<th>B_below KB</th>
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<tr>
<td>38/16-1</td>
<td>1933.5-2200m</td>
<td>(6343-7217ft)</td>
</tr>
<tr>
<td>39/7-1</td>
<td>3496-3614m</td>
<td>(11470-11856ft)</td>
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<td>43/2-1</td>
<td>2984-3083.5m</td>
<td>(9790-10116ft)</td>
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<tr>
<td>44/2-1</td>
<td>2777.5-2862m</td>
<td>(9113-9390ft)</td>
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</table>
Lithology
The Scremerston Formation comprises alternations of sandstone, siltstone, mudstone and coal, with occasional thin dolomite or limestone beds. The sandstones are white, grey, brown or reddish brown, argillaceous and micaceous. They form beds with blocky or ratty gamma-log profiles that are typically less than 15m thick, but one multistorey bed encountered in well 38/16-1 is 60m thick. Sand grain size is mainly fine or medium in the wells 43/2-1 and 44/2-1, and in equivalent coal measures of Berwickshire (Smith 1967), but is relatively coarse in wells 36/13-1 and 38/16-1. The sandstones constitute about 50% of most sections but are less abundant in well 43/2-1. Interbedded siltstones and mudstones are grey or brownish grey, and non-calcareous. Coal seams up to 1.5m thick comprise less than 5% of most sections, but are thicker and more abundant in well 39/7-1. The limestones and dolomites are white, grey or yellowish brown, and are typically argillaceous and microcrystalline.

Upper boundary
The top of the Scremerston Formation in wells 39/7-1 and 43/2-1 is defined by the base of the lowest high-velocity marine limestone bed of the Yoredale Formation. However, the transition to Yoredale facies is gradational, with prominent coal seams occurring for up to 64m above the boundary in well 43/2-1. The Scremerston Formation is unconformably overlain by Lower Permian desert sediments or Upper Permian marine sediments and evaporites in all other North Sea sections.

Lower boundary
In the two offshore wells to have penetrated the boundary between the Scremerston and Fell Sandstone formations, it is defined by an abrupt facies transition from argillaceous coal measures to massive sandstones. The boundary is marked by a sharp downward decrease in gamma-ray response and velocity in well 44/2-1. A thin coal seam occurs close above the facies transition in well 44/2-1. Onshore, the equivalent boundary is gradational, with mudstone and cementstone beds occurring for up to 60m beneath the base of the coal-bearing strata (Smith 1967).

Distribution and thickness
The Scremerston Formation may be continuous from the Northumberland coast across western crestal areas of the Mid North Sea High and along its southeastern flank to the median line. The formation is 100m thick in well 43/2-1, but more than 266m thick in well 38/16-1. Equivalent early Asbian coal measures are between 100 and 300m thick in southeast Scotland and northeast England (Smith 1967; Leeder et al. 1989). These strata are thought to pass southwards into sand-prone facies onshore (Leeder et al. 1989), and are hence unlikely to continue to the southern margin of the Northumberland Trough either onshore or offshore. Well 39/7-1 proved an outlier of the Scremerston Formation on the northeastern flank of the Mid North Sea High. This outlier may be more extensive across the median line in adjacent Danish, German and Dutch waters than in the UK sector.

Regional correlation
Equivalent sediments in Dutch sector well E2-1 contain relatively few coal seams (see Panel 1), and will form an upper division of the Middle Clastics Member of the Ellesborough Formation. In the Central North Sea, equivalent coal-bearing strata in the Forth Approaches Basin and Outer Moray Firth are included within the Firth Coal Formation (Cameron 1993).

Genetic interpretation
The Scremerston Formation was deposited in a range of delta-plain and backswamp environments (see Leeder et al. 1989). The thickest sandstones represent the deposits of distributary channels; other sandstones accumulated in crevasse channels or in minor mouth bars where channel flows decelerated on entering marginal lakes or brackish bays. The mudstones accumulated from suspension in lakes, brackish bays and marine embayments, whereas the coal seams are the products of wetland environments.

Age
Late Dinantian, Asbian, possibly ranging up to Brigantian in well 39/7-1.

References


**LITHOLOGY**

- Mudstone
- Siltstone
- Interbedded mudstone, siltstone and sandstone
- Limestone
- Coal
- Anhydrite
- Dolomite

**Distribution Map**

- SCREMERSTON FORMATION
- SCREMERSTON FORMATION
- YOREDALE FORMATION
- YOREDALE FORMATION
- FELL SANDSTONE FORMATION
- DINANTIAN
- FARNE GROUP

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The term Yoredale Formation is introduced here for a late Dinantian (late Ashian/Brigantian) to early Namurian unit, characteristically containing minor marine limestone beds within deltaic deposits. Wells have encountered the unit in Quadrants 41, 42 and 43, and on the northeastern flank of the Mid North Sea High. Equivalent sediments in northern England comprise stacked sequences of Yoredale cycles, which by Brigantian times were being deposited from the England/Scotland border at least as far south as the Tees estuary (Leeder 1992). Yoredale deposition continued through the Pendleian into the early Arnberian across most of northeastern England and persisted into the Kinderscoutian (Middle Namurian) over the Alston Block (Ramsbottom et al. 1978).

In the Southern North Sea, the Yoredale Formation rests on late Dinantian coal measures (Scremerston Formation) in two wells. Its base has not been penetrated elsewhere, but it may rest locally on Ashian platform carbonates, as over the Alston Block onshore, or on basinal marine sediments as in the Stainmore Trough. The Yoredale Formation is either conformably overlain by basinal mudstones or deltaic deposits of the Whitehurst Group, or unconformably overlain by Permian strata.

In the Dutch sector, a Brigantian unit containing numerous thin beds of marine limestone within deltaic deposits will be designated the Yoredale Member of the Elleboog Formation.

References


Name. The concept of Yoredale cycles was introduced by Phillips (1836). The term is derived from Uredale, the former name for the valley of Wensleydale in North Yorkshire.

Type section: 41/24a-2: 2501-3265mTD (8205-10515ft TD) below KB.

UK reference sections

39/7-1: 3076.5-3496m (10094-11470ft)
42/10a-1: 2528-2998mTD (8294-9836ft TD)
43/2-1: 2683.5-2984m (8804-9790ft)
**Lithology**

The Yoredale Formation is characterized by marine limestones and mudstones occurring within a dominantly deltaic association of mudstones, siltstones, sandstones, and occasional thin coal seams. The sandstone beds are white, pale grey, or pale brown, mostly less than 15m thick, and constitute between 10% and 30% of the formation. Sand grain size is mainly very fine or fine, but the thickest beds are often coarser grained and are moderately or poorly sorted. Some sand beds are argillaceous; others contain abundant carbonaceous detritus. Minor pale grey siltstones occur within the argillaceous sections, but such sections tend to be dominated by dark grey and black carbonaceous mudstones, and are up to 30m thick. Mudstones in the uppermost part of the formation have been affected by secondary reddening where they subcrop the base-Permian unconformity. The limestone beds are generally thin but exceptionally are up to 15m thick, and comprise between 1% and 10% of the Yoredale Formation in different wells. The limestones are mainly microcrystalline or cryptocrystalline, white, pale grey, or brownish grey, and are argillaceous. Many limestone beds are fossiliferous; others are black, foetid, and unfossiliferous. Coal seams constitute less than 1% of the formation, and are generally less than 1m thick.

In northern England, a typical Yoredale cycle comprises a basal marine limestone overlain by marine shales and a variety of delta-related sedimentary facies, often including seat earths and coals (Elliott 1975). Such cycles are between 15m and 90m thick in Northumberland (Leeder et al. 1989). Yoredale cycles can also be identified in the North Sea wells (e.g. 41/24a-2) by their gross upward coarsening log responses, and are between 30m and 130m thick. Basal limestones generate high sonic velocities, where well developed, but are generally thin but exceptionally are up to 15m thick, and comprise between 1% and 10% of the Yoredale Formation in different wells. The limestones are mainly microcrystalline or cryptocrystalline, white, pale grey, or brownish grey, and are argillaceous. Many limestone beds are fossiliferous; others are black, foetid, and unfossiliferous. Coal seams constitute less than 1% of the formation, and are generally less than 1m thick.

In northern England, typical Yoredale cycles can also be identified in the North Sea wells (e.g. 41/24a-2) by their gross upward coarsening log responses, and are between 30m and 130m thick. Basal limestones generate high sonic velocities, where well developed, but are generally thin but exceptionally are up to 15m thick, and comprise between 1% and 10% of the Yoredale Formation in different wells. The limestones are mainly microcrystalline or cryptocrystalline, white, pale grey, or brownish grey, and are argillaceous. Many limestone beds are fossiliferous; others are black, foetid, and unfossiliferous. Coal seams constitute less than 1% of the formation, and are generally less than 1m thick.

**Upper boundary**

The top of the highest marine limestone bed defines the boundary between the Yoredale Formation and Millstone Grit Formation in wells 39/7-1 (not illustrated) and 39/7-1, and between the Yoredale Formation and Bowland Shale Formation in well 41/24a-2. In well 39/7-1, the boundary occurs within a secondarily reddened section, and the highest limestone bed marks a sharp downward transition from large scale (50-100m) to relatively small scale upward-coarsening cyclicity.

The Yoredale Formation is unconformably overlain by Lower Permian desert sediments or Upper Permian marine and evaporitic sediments in all other wells.

**Lower boundary**

The base of the lowest high-velocity marine limestone bed defines the boundary between the Yoredale and Scremerton formations in wells 39/7-1 and 43/2-1. However, the downward transition from Yoredale facies is gradational, with prominent coal seams occurring for up to 65m above the boundary in well 43/2-1. The base of the Yoredale Formation has not been penetrated in other North Sea wells.

**Distribution and thickness**

The Yoredale Formation is likely to be widespread in the UK sector between 54°N and 55°N. An outlier has been proved at the northeastern flank of the Mid North Sea High, and the formation may also be distributed patchily across western creastal areas of the High. The formation is 420m thick in well 39/7-1, and more than 704m thick in well 41/24a-2. In northern England, equivalent sediments are 1210m thick at Seal Sands in the eastern Stainmore Trough (Dunham & Wilson 1985), and 827m thick at Horton on the southern margin of the Northumberland Trough (Ridd et al. 1970).

**Regional correlation**

The Yoredale Formation is laterally equivalent to the Lower, Middle and Upper Limestone groups of the Northumberland Trough. Equivalent sediments in the Dutch sector will be designated the Yoredale Member of the Elleboog Formation.

A lateral equivalent of the onshore Great Limestone is likely to be present above 2755m in well 41/24a-2 and above 2726m in well 42/10a-1. The Great Limestone lies close above the Dinantian/Namurian boundary.

**Genetic interpretation**

Yoredale cycles are the product of the periodic advance of delta lobes across a marine carbonate shelf, but the reasons for this periodicity are still not fully resolved. One solution proposed by Leeder & Stradwick (1987) is that the carbonate shelves developed during periods of relatively uniform regional subsidence, delta advance occurring principally during periods of tectonic instability and movement on the faults bounding the major depositional basins.

Onshore, the limestones at the base of most cycles are biomicrites, containing a restricted benthonic fauna suggestive of shallow, possibly hypersaline, conditions (Ramsbottom 1974). The overlying clastic sediments include a wide range of fluvio-deltaic lithofacies, including those of mouth bar, bay, levee, crevasse, lake, swamp, and distributary channel environments (Elliott 1975). Calcareous barrier-beach sandstones were deposited locally by post-abandonment reworking of the deltaic deposits.

**Age**

Dinantian (Late Asbian or Brigantian) to Early Namurian.

**References**


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ZEELAND FORMATION
(provisional)

The term Zeeland Formation is being introduced by van Adrichem Boogaert & Kouwe (in preparation) for the Dinantian platform carbonates that extend from the Netherlands across the southern Dutch sector of the North Sea. The term is adopted here for Dinantian carbonates encountered by UK wells along the northern flank of the London-Brabant Massif. They are continuous from the UK/Dutch median line across Quadrants 52 and 53 into eastern England (Cameron et al. 1992). Equivalent carbonates, proved in the Somerton No.1 well in north-east Norfolk, are widespread on the East Midlands Shelf (Strank 1987). These carbonates have not been formally named in the UK.

The Zeeland Formation spans most or all of the Dinantian in the Netherlands and beneath the North Sea. In eastern England, successively younger Dinantian carbonates onlap the London-Brabant Massif, and uppermost beds are locally truncated beneath Westphalian strata (Strank 1987). The Southern North Sea carbonates subcrop Namurian or Westphalian fluviodeltaic sediments. Their base has not been penetrated, but comparison with onshore equivalents indicates that they are likely to rest on Lower Paleozoic basement.

Onshore in England, the Dinantian carbonates pass northwards into the thick clastic mudstones, argillaceous limestones, turbiditic limestones and sandstones, and local lime mudbank complexes of the Craven Basin (Leeder 1992). In the Southern North Sea, a comparable facies change may occur across the Dowsing Fault Zone and its southeastwards continuation across Quadrant 53 (Cameron et al. 1992).

References


Name. From the Dutch province of Zeeland (van Adrichem Boogaert & Kouwe in preparation).

Type section

Dutch well S2-2: 1883-2836m (6178-9304ft) below KB.

UK reference section

53/12-2: 1882-233lm TD (6174-7650ft TD) below KB.
Lithology
The Zeeland Formation in well 53/12-2 comprises 300m of pale brown to dark brown, microcrystalline and very finely crystalline dolomitic limestone, with occasional oolitic beds, overlying 150m of dark brown and dark grey, finely crystalline dolomite. In the Somerton No.1 well (East Anglia), partly equivalent to late Dinantian limestones contain partings of grey mudstone, and have fossiliferous beds containing abundant corals, brachiopods, bivalves, bryozoans and crinoids.

Upper boundary
The top of the Zeeland Formation is a regional unconformity. Its boundary with overlying late Namurian or Westphalian fluviodeltaic sediments (Millstone Grit Formation or Westoe Coal Formation) is a clearly defined lithological transition, marked by a sharp downhole decrease in gamma-ray response and increase in velocity (e.g. 53/12-2).

Lower boundary
Dinantian carbonates of the East Midlands Shelf generally rest on deformed Lower Paleozoic basinal-marine and volcaniclastic sediments (Strank 1987). In the Somerton No.1 well, however, the carbonates overlie a local development of mid-Dinantian sandstones and mudstones. The base of the Zeeland Formation has not been drilled in the UK sector, but the formation is known to rest on Upper Devonian clastic sediments (Famenne Shale) in parts of the southern Netherlands.

Distribution and thickness
Because of the scarcity of well penetrations, the distribution of the Zeeland Formation can be determined only by seismic methods. The base and top of the Dinantian carbonates generate high-amplitude seismic reflectors in Quadrants 52 and 53, and the southward convergence of these reflectors defines the southern limit of the carbonate, as illustrated in the accompanying distribution map. Their northern limit has been equated with the limit of the top-carbonate reflector in northeastern Quadrant 53 (Cameron et al. 1992). Seismic definition of the carbonates is relatively poor north of East Anglia, though in eastern England they occur to at least as far north as the Humber Estuary. Well 53/12-2 penetrated only the uppermost 450m of Dinantian carbonates in an area where seismic interpretation suggests that they may be locally more than 1km thick (Cameron et al. 1992). Equivalent carbonates have a proven thickness of 140m in the Somerton No.1 well (East Anglia). They are more than 500m thick on parts of the East Midlands Shelf (Strank 1987), are 953m thick in Dutch well S2-2, and are up to 750m thick in the Netherlands (van Staalduinen et al. 1979).

Regional correlation
Equivalent carbonates are widespread along the northern and southern flanks of the London-Brabant Massif.

Genetic interpretation
Much of the Zeeland Formation accumulated on a gently sloping carbonate shelf. Locally condensed sequences and reworking of Courceyan fossils into younger Dinantian sediments in the Netherlands (van Staalduinen et al. 1979) and eastern England (Strank 1987), indicate that sedimentation was punctuated by intervals of uplift or regression and local erosion of the carbonate shelf. Tubb et al. (1986) speculated that Dinantian reefs may have formed locally in central Quadrant 53 on the footwalls of syndepositional faults. Local reef developments, including Chadian mud-mounds or bioherms and Asbian shelf-edge reefs, have been reported from the East Midlands Shelf (Strank 1987).

Age
Dinantian, Courceyan to Brigantian.

References
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UPPER OLD RED GROUP
C  1993

KYLE GROUP
BUCHAN
FORMATION
CEMENTSTONE FORMATION
TAYPORT FORMATION
YOREDALE FORMATION
WESTOE COAL FORMATION
CAISTER COAL FORMATION
ZEELAND FORMATION

CARBONIFEROUS
NAMURIAN

WESTPHALIAN D
WESTPHALIAN C
WESTPHALIAN B
WESTPHALIAN A
YEADONIAN
MARSDENIAN
KINDERSCOUTIAN
ALPORTIAN
CHORKRIAN
ARNSBERGIAN
PENDELIAN
BRIGANTIAN
ASRIAN
HOLKERIAN
ARULDIAN
CHAZIAN
COURCEYAN

DEVONIAN

UPPER RED GROUP
BUCHAN
FORMATION
VYLE GROUP
TAIPORT FORMATION
SCEMMERSTON FORMATION
FELL SANDSTONE FORMATION
CEMENTSTONE FORMATION

BASE NOT GENERATED

Age of boundary conjectural

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The term Upper Old Red Group was introduced by Cameron (1993) for the mainly fluvial, terrestrial sediments of Late Devonian to Early Carboniferous age beneath the North Sea. These sediments are broadly equivalent to the Upper Old Red Sandstone of mainland Britain. However, they have a wider stratigraphic range, locally extending up to latest Dinantian or early Namurian at the Buchan Field in the Central North Sea, and into the Courceyan in other areas.

In southeast Scotland, the Upper Old Red Sandstone is mainly composed of red, yellow and buff fluvial sandstones, with local conglomerates. These sediments rest on deformed Lower Paleozoic turbidites and shales, and are overlain by the Lower Border Group. Their boundary with the latter is a diachronous facies transition close above the top of the Devonian, and defined by the lowest of many horizons of primary argillaceous carbonate or cementstone (Mykura 1991).

The equivalent Upper Old Red Group extends eastwards from the coast of southeast Scotland along the crest and southern flank of the Mid North Sea High; its distribution farther south is unknown. It rests conformably on Givetian to early Frasnian marine beds (Kyle Group) near the international median line (Cameron 1993), and possibly also in northern Quadrant 44 (Cameron et al. 1992). Elsewhere, it is likely to rest on deformed Lower Paleozoic strata. The Upper Old Red Group generally underlies Permian or younger strata, but is conformably overlain by the Cementstone Formation along the southern flank of the Mid North Sea High.

### References


### Name

From Upper Old Red Sandstone, a widely used facies term for terrestrial Upper Devonian sediments of Britain.

### Constituent formations

- **Buchan Formation**
- **Tayport Formation**

### Age

Late Devonian to Courceyan (early Dinantian).
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BUCHAN FORMATION

The term Buchan Formation was formally introduced by Cameron (1993) for Upper Devonian and Lower Carboniferous fluvial, dominantly sandy sediments of the Upper Old Red Group in the Central and Northern North Sea. The definition of the term is expanded here to include equivalent sediments of the Southern North Sea, as proved at the northeastern flank of the Mid North Sea High. The formation's southern extent in the UK sector is unknown, because of insufficient well penetration of the Upper Old Red Group south of the Mid North Sea High.

A diachronous facies transition separates the Buchan Formation from overlying mudstones and sandstones of the Tayport Formation in the Central North Sea (Cameron 1993). This transition occurred during the late Frasnian or early Famennian over the Mid North Sea High; whereas the Buchan Formation is largely Frasnian in age in well 38/3-1, only Famennian and Courceyan palynomorph assemblages have been recovered from the Tayport Formation in nearby wells.

References

Name. From the Buchan Field in UK block 21/1 (Cameron 1993, p.135).

Type section
21/1-6 (Cameron 1993, p.136): 2685-3360m TD (8809-11023ft TD) below KB.

Reference section (Southern North Sea)
38/3-1: 2528.5-3611m (8296-11848ft)
Lithology
The Buchan Formation in well 38/3-1 is largely composed of fine, and fine to medium grained, reddish brown and white sandstones; these are anhydritic near the top, and locally dolomitic towards the base of the formation. Beds of sandy conglomerate are interbedded with sandstone in the basal 85m, and sporadic thin beds of reddish brown and greenish grey mudstone and siltstone occur throughout. Principal clast types in the basal conglomerate are white microcrystalline dolomite, phyllite, and vein quartz.

Eleven thin coal seams have been reported between 2880 and 3345m in well 38/3-1. However, these are not interbedded within typical coal measures, and are interpreted as beds of detrital coal. Two thin beds of pale grey to green 'porphyritic' tuff have been reported in the well at 3587m and 3590m.

Upper boundary
The Buchan Formation is known to be unconformably overlain by Lower Permian (Auk Formation) sandstones in well 38/3-1, although the precise position of the boundary is open to question. Where Devonian sandstones are overlain by Lower Permian sandstones in the Central North Sea, the boundary is often marked by a significant downhole increase in sonic velocity (Cameron 1993), but this is not displayed in well 38/3-1. The highest recorded Frasnian palynomorphs occur at 2591m, but the most likely position of the boundary is at the downhole decrease in gamma-log response at 2528.5m. The alternative position favoured by the well operators is at 2240m, although there is no wireline-log break at this level.

Lower boundary
In well 38/3-1, the Buchan Formation rests conformably on mid-Devonian marine beds of the Kyle Group, and the boundary is defined by the sharp downward transition from interbedded reddish sandstones, sandy conglomerates and minor volcanics to dark grey mudstones. Beyond the limits of the Kyle Group, the Buchan Formation is likely to rest on Lower Paleozoic strata.

Distribution and thickness
In well 38/3-1, the Buchan Formation is at least 1081m, and perhaps as much as 1371m thick. The formation is widespread in the Central North Sea (Cameron 1993); it may continue beneath the Tayport Formation south and west of 38/3-1.

Regional correlation
Sandstones similar to those in well 38/3-1, but lacking coal seams, have been proved 35km to the north in the Argyll Field. These sandstones, informally termed the 'Gamma Unit' by Bifani et al. (1987), were formerly interpreted as Lower Permian, but are now regarded as Upper Devonian (Robson 1991). The Buchan Formation ranges up to late Dinantian or early Namurian in age at the Buchan Field (see Hill & Smith 1979).

Genetic interpretation
The contemporaneous sandstones in the Argyll Field were deposited by alluvial-fan systems, possibly prograding off the flank of the Mid North Sea High into a subsiding basin (Bifani et al. 1987). Sinuous, ephemeral streams flowed through the distal flanks of this fan system onto an alluvial plain, forming terminal fans, or prograded into desert lakes. Small sand dunes formed and reworked the fluvial sediments around the margins of these lakes. The presence of Frasnian coal beds of likely detrital origin in well 38/3-1 indicates that there were poorly drained swamps in the catchment area at that time.

Age
Late Devonian, mainly Frasnian in well 38/3-1.

References
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TAYPORT FORMATION

The term Tayport Formation was introduced by Cameron (1993) for mainly red, interbedded mudstones and fluvial sandstones of late Devonian to early Carboniferous age in the Central North Sea. These sediments are widespread around the Outer Moray Firth, where they comprise a transitional facies between underlying, dominantly fluvial, sandstones (Buchan Formation) and overlying Dinantian coal measures (Firth Coal Formation).

The definition of the Tayport Formation is expanded here to include equivalent mudstones and sandstones of the Southern North Sea. The formation is widespread along the crest and southern flank of the Mid North Sea High, where it is overlain either conformably by dolomitic carbonates and clastic sediments (Cementstone Formation) or unconformably by Permian strata. Its southern extent in the UK sector is unknown.

Name. From the town and seaport on the Firth of Tay, eastern Scotland (Cameron 1993, p. 139).

Type section
21/2-7 (Cameron 1993, p. 140): 3714-3869m (12185-12693ft) below KB.

Reference sections (UK Southern North Sea)
37/10-1: 1822.5-2471.5m TD (5980-8108ft TD)
37/23-1: 2313.5-2537 m TD (7590-8324ft TD)
38/24-1: 2465-2777m TD (8088-9110ft TD)

Reference
Lithology
The Tayport Formation in the Southern North Sea is composed of alternating mudstone or siltstone beds, up to 15m thick, and sandstone beds up to 60m thick. The mudstones are red, reddish brown, grey, greenish grey or occasionally purple, and the sandstones are grey, purplish grey or white. The thickest sandstones display complex, upward-fining, or blocky gamma-log motifs. Their grain sizes range from fine to coarse; they are locally pebbly, and are poorly sorted. The formation displays gross upward-coarsening trends in well 37/10-1 and below 2595m in 38/24-1. The sediments are commonly micaceous, and they are locally very micaceous.

Upper boundary
Over the crest of the Mid North Sea High, the Tayport Formation is unconformably overlain by Upper Permian carbonates and evaporites of the Zechstein Group. Along the southern flank of the High, the formation is conformably overlain by dolomitic carbonates (cementstones) and clastic sediments of the Cementstone Formation, the boundary being marked by the base of the sonic-log spike corresponding to the lowest cementstone bed (e.g. 44/2-1, p.43).

Lower boundary
The base of the Tayport Formation has not been penetrated in the Southern North Sea. In the Central North Sea, the formation rests on fluvial sandstones of the Buchan Formation (Cameron 1993). The Buchan Formation may also occur beneath the Tayport Formation in the Southern North Sea.

Distribution and thickness
The Tayport Formation has been proved by wells along the crest and southern flank of the Mid North Sea High. As equivalent sediments are absent in much of central and northern England (Dineley 1990), the formation may not extend far to the south of well 44/2-1 offshore. Its maximum drilled thickness is 649m in well 37/10-1.

Regional correlation
Laterally equivalent sequences of alternating mudstone and sandstone beds have been encountered in the northern Dutch sector (the section from Dutch well E2-1 is illustrated in Panel 1). Soft, Upper Devonian dark red-brown sandstones and mudstones crop out on the coast of Berwickshire, where they are 45m thick at Burnmouth (Smith 1967) and are informally termed 'Upper Old Red Sandstone'.

Genetic interpretation
The Tayport Formation was probably deposited in a range of fluvial and playa lake environments within a low-lying alluvial floodplain. This floodplain lay downstream of the regional Late Devonian easterly to southeasterly palaeoslope of southern Scotland (see Paterson et al. 1976). Thick sandstone units were deposited in major distributary channels or as sheet floods, whereas the mudstones accumulated during frequent intervals when the floodplains became waterlogged. The sediments acquired their red colour by oxidation during repeated post-depositional lowering of the local water table.

Age
Mainly Famennian (Late Devonian) to early Courceyan (early Dinantian). In well 44/2-1, the top of the formation is about 55m above the Devonian/Carboniferous boundary.

References


TAYPORT FORMATION

DISTRIBUTION MAP

PROBABLY PRESENT AT DEPTH

LITHOLOGY
- Mudstone / shale
- Sandstone
- interbedded mudstone and sandstone
- Dolomite
- Polyhalite
- Salt

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The term Kyle Group was introduced by Cameron (1993) for the mid-
Devonian limestones and overlying mudstones and dolomites, with local
anhydrite, that have been proved at the Auk and Argyll fields and at the
northeastern flank of the Mid North Sea High. These strata rest on Lower
Paleozoic basement in the Auk Field, and are either overlain conformably by
the Upper Old Red Group or unconformably by Lower Permian sediments.

Middle Devonian limestones generate a continuous, very strong seismic
reflector in the Auk/Argyll area (Pennington 1975). A similar reflector occurs
at ca. 900m beneath the top of the Upper Old Red Group in parts of northern
Quadrant 44 (Cameron et al., 1992), suggesting that the Kyle Group may also
be present along the southeastern flank of the Mid North Sea High.

Although the Kyle Group displays a clear two-fold division in the sections
currently available, the geographic coverage is considered to be too limited as
yet for the designation of formal divisions. Two informal units, the Kyle
Limestone unit and the Kyle Mudstone unit, were proposed by Cameron
(1993).

References
Cameron, T.D.J. 1993. Triassic, Permian and Pre-Permian of the Central
Lithostratigraphic nomenclature of the UK North Sea. British Geological
Survey, Nottingham.

Cameron, T.D.J., Crosby, A., Balson, P.S., Jeffery, D.H., Lott, G.K.,
Bulat, J. & Harrison, D.J. 1992. United Kingdom Offshore Regional
Report: the geology of the southern North Sea. HMSO, London, for the
British Geological Survey.


Name. From the Scottish term for a narrow marine channel between islands
or between an island and the mainland.

Key sections
38/3-1: 3611-3798m TD 11848-12460ft TD below KB.
30/16-5: 2580.5-2707m (8466-8882ft)
30/24-3: 2950.5-3085m TD (9680-10122ft TD)
30/25a-2: 2846-2974m TD (9337-9758ft TD)
Lithology
The Kyle Group is characterized by white, buff, brownish grey, or pink limestones and thin grey shales, with an overlying, more variable unit of marine, lagoonal, and basin-marginal sabkha facies. The limestones of the basal unit are generally argillaceous, with a thin basal mudflake conglomerate in the Auk Field. Their texture varies between cryptocrystalline, microcrystalline, and coarsely crystalline. They contain both tabulate and rugose corals in the Argyll Field (Pennington 1975), and have also yielded ostracods, brachiopods, bivalves, gastropods, and crinoids. In well 38/3-1, the interbedded shales contain ostracods and a sparse brachiopod fauna that includes lingulids and strophomenids.

In well 38/3-1, the limestones are overlain by dark grey mudstones containing brachiopods and veins of dolomite. In different sections in the Auk-Argyll area, equivalent sediments include microcrystalline dolomite (e.g. 30/25a-2), reddish brown or grey calcareous mudstone with thin limestone and dolomite beds (e.g. 30/16-5), or interbedded sandy siltstone, shale, anhydrite and dolomite (e.g. 30/24-3).

Upper boundary
In and around the Auk Field, the Kyle Group underlies Lower Permian sandstones, beneath the regional base-Permian unconformity. In well 38/3-1 and in the Argyll Field, the Kyle Group is conformably overlain by the Upper Old Red Group, the boundary being taken at the transition from marine or lagoonal to continental red-bed facies. At 38/3-1, the boundary is marked by a downward change from sandstones, conglomerates and minor volcanics to marine mudstones, but does not generate a significant wireline-log break.

Lower boundary
An angular unconformity separates Kyle Group limestones from underlying reddened Lower Paleozoic turbidites and shales in well 30/16-5. The base of the limestones has not been penetrated elsewhere. However, they probably rest on Lower Paleozoic basement at 38/3-1, as Lower Devonian strata are unknown in the Central North Sea south of the offshore continuation of the Southern Uplands Fault (Gatliff et al., in press).

Lithostratigraphic subdivision
On the basis of the lithological sequence described above, the mid-Devonian marine beds can be informally divided into two units. The basal limestone-dominated section may be informally designated the Kyle Limestone Unit (K1). The overlying mudstone-dolomite-anhydrite section, which is commonly between 90m and 100m thick, may be designated the Kyle Mudstone Unit (K2). The top of the Kyle Limestone unit generates a sharp downhole decrease in gamma-ray response, which in well 38/3-1 is slightly out of phase with a corresponding downhole increase in sonic velocity and resistivity.

Distribution and thickness
The Kyle Group has been proved in five wells along the western flank of the south Central Graben. It is more than 177m thick in well 38/3-1, and more than 130m thick in the Argyll Field. In well 30/16-5, 127m of mid-Devonian marine beds are preserved between the base-Permian and base-Devonian unconformities.

Regional correlation
Mid-Devonian marine beds are unknown elsewhere in the North Sea area. The nearest equivalent marine beds occur in southern England, and in the Netherlands and northern Germany (Ziegler 1982).

Genetic interpretation
Ziegler (1982) speculated that Middle Devonian marine sediments at Auk and Argyll were deposited in an embayment of the Proto-Tethys Ocean of northern Europe, that developed by northward transgression along a trend adopted later by the Central Graben of the North Sea. The fossil content of the basal limestones suggests that they accumulated in a shallow, warm-water marine environment. The overlying sediments in wells 30/16-5 and 30/24-3 are interpreted as nearshore marine and basin-marginal sabkha and quasi-marine facies, deposited during late Givetian to early Frasnian regression of oceanic waters from the area. Equivalent grey mudstones and shales in well 38/3-1 may have accumulated in a brackish-water, possibly lagoonal environment.

Age
Givetian to early Frasnian. Middle Devonian ostracods were recorded towards the base of the Kyle Mudstone unit in the Argyll Field by Pennington (1975), but Frasnian palynomorphs have been recorded from higher levels of the unit in well 38/3-1.

References


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CORRELATION PANELS
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Note: High-velocity spikes in sections through Yoredale Formation and Cementstone Formation and their Dutch sector equivalents correspond to dolomite beds.
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CARBONIFEROUS

CORRELATION PANEL 2

LITHOLOGY

Undifferentiated lithologies—see individual panels for details

Sandstone

Limestone

Coal

Anhydrite

Dolomite

Zechstein Group

Rotliegend Group

Westoe Coal Formation

Caister Coal Formation

Millstone Grit Formation

Bowland Shale Formation

Yoredale Formation

Base not penetrated

Westphalian A

Namurian

Antian

Conway GP

Whitehurst GP

Farn Group

Schooner Formation

C / B
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CARBONIFEROUS

LITHOLOGY
- Muscovite, silicified and thin sandstone beds
- Sandstone
- Mudstone, siltstone and thin sandstone beds
- Coal
- Halite

ROTLEGEND GROUP

Ketch Member
WESTOE COAL FORMATION
CAISTER COAL FORMATION

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NOTE: Sonic log unreliable below 4200m

LITHOLOGY

- Mudstone, siltstone and thin sandstone beds
- Sandstone
- Coal

WESTOE COAL FORMATION
CAISTER COAL FORMATION
MILLSTONE Grit FORMATION
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APPENDIX

Carboniferous to Middle Devonian biorstratigraphic markers

N. TURNER

The aim of this review is to identify and describe the most important Southern North Sea Carboniferous to Middle Devonian biorstratigraphic markers. The biomarkers selected are, in general, commonly and consistently used by industry, non-proprietary defined, well known and easily identifiable. They do not, therefore, provide the most definitive or refined biorstratigraphic subdivision of the Carboniferous to Middle Devonian succession. Other schemes exist that provide a detailed breakdown of specific parts of equivalent onshore successions (e.g. Clayton et al. 1977, 1978; Higgs et al. 1988; Owens et al. 1977; Richardson & McGregor 1986; Smith & Butterworth 1967).

Many of the biomarkers are based on FDOs and FDAOs (first downhole acme or first downhole abundance) of taxa that have never been fully defined; in some instances one specimen of the nominate species may be sufficient to recognize an FDO; in other instances a consistent downhole presence is necessary. Undoubtedly, different criteria are operated at different times. Similarly, the definition of same occurrences may be problematical. However, a revision and formal definition of the biomarkers is outside the scope of this synthesis. This contribution is primarily concerned with the relative order of the biomarkers, rather than with their chronometric assignment.

POLLEN AND SPORES

Early descriptive and stratigraphic work on pollen and spore floras of the Carboniferous of Northwest Europe concentrated on fossils derived from coal (Alpern et al. 1955; Balme & Butterworth 1952; Bhardwaj 1955; Butterworth & Millott 1968; Potonie & Kemm 1955, 1956a, 1956b; Venkatachala & Bhardwaj 1964). The culmination of this early work was the attempt by Smith & Butterworth (1967) to construct a zonation scheme using only data from the coals of the Carboniferous of the British Isles.

Important progress was made by Neves (1958, 1961) who established a significant informal zonation for the Namurian based on evidence of miospores and by Neves et al. (1972, 1973) who established and improved upon a zonation for the Dinantian based on both coals and miospores (see Riley 1993 for synopsis). Owens et al. (1977) incorporated much of this earlier work and established a palynological zonation scheme for the Namurian of Britain linked to the international nomenclature. Clayton et al. (1977) reviewed the published zonations for the Carboniferous of Northwest Europe, including the work of grey horizon zonations for the Carboniferous of the Devonian of the Southern North Sea. Richardson & McGregor (1986) erected a miospore biozonation scheme for the Silurian and Devonian sediments of the Old Red Sandstone Continent and adjacent areas. This scheme incorporated, with modifications, zones proposed for parts of the Devonian by Streeł (1966), Richardson (1974), McGregor & Camfield (1976) and others.

POLLEN

Emiliania huxleyi var. variabilis Definition. The FDO of Emiliania huxleyi var. variabilis. Age. Late Frasnian.

Ancyrospora involucra Definition. The FDO of Ancyrospora involucra. Age. Late Frasnian.

Perotrilites annulatus Definition. The FDO of Perotrilites annulatus. Age. Late Frasnian.

Ancyrospora solenopora Definition. The FDOs of Ancyrospora solenopora. Age. Middle Frasnian.


References


DIBOLISPORITES VARIABILIS Definition. The FDO of Dibolisporites variabilis. Age. Late Frasnian.


The sporomorphs from the Upper Carboniferous coals of the Saar and their value in stratigraphical studies. Palaeobotanist 41, 1-169.


DIBOLISPORITES VARIABILIS Definition. The FDO of Dibolisporites variabilis. Age. Late Frasnian.


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